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FACULTY OF TECHNOLOGY
PROCESS ENGINEERING DEPARTMENT

COURSE HANDOUT

WASTE MANAGEMENT AND REMEDIATION OF SOIL AND GROUNDWATER

2nd YEAR 'MASTER' LEVEL
WATER ENGINEERING AND MANAGEMENT

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Preface

This document is a course material concerning the subject entitled *Waste management and remediation of soil and groundwater*, taught in the Department of Process Engineering at University of Boumerdes and intended for students in the second year of the Master's cycle in engineering and water management. The course describes the different types and sources of waste, the principles fundamental of waste management, the skills on how to manage wastes, as well as national and international policies and legislation relating to waste management. It also covers the various characteristics of soil and groundwater contamination due to poor waste management and its remediation using economical and sustainable technologies.

Course Objectives

By the end of this course, the student should be able to:

- Determine the type, nature and estimated volumes of waste generated
- To identify any potential environmental impacts from the generation of waste
- Understand the fundamental principles of waste management.
- Provide with knowledge on integrated waste management. Identification of the main factors of the problem of waste management.
- Understanding the concept of waste minimization, reuse and recycling.
- Evaluate options for waste disposal and know of deposition techniques in landfills and the control of movement of gases and leachate, and monitoring systems.
- Explore innovative technologies and methods for waste reduction.
- Acquire knowledge and skills in relation to soil and groundwater pollution.
- Handle contaminated soil and groundwater due to improper waste management.
- Describe the properties and transport of pollutants in soil and groundwater
- Explain the main principles of soil and groundwater remediation
- Develop skills to promote sustainability and environmental responsibility.

Course Contents

1.1. Introduction

Environmental problems have led to the implementation of sustainable development because we can no longer function as before, in harmony with the requirements of nature, we have completely broken our balanced relationships with it. To remedy this, we must operate according to a new, more balanced and more sustainable concept. Since the end of the Second World War, our daily practices have changed a lot, our behaviors have been modified by new lifestyles and consumption patterns. We produce products, we consume them, we often discard them after use. We get rid of them without taking into account the consequences that can affect our environment and our health. The ecological impact of human activities is increasingly worrying. When an object reaches the end of its life, our reflex is to want to get rid of it as quickly as possible, even if it can still be used and without asking ourselves questions: Can it still be used by someone else? Does it still have value? Can it still be used and where? How? For whom? How to get rid of it without throwing it away? These are the first behavioral elements that we must put into practice in our daily lives when faced with an object at the end of its life. What does this object represent in time, in space? What is its value? Is it waste? What definition can we then give to waste?

Waste is not simple and can be linked to a truth:

- ✓ Economic: negative or positive value
- ✓ Legal: abandonment, valorization
- ✓ Ecological: pollution of water, air, public health and land use planning.
- ✓ Technological: flaw, gap in the technological process
- ✓ Sociological: acceptance by society (NIMBAY syndrome, "not in my backyard"), job creation.

It can be relative and depend on:

- ✓ The individual: an object can be considered waste for one person but not necessarily for another.
- ✓ Time: at a given moment, an object can be considered waste while with time and technological development (example of clinkers), it can represent an economic value again. At what point does an object become waste and at what point does it cease to be?
- ✓ From the place: the notion of waste is different depending on the region, the place, the country

- ✓ Its state: dry or wet? Here too, the problem of evaluation arises. Dry, the waste will have lost mass, for some solid waste (sludge) the water content can reach 98%
- ✓ Its effect on the environment: dangerous, biodegradable, neutral?
- ✓ The unit of measurement: mass or volume? In the current state, the measurement is carried out in mass and not in volume, why this choice? Waste is extremely varied, which leads to very significant differences between densities and can pose the principle of the unit of measurement. For example, the density of household waste in bags and bins is around 150 to 200 kg/m^3. The lighter it is, the greater the volume, the more interesting the commercial transaction.

1.2. What is waste?

- **Regulatory**

Any residue from a production, transformation or use process, any substance, material, product or more generally any movable property that is abandoned or that its holder intends to abandon.

- **Economic**

Object whose economic value is zero or negative at a given time and in a given space. Can be the source of job creation.

- **Functional**

Material flow from a functional unit representing an activity or set of activities.

- **Legal**

From a legal point of view, two concepts emerge from waste:

- ✓ Subjective concept: a good becomes waste when its owner confirms his willingness to abandon all property rights.
- ✓ Objective concept: waste is a good whose management must be controlled for the benefit of protecting public health and the environment.

- **Environmental, ecological**

Waste constitutes a threat from the moment we consider its contact with the environment, whether direct or after treatment, the interfaces can be:

- ✓ With the soil: controlled or illegal landfills
- ✓ On water: pollution of ground and surface water
- ✓ On air: release of biogas from landfills (mainly methane), dioxin, furans, polycyclic aromatic hydrocarbons (PAH) from incinerator plants.

- **Sociological**

The NIMBAY syndrome from the English "not in my back yard" is quite significant insofar as society is not always able to accept certain practices in waste management.

- **Synopsis**

Product that no one wants in the place where it is. This definition summarizes in a simple and figurative way what waste is.

Waste is a discarded product or by-product of an industrial or domestic activity that is considered useless or polluting. Solid waste can be recycled, composted or incinerated, while liquid and gaseous waste must be treated before being released into the environment. Radioactive waste must be stored in special facilities to avoid environmental contamination. Waste management is a major challenge for communities and industries, as it can pollute the air, water and soil, and contaminate the food chain. Waste management requires adequate planning and infrastructure, as well as public awareness of the need to reduce, recycle and compost.

Among the consequences of our way of life, the production of waste that continues to grow in quantity, complexity, and even harmfulness. They represent a major risk, because disposed of without precaution, they risk not only degrading the landscape, but also affecting human health and the environment.

1.3. Analytical characteristics of waste

The choice of a treatment process for waste or a by-product requires a good knowledge of its analytical characteristics. Originally, the concept of process refers to a series of operations. In the field of waste treatment, this refers to all the operations to be implemented to achieve the desired results:

- ✓ waste recovery;
- ✓ and/or eco-compatible discharge of decontaminated effluents;
- ✓ and/or storage of ultimate waste.

The following different data are necessary for a good knowledge of waste or a by-product:

(a) Composition (for any waste):

- A Elementary chemical composition (Metals, C, H, N, P, S, Cl, etc.) and molecular composition (Benzene, phenols, proteins, sugars, etc.; mineral salts, oxides, polymers, etc.).

- A Mineralogical composition (nature of the constituent minerals) in the case of solid waste.

- A Nature of the different phases constituting a multiphase waste (residual gas, liquid-liquid, liquid-solid, solid-solid mixtures) and chemical composition of these phases.

(b) Physicochemical properties

- **Lower calorific value (LCV):** corresponding to the heat released by the combustion of a unit of mass of waste (or enthalpy of combustion, changed sign), water being formed in the vapor state.
- **Higher calorific value (HCV):** same, but water formed in the liquid state

The calorific values of a product of given chemical composition are obtained by calculation from the standard enthalpies of formation of this product, of CO_2 and of H_2O

ΔH^0_{298} CO_2 = – 94,05 kcal/mole = – 393,1 kJ/mole

ΔH^0_{298} $H_2O(v)$ = – 57,80 kcal/mole = – 241,6 kJ/mole

ΔH^0_{298} $H_2O(l)$ = – 68,31 kcal/mole = – 285,5 kJ/mole

(b) Physico-mechanical, mineralogical and structural properties

- ✓ Physical state: solid, liquid, pasty, gaseous, mixture of phases.
- ✓ Density.
- ✓ Granulometry, fineness, porosity, specific surface area.
- ✓ Structural state (amorphous, vitreous, crystallized).
- ✓ Plasticity index, compaction quality, optimum water content.
- ✓ Mechanical properties (hardness, grindability, mechanical resistance).

(d) Specific properties

- ✓ Ash content, C/N ratio, color, biodegradability, etc.
- ✓ Toxicity to living beings (cyanides, phenols, chromates, chlorine, sulfur, H_2S, CO, heavy metal salts: Pb, Cd, Hg, Cu, etc.) or to facilities (alkali, chlorine, silica, volatile metals).
- ✓ Chemical reactivity and aggressiveness.

- ✓ Leaching behavior (How can they be carried away by the environment surrounding the waste once solidified?).
- ✓ Fertilizing power.
- ✓ Evolution over time.
- ✓ Radioactivity
- ✓ Quality factor (purity of the waste) and energy content.

1.4. Types of waste

Besides the classification based on their sources of origin, such as Solid waste, Liquid waste, and Gaseous waste also waste can be classified as Biodegradable, Non-biodegradable, Hazardous wastes and Non- hazardous wastes.

1.4.1. Solid wastes

Solid waste is a non-liquid, non-soluble material ranging from municipal garbage to industrial waste that sometimes contains complex and hazardous substances.

Solid waste is dangerous because it is very varied and does not all have the same effects. It is classified according to its origin but also its degradability.

Several tonnes of solid waste are left uncollected on the streets of most developing cities each day. It acts as a breeding ground for pests that spread disease, obstruct the sewers, and cause other infrastructural issues.

Solid waste disposed of without precautions risks not only degrading the landscape, but also polluting the environment and exposing people to nuisances and dangers, some of which can be very serious. Poor management of the collection and disposal of solid waste may lead to leachate pollution of surface water or groundwater.

Industrial solid waste presents a health risk. It is considered hazardous when it can directly harm human health because it has one or more of the following characteristics:

- Irritants: It can cause an inflammatory reaction through immediate, prolonged or repeated contact with the skin or mucous membranes.
- Harmful: They can cause serious risks through inhalation, ingestion or skin penetration.
- Toxic: They can cause serious, acute or chronic risks, or even death, through inhalation, ingestion or skin penetration.
- Carcinogenic: They can cause cancer or increase its frequency through inhalation, ingestion or skin penetration.

- Infectious: They contain viable microorganisms or their toxins, which cause diseases in humans or other living organisms.
- Teratogenic: They can cause non-hereditary birth defects or increase their frequency through inhalation, ingestion or skin penetration.
- Mutagenic: They can cause hereditary genetic defects or increase their frequency through inhalation, ingestion or skin penetration.

The accumulation of rubbish causes the deterioration of the landscape and its metamorphosis, often detrimental to the future of an area, or even a country. The general public and environmentalists give importance to the protection of landscapes and the nuisances caused by waste.

Waste, due to the fumes it releases, is one of the reasons that has led to the impoverishment of the natural environment through the marked decline of fauna and flora. Certain species of birds, excellent indicators of the quality of the natural environment, are in decline, or even disappear completely due to the lack of a healthy environment.

1.4.2. Liquid wastes

Liquid waste is a type of waste that is in liquid form. It is typically generated from industrial, commercial, or domestic processes. Liquid waste can contain a variety of chemicals, contaminants, or pollutants, making it potentially hazardous to the environment and public health if not managed properly.

Here are some of the main types of liquid waste:

- Wastewater: Wastewater is produced from domestic, industrial, and commercial activities. It contains organic matter, chemicals, bacteria, and other contaminants from water treatment facilities, sewers, and plumbing systems.
- Industrial effluent: Industrial effluent is liquid waste produced from manufacturing, production, and processing activities. It can contain toxic chemicals, heavy metals, oils, solvents, and other hazardous substances specific to each industry.
- Liquid Medical Waste: Healthcare facilities generate liquid waste such as expired pharmaceutical solutions, contaminated cleaning products, coolants, and potentially infectious body fluids.
- Liquid Chemical Waste: This is waste from laboratories, research facilities, and chemical production. It may include unused chemicals, reaction residues, acids, bases, solvents, toxic and corrosive chemicals.

- Used Oil: Used oil from engines, industrial machinery, and other equipment contains contaminants such as heavy metals, toxic chemicals, and impurities.

These pollutions can cause various types of nuisances: increasing the mortality of certain animal or plant species to the point of sometimes making them disappear, altering their physiological capacities, deteriorating the quality of the water to the point of making it unfit for certain uses, such as human food.

It is important to note that liquid waste management is subject to strict regulations to protect the environment and public health. Industries must therefore ensure that they comply with these regulations when treating and disposing of their liquid waste.

1.4.3. Gaseous wastes

Gaseous waste refers to waste materials in the form of gases that are produced as byproducts of industrial processes, such as carbon dioxide, carbon monoxide, methane, and nitrogen oxides. These gases can have various negative impacts on the environment, including global warming, acid rain, and air pollution.

A gaseous waste is therefore any substance released by the incineration of an object or by any chemical reaction that can lead to a nuisance or pollution. These come either from households or from industries. We distinguish: Gaseous household waste: which are fumes from households, from the burning of household waste in the open air, gas emissions from solid waste dumps, etc. As emissions we have: Carbon dioxide (CO_2), NO_2; Methane.

Gaseous industrial waste: these come from the energy, manufacturing, construction, transport, trade and services industries, incinerators, etc. These include: Carbon monoxide; Nitrogen oxides, Chlorofluorocarbons, Sulfur dioxide.

CO_2 is one of the greenhouse gases (GHG), which contribute to global warming following certain human activities. Transport (automobile, maritime and air) is one of the main causes of emissions of this carbon dioxide. This is why the use of public transport, as well as carpooling are strongly recommended in order to reduce carbon dioxide emissions, and therefore to preserve our environment. This gas can cause: dyspnea (inability to breathe), increased heart rate, headaches, dizziness, visual distortion, hearing impairment, retinal damage and nowadays we see that eye problems are increasingly recurring etc. Once it is concentrated in the atmosphere, it causes global warming, which is disastrous for the environment, which therefore increasingly causes climate change, melting ice, and the extinction of many animal, plant and organic species.

Methane (CH_4) is a powerful greenhouse gas. It contributes to global warming: it has an impact on the greenhouse effect about 25 times more powerful than carbon dioxide (CO_2). It absorbs some of the infrared radiation emitted by the Earth, and thus prevents it from escaping into space. In addition, it also contributes indirectly to the greenhouse effect by reducing the capacity of the atmosphere to oxidize other greenhouse gases. Upon skin contact, this gas does not irritate the skin. Contact with compressed gas or refrigerated liquefied gas escaping from a pressurized cylinder can cause frostbite or cold burns. Symptoms of mild frostbite include numbness, tingling, and itching of the affected area. Symptoms of more severe frostbite include a burning sensation and stiffness of the affected area. The skin may turn yellow or waxy white. Some severe cases may be accompanied by blistering, necrosis, and gangrene.

CFCs (Chlorofluorocarbons) are chemical compounds commercially called Freon. Colorless, odorless, non-flammable, non-corrosive in gaseous or liquid state, they are not really toxic, but some of their decomposition products can be dangerous. CFCs are responsible for the degradation of the ozone that protects the Earth at high altitudes (stratosphere) and absorb high-energy ultraviolet radiation, thus actively contributing to the increase in the greenhouse effect. Its effects on human health are the alteration of cellular functions at the points of impact that constitute the mucous membranes (especially ocular and pulmonary). It disrupts, under certain conditions, respiratory function not only in asthmatics, but also in healthy adults and children. Studies have shown that it can cause irritation of the eyes and upper airways, causing coughing and headaches.

Carbon monoxide (CO) is a colorless, odorless gas that is essentially created anthropically. It comes from the incomplete combustion of fuels and fuels, with complete combustion producing CO_2. This combustion occurs in air that is depleted of oxygen. This gas is thus produced in poorly ventilated rooms in homes, by heating systems, stoves, etc. Smoking is also a source of carbon monoxide in indoor air. Carbon monoxide is also emitted by automobiles (gasoline combustion). Its effects on health, carbon monoxide binds to the hemoglobin in the blood, with an affinity 200 times greater than that of oxygen. The organs most sensitive to this reduction in oxygenation are the brain and the heart. Inhalation of CO causes headaches and dizziness. Nausea and vomiting appear at high concentrations. In case of prolonged exposure to high levels in a confined environment, this pollutant can have a fatal asphyxiating effect. As for its effects on the environment, this gas contributes to the acidification of the air, soils, and waterways, which affects ecosystems. Carbon monoxide can contribute to the formation of tropospheric ozone; the ozone we breathe. It can also be transformed into CO_2 by chemical reaction, one of the main gases responsible for the greenhouse effect.

Sulfur dioxide (SO2) is a colorless, non-flammable gas with a pungent odor. It reacts on the surface of a variety of suspended solid particles, is soluble in water, and can be oxidized in wind-borne water droplets. Sulfur dioxide is mainly produced by the combustion of fossil fuels (coal, fuel oil, etc.), during which sulfur impurities in the fuels are oxidized by oxygen in the air O2 to sulfur dioxide SO2. This gaseous pollutant is thus released by multiple small sources (domestic heating systems, diesel vehicles, etc.) and by larger point sources (electricity or steam production plants, district heating plants, etc.). Some industrial processes also produce sulfur effluents (sulfuric acid production, oil refining, non-ferrous metallurgy, etc.). Coal combustion is the largest man-made source of sulfur dioxide accounting for about 50% of annual global emissions, with oil burning accounting for another 25-30%. On the environment, sulfur dioxide causes physiological and biochemical disruption of photosynthesis, respiration and transpiration, slowing of growth, yellowing and loss of leaves and leaf necrosis. As impacts on human health, sulfur dioxide could cause opacification of the cornea, breathing difficulties, inflammation of the respiratory organs, eye irritations, psychological disorders and pulmonary edema, bronchitis, circulatory and cardiac disorders, liver and kidney function problems, hearing loss, dermatological problems, suffocation and pulmonary embolism, damage to the immune system, gastrointestinal disorders.

1.4.4. Biodegradable waste

Biodegradable waste is organic waste that can be broken down naturally by microorganisms such as bacteria and fungi. It mainly includes food waste, garden waste, dead leaves, plant remains, wood chips, paper and cardboard, natural textiles such as cotton and linen, and other similar organic materials.

Biodegradation is a natural process where microorganisms break down waste into simpler substances, such as carbon dioxide, water, and nutrients. This process can occur under aerobic (in the presence of oxygen) or anaerobic (in the absence of oxygen) conditions.

Biodegradable waste management is important because it helps reduce the amount of waste sent to landfills, which helps preserve the environment. Common methods used to manage biodegradable waste are:

- Composting: Composting is a process of controlled decomposition of organic waste. Food waste, yard waste, and other organic materials are placed in a composter, where they are broken down by microorganisms into a material called compost. The compost can then be used as a natural fertilizer for plants.

- Methanization: Methanization: is an anaerobic process in which biodegradable waste is decomposed by micro-organisms to produce biogas, mainly methane. Biogas can be used as a renewable energy source for the production of electricity and heat.
- Vermicomposting: Vermicomposting uses earthworms to break down organic waste. The earthworms consume the waste and produce vermicompost, a nutrient-rich fertilizer.

It is essential to separate biodegradable waste from other types of waste, such as plastic and glass, to facilitate their proper management. Many municipalities encourage waste separation at source, which means that biodegradable waste is collected separately and treated appropriately.

In summary, biodegradable waste is organic waste that can be decomposed naturally by microorganisms. Composting, methanization and vermicomposting are commonly used methods to manage this waste in an ecological way. By properly managing biodegradable waste, we can contribute to the preservation of the environment and the production of renewable energy.

1.4.5. Non-biodegradable Waste

In nature, the decomposition process carried out by bacteria and fungi recycles organic matter, breaking it down into smaller and less complex molecules or inorganic substances. However, there are substances that microorganisms are unable to act on to break them down. We call these substances non-biodegradable.

They are generally produced and used industrially and in worrying quantities that end up in the environment and accumulate there. In addition, when a living being ingests or absorbs these substances, it will not be able to eliminate them and they will accumulate in its body, disrupting its functioning. If a substance made of non-biodegradable materials is thrown into nature, it will remain intact for many years. These are plastic materials: utensils, containers, boxes of cosmetic or pharmaceutical products, yoghurt pots, tyres, packaging materials, synthetic threads, oilcloth, syringes, rubber materials etc. Glass materials: bottles, glasses, porcelain objects. Metal materials: aluminium or steel boxes or packaging, products containing lead, etc.

Most non-biodegradable waste takes a long time to dissolve in nature or simply does not decompose. It is also important to know the decomposition period of certain materials: for example, an aluminum Coca Cola can take more than 200 years; a plastic bottle, 450 years; a plastic cup, 50 years; glass 1000 years; metal more than 100 years. For rubber, the duration is not determined. These materials have harmful consequences on the environment and human beings. Non-biodegradable and polluting substances, such as lead and mercury, are not eliminated by living beings and contaminate consumers at the end of the chain. "Living beings cannot break down the molecules of these substances. When they are eliminated, they are assimilated by producers, such as algae. For algae, the amount assimilated will not be toxic, but these organisms will be consumed by others, such as fish. When reaching humans, the concentration of toxic compounds will already be higher and can cause health problems, even death.

1.4.6. Hazardous wastes

These are wastes that can cause harm to humans or the environment. They may have one or more of the hazardous properties listed below, which requires certain special precautions. This waste is subject to strict administrative control (production, storage, transport, disposal). They have appropriate labelling.

The hazardous properties taken into account are as follows:

- Explosive
- Oxidizing
- Highly flammable
- Flammable
- Irritant
- Harmful
- Corrosive
- Infectious
- Toxic for reproduction/Carcinogenic
- Mutagenic/Carcinogenic
- Substances and preparations which, when in contact with water, air or an acid, release a toxic or very toxic gas.

- Substances and preparations which, after disposal, may give rise by any means whatsoever to another substance which has the same properties as before.

Examples of hazardous waste and hazardous recyclable materials include any solid, liquid, gas, sludge or paste that exhibits certain hazardous characteristics such as toxicity, corrosivity or flammability. Because of the hazardous properties of these materials, special recycling and disposal operations must be conducted at licensed facilities that manage the materials in a manner that protects the environment and human health.

Hazardous waste management can be very complicated. Handling, recovering and disposing of hazardous waste, even on a small scale, poses potential risks to health, the environment and property. In general, the employer should have qualified and competent personnel with a thorough knowledge of chemistry to manage the hazardous waste management program. If the organization does not employ qualified personnel in this area, an expert or company specializing in commercial waste disposal should be contacted.

1.4.7. Non- hazardous wastes

Non-hazardous waste is all waste that is not inert and does not have any of the properties of hazardous waste (explosive, flammable, irritant, toxic, etc.).

Non-hazardous waste, by contrast, does not pose a direct threat to human health or the environment, but it still cannot be dumped into a trash receptacle or a sewer line because of the risks it could pose.

Non-hazardous waste (recoverable and non-recoverable) is mainly generated by businesses and industrialists, but also by communities and households. The main non-hazardous waste is: ferrous and non-ferrous metals, plastic materials: PVC, PE, polystyrene, etc., untreated wood, plastic films, pallets, paper, cardboard, uncontaminated packaging, green waste, …

The United States Environmental Protection Agency defines non-hazardous waste as waste generated from processes associated with the production of goods and products, such as electric power generation and manufacturing of materials such as pulp and paper, iron and steel, glass and concrete.

1.5. Sources of wastes

The sources of waste are diverse. They come from several sectors. The different sources identified are:

1.5.1. Domestic sources of wastes

Domestic waste (also known as garbage) is any waste produced in the home as part of everyday activities.: It encompasses a variety of materials and substances resulting from household routines, including kitchen scraps, packaging, disposable products, and other common wastes produced in the course of daily life. Household waste is often diverse, including items such as: organic waste from the kitchen, recyclable materials such as paper, plastic, and glass, as well as non-recyclable waste. This waste can come from different parts of the home, including the kitchen, bathroom, and other living spaces. Managing household waste responsibly is essential to minimizing environmental impact and promoting sustainable living. This often involves practices such as sorting waste, composting organic waste, and reducing the use of single-use products. By understanding the composition and proper management of household waste, everyone can contribute to preserving the environment and reducing their ecological footprint.

Domestic waste management is a major concern for communities. Domestic waste can contain materials that are hazardous to health and the environment, and can be difficult and costly to dispose of. Communities need to implement effective domestic waste management programs to reduce health and environmental risks.

Recycling of domestic waste is an important solution to reduce waste and keep it in the material cycle. It reduces the amount of waste that needs to be processed and disposed of, and also reduces the consumption of raw materials. In addition, recycling household waste can have a positive impact on the environment, by reducing greenhouse gas emissions and conserving ecosystems. There are different ways to recycle domestic waste. Waste sorting is an important method to separate waste according to its composition. Recyclable waste can then be collected and processed to be reused in new products. Organic waste can be composted and used as a natural fertilizer. There are also incinerators that burn waste to reduce its volume, and controlled landfills where waste is buried. Reducing household waste is an important topic because waste can have a negative impact on the environment. Domestic waste can contain toxic substances that can pollute the air, water and soil. In addition, domestic waste can be a source of olfactory and visual nuisances, and can lead to health problems.

1.5.2. Medical or Clinical sources of wastes

Medical waste generally refers to waste resulting from healthcare activities in hospitals, medical or research facilities, or which is produced during the implementation of public health campaigns, such as vaccination campaigns. Ils sont en grande partie produits par les structures de soin direct, notamment par les centres hospitaliers universitaires, les hôpitaux périphériques, les cliniques ou les dispensaires de soins externes. The healthcare activities that generate the most infectious medical waste are emergency units (hospital or mobile), surgical and obstetric units, dialysis centers, blood collection facilities and long-term care units. In addition, establishments related to the health sector such as medical analysis laboratories, research laboratories, biomedical industries and morgues are classified among the major producers of medical waste.

They are often classified into two main categories, according to their degree of danger: on the one hand, medical waste similar to household waste (such as packaging), without a direct risk to human health or the environment, which represents approximately 80% of total production, and on the other hand, medical waste presenting an infectious or health risk for the remaining 20%. Medical waste at risk is listed according to its origins. Waste related to care procedures representing used medical devices, such as compresses, syringes and including sharp or pointed objects, such as needles or scalpels. Sharp and pointed objects represent 1% of the total volume of medical waste. Waste of human origin, such as biological liquids and materials, such as urine, blood, anatomical parts from surgical activity, corpses of laboratory animals used in medical research. The latter represent 15% of the total medical waste. Usually inert elements contaminated by an infectious or radioactive agent. Certain medicinal molecules such as cytotoxic chemotherapeutic products, iodine derivatives, antiseptics, serums, vaccines or expired medicinal products. Medicinal waste represents 3% of the volume of waste and cytotoxic substances 1%. Products such as laboratory reagents containing formaldehydes or benzenes, as well as reagents used in radiology for developing photographs, heavy metals such as lead, or certain gases are considered here as medical waste.

Health care waste contains potentially harmful microorganisms that can infect hospital patients, health care workers and the public. Other potential hazards include drug-resistant microorganisms that spread from health care facilities to the environment.

The treatment and disposal of healthcare waste can pose indirect health risks due to the release of pathogens and toxic pollutants into the environment.

Health care waste management requires increased attention and diligence to avoid adverse health effects associated with poor practices, including exposure to infectious agents and toxic substances. Key elements to improve health care waste management include:

- promoting practices that reduce the volume of waste generated and ensure proper waste separation;
- developing strategies and systems, as well as rigorous monitoring and regulation, to improve waste separation, destruction and disposal practices with the ultimate aim of meeting national and international standards;
- where possible, promoting safe and environmentally sound treatment of hazardous health care waste (e.g. autoclaving, microwave or steam treatment combined with internal shredding, and chemical treatment) rather than incineration of medical waste;
- creating a comprehensive system, defining responsibilities, and covering resource allocation, treatment and disposal of waste. This is a long-term process, supported by incremental improvements;
- awareness of the risks of health care waste, and safe practices; and the choice of safe and environmentally friendly management options to protect people from hazards during the collection, handling, storage, transport, treatment or disposal of waste.

Government commitment and support are needed for universal and long-term improvement, but immediate action can be taken at local level.

1.5.3. Agricultural sources of wastes

Agricultural waste is defined as residues from crop production and animal husbandry by farms. This includes materials from crop production itself, such as biomass from intercropping, crop residues and waste (grass, grain, tubers), as well as waste from animal husbandry, such as grass, hay, bedding and animal feed.

In large quantities, agricultural waste can have a negative impact on the environment and habitat, for example by emitting greenhouse gases, creating unpleasant odours and toxic liquids that can seep into sources, allowing pests to multiply. Frequent and large-scale burning of agricultural waste also has negative effects on the health of people who are exposed to toxic smog from fires. Large-scale burning of agricultural waste worldwide results in frequent smog, especially in early autumn.

In addition to the impact on air quality, burning agricultural waste in fields also has a negative impact on soil fertility, economic development and the climate. The lack of environmentally friendly management of agricultural waste also leads to animal suffering, water pollution, the need for fertilisers and the decline of biodiversity, among other things.

According to the waste hierarchy, burning agricultural waste for energy production is a less environmentally friendly treatment method than recycling or reusing it. In addition, incineration for energy production can only be done once, while consumer goods (such as paper made from agricultural waste) can be recycled seven times. After that, they can possibly be burned again to produce energy, or even transformed into biogas or compost through fermentation.

In order to reduce the negative impact of agricultural waste on the earth, some companies have focused on developing new technologies that can put agricultural waste to good use.

The material or energy disposal of waste can be carried out in different ways, for example by composting, methanisation, direct spreading on the soil or by methanisation with other substrates in agricultural biogas plants. The biomass potential of waste from agriculture is widely exploited. The majority of this waste is treated in composting or methanisation plants and can then be reused by agriculture, in the form of compost or digestate.

Most farmers in developing countries are unaware of the different options and therefore consider burning as the best option. Therefore, large-scale awareness programs are needed to:

- Recognize agricultural waste as a waste stream;
- Educate on the adverse effects of unsavory waste treatment methods such as incineration and landfilling;
- Educate farmers on the existence of economically viable options higher up the waste hierarchy and their benefits to them and the environment.

1.5.4. Industrial sources of wastes

Industrial waste is a waste generated in the manufacturing of the product or during industrial processes. Types of industrial waste include cafeteria waste, dirt, gravel, masonry, concrete, scrap metal, garbage, oil, solvents, chemicals, wood, lumber and other similar wastes. Industrial waste can be solid, liquid or gaseous which are divided into 2 categories hazardous waste and non-hazardous waste. Hazardous waste can result from the manufacturing of the product or from the industrial process. Some commercial products such as stain removers, paint or pesticides that are discarded by some commercial buildings are also defined as hazardous waste. Non-hazardous industrial waste does not meet the Ministry of the Environment definition of non-hazardous waste and is not municipal waste. Waste has been a problem since the industrial revolution. Industrial waste can be toxic and corrosive. If this waste is not properly treated it can be dangerous for health and the environment.

Industrial waste management involves the collection, transportation, treatment, and disposal of an organization's industrial waste. This ranges from contaminated soil to dry pesticides to chemical waste. The entire process revolves around the responsible and efficient disposal of this waste, thereby reducing the organization's environmental impact and costs.

Proper industrial waste management is essential for modern businesses. Since industrial waste can be hazardous, it is essential to dispose of it properly so as not to harm the environment, employees, and those around you. That is why most organizations spend a lot of time and effort on their industrial waste management practices, and it may be time for you to start strengthening your processes. In addition to helping organizations reduce their impact on the environment, proper waste management increases efficiency while reducing costs. It is much more cost-effective to treat and manage waste properly than to let it accumulate and cause problems later on.

Industrial waste management can be different for every company and organization. That's why it's important to create a team that can identify all the industrial waste produced by the organization and the best ways to manage it. While the process of industrial waste management is different from one organization to another, there are some best practices that you can adopt. These practices include the following:

- Reduce, reuse, and recycle waste in your organization;
- Train employees on the company's waste management practices;
- Use approved haulers for your hazardous waste to safely dispose of it;
- Continuously evaluate your waste management practices and make improvements as needed;
- Identify the waste produced by your organization;
- Ensure that all employees separate the waste they produce.

1.5.5. Wastes from Construction or Demolition

Construction and demolition waste is generated from construction, renovation, repair, and demolition of houses, large building structures, roads, bridges, piers, and dams.

Construction and demolition waste is mainly composed of debris collected during the demolition, construction and renovation of buildings. This type of waste, mainly present in the form of heavy bulk materials, such as concrete, bricks, wood, metals, glass and reclaimed building components, contains a mixture of mineral and non-mineral materials.

The challenges of dealing with construction and demolition waste are due to the varying properties of the materials. By nature, waste produced on demolition sites is bulky and often heavy, increasing transportation costs. Reducing, separating and sorting waste early in the recycling process allows for easier and faster handling for increased efficiency and productivity. The closer this treatment is to the site, the less need there is for costly and time-consuming operations that not only cost money but also generate unnecessary gas emissions and worker safety risks.

Recycling construction and demolition waste helps reduce the amount of waste that ends up in landfills. By recovering recyclable materials, we reduce the volume of waste that ends up in landfills. This extends the life of these sites and reduces associated environmental problems such as soil and groundwater pollution. In addition, recycling materials avoids the exploitation of new resources, which contributes to the preservation of our environment.

By recycling construction and demolition waste, we limit the exploitation of natural resources by avoiding the extraction of new materials. The recycled materials can then be reused in the construction of new buildings, which reduces the demand for raw materials. The process of recycling construction and demolition waste has a significant positive impact on reducing CO_2 emissions. Indeed, the exploitation of natural resources to obtain new construction materials is a major source of greenhouse gas emissions. The extraction of raw materials, their transformation into finished products, and their transport to construction sites, each step of this process contributes to the increase of our carbon footprint. On the other hand, recycling construction and demolition waste generates significantly less CO_2 emissions. Recycled materials are often processed locally, which reduces the need for transport and therefore the associated emissions. In addition, the use of recycled materials avoids the extraction and transformation of new resources, two very energy-intensive and CO_2-producing activities.

1.5.6. Commercial sources of wastes

Commercial waste refers to all types of waste generated and discarded by a business, including home-based enterprises. It does not matter if you throw it in a bin, incinerate it, rinse it away or send it to a collection site everything you don’t use or results from usage is commercial waste.

Conventional commercial waste is essentially all waste that cannot be classified as either construction and demolition waste or municipal waste. The composition includes plastic waste, paper, wood and textiles. However, special production residues from industry are classified as commercial waste. Waste from medical institutions and hospitals- cotton, bandages, syringes, saline bottle, wrappers of medicine, etc.

The waste comes from waste collection in industry and commerce. This includes large industrial companies as well as catering, trade and offices. Most of the waste is bagged and is therefore also called commercial waste, like household waste.

Like construction and demolition waste, commercial waste is delivered to appropriate treatment plants where it is examined and sorted to extract the recyclable components. In this case too, the non-recyclable sorting residue is then sent for thermal recycling.

1.5.7. Mining sources of wastes

Mining waste can be defined as any mineral product or mineral deposit resulting from the exploration and mining or processing of ore. These residues can be raw (clear waste, non-exploitable mineralized products), more or less reworked, from the ore processing and enrichment phases (washing rejects) containing possible chemical, mineral or organic additives, or artificial, generated during processes of extraction of the useful substance during a calcination or fusion stage (ash, slag).

The volume and mineralogical nature of mining waste are closely linked to the geological context of the operation (sedimentary, metamorphic, igneous rocks), the type of operation (underground mine, open-pit mine) and the nature of the processes developed on the extraction site. They are mainly made up of silicate minerals (quartz, feldspars, clays, etc.), sometimes carbonates (calcite, dolomite, etc.), more rarely metal oxides and high-temperature silicates from pyrometallurgical processes. Their granulometric homogeneity varies greatly from one site to another, from one deposit zone to another. It depends on the nature of the extracted substrate, the stage of the operation (uncovering, gallery, etc.), and the processes used to concentrate the substance exploited (crushing, flotation, extraction, etc.).

From an environmental perspective, their potential to harm the natural environment is directly related to the useful substances exploited, also called mineralizations, and the minerals that accompany their installation (gangue minerals). These mineral phases, which are found at various concentration levels in mining waste, are likely to pollute the surrounding environment by releasing toxic elements (heavy metals) and anions that disrupt the physicochemical characteristics of the water (acidity, sulfates, halides, etc.). And this in the event of degradation of their structure after exposure to climatic conditions. To this potential, we must also add the products used during the physicochemical treatments necessary for refining the extracted substances. Thus, the specific features of each site and each type of residue can only be properly assessed by direct observation: assessment of pollution or proven physicochemical instabilities on the site where the dumps likely to provide secondary raw materials are stored, characterization of the residues by mineralogical and chemical analyses (identification and speciation of potential pollutants, analysis of the susceptibility to be mobilized by leaching tests, etc.). Concerning a certification process that remains to be established, and apart from the natural (Hg) or artificial (CN, complexing agents, etc.) toxic compounds introduced during ore processing and which will have to be strictly evaluated, several approaches are possible to guide potential uses:

- assess the overall heavy metal content of the material, which should not exceed certain thresholds established from the material's receiving environment;
- for sulphurous dumps, estimate the acidification potential, which must ensure the neutrality of the waste with respect to the receiving environment;
- carry out leaching tests in an oxidizing environment to estimate the potential for the release of metals and salts. From these tests, in comparison with the natural geotechnical implementation environment (scenario), and pilot tests, it should be possible to consider their use in a manner adapted to each intended application.

1.5.8. Radioactive sources of wastes

Electricity production, but also hospitals, universities and certain non-nuclear industries generate radioactive waste. All regulations specific to waste in general apply to radioactive waste. But radioactive waste emits radiation and therefore presents a specific risk to human health and the environment. It is therefore necessary to manage it with special precautions, from its production to its final destination. The creation of suitable disposal channels is a major challenge for all the stakeholders involved, industrialists, regulatory authorities, public authorities, local communities and the population.

Radioactive waste is a radioactive substance for which no further use is planned or envisaged. It is said to be "ultimate" when it can no longer be treated under the technical and economic conditions of the moment, in particular by extracting its recoverable part or by reducing its polluting or dangerous nature. Therefore, the creation of disposal channels is a major challenge for manufacturers, regulatory authorities, public authorities, local communities and the population. Radioactive waste is classified according to two criteria:

- the level of activity of the radionuclides
- the lifetime of the radionuclides (or radioactive period).

Radionuclides contained in radioactive waste can be of artificial origin, such as cesium 137, or natural, such as radium 226.

The radioactive characteristics of waste are: the type of radionuclides contained and the radiation emitted (alpha, beta, gamma), the activity (number of atomic nuclei that spontaneously disintegrate per unit of time) the radioactive period (time required for the activity of a radionuclide in a sample to decrease by half).

Radioactive waste comes mainly from the nuclear industry. The remainder comes from the use of radioactive elements in hospitals, universities and certain non-nuclear industries, as well as from defence-related activities.

Radioactive waste emits radiation and therefore presents a specific risk to human health and the environment. It is therefore necessary to manage it with special precautions, from its production to its final destination. The creation of suitable disposal channels is a major challenge for all the stakeholders involved, industrialists, regulatory authorities, public authorities, local communities and the population.

The sustainable management of radioactive materials and waste of all kinds, resulting in particular from the operation or dismantling of facilities using radioactive sources or materials, is ensured in compliance with the protection of human health, safety and the environment. Research and implementation of the means necessary to secure radioactive waste are undertaken in order to prevent or limit the costs that will be borne by future generations; producers of spent fuel and radioactive waste are responsible for these substances.

1.5.9. Electronic sources of wastes (E-Waste)

Electronic waste, or e-waste, is a term that covers any discarded electrical or electronic device that has reached the end of its useful life. E-waste can include everything from old cell phones and laptops to refrigerators and televisions.

E-waste is not only a huge environmental problem, but also a waste of valuable resources. Many electronic devices contain precious metals, such as gold, silver, platinum, and palladium, as well as other useful materials, such as copper, iron, aluminum, and plastic. These materials can be recovered and reused if the e-waste is properly recycled. However, if e-waste is thrown into landfills or incinerated, these materials are lost forever and can cause serious harm to human health and the environment.

Electronic waste can be classified into different categories:

- Large household appliances, such as refrigerators, freezers, washing machines, dryers, dishwashers, ovens and microwaves.
- Small household appliances, such as vacuum cleaners, toasters, coffee makers, hair dryers, electric shavers and fans.
- Information technology (IT) equipment, such as computers, laptops, tablets, monitors, keyboards, mice, printers, scanners, routers and servers.
- Consumer electronics, such as televisions, DVD players, game consoles, cameras, camcorders, speakers, headphones and musical instruments.
- Lamps and lighting fixtures, such as fluorescent tubes, LED bulbs, desk lamps and chandeliers.
- Toys and recreational equipment, such as electric toys, video games, sports equipment with electronic components (e.g. treadmills) and recreational equipment (e.g. sewing machines).
- Tools and machines, such as drills, saws, soldering irons, welding machines, lawn mowers, and generators.
- Medical devices and equipment, such as X-ray machines, ultrasound machines, blood pressure monitors, and thermometers.
- Monitoring and control instruments, such as thermostats, smoke detectors, fire alarms, and security cameras.
- Vending machines such as cash dispensers and cash machines.

E-waste is a growing problem that affects everyone who uses electronic devices. E-waste can contain hazardous components that can harm human health and the environment if not disposed of properly. E-waste can also contain valuable materials that can be recovered and reused if properly recycled. Therefore, it is important to consider some alternatives to e-waste disposal, such as repair, reuse, or recycling. These alternatives can help extend the life of electronic devices, save money, benefit society, and protect the environment.

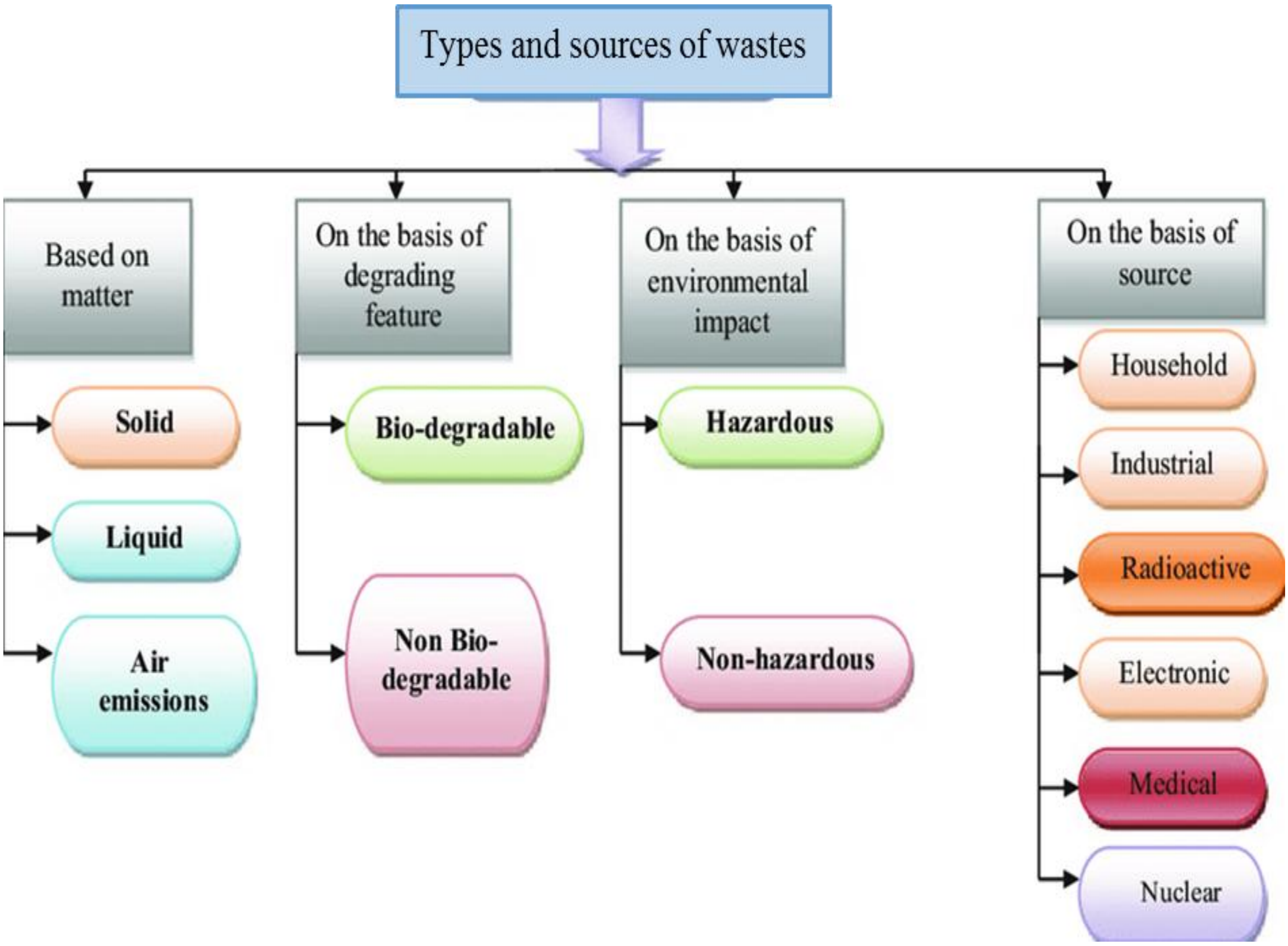

Figure 1.1. waste types and sources (Mondal & Palit, 2019)

1.6. Effects of waste on health and the environment

Over the past several decades, waste generation has increased significantly, with a clear and devastating impact on the environment and human health. Mismanaged waste creates a variety of adverse effects, including:

• Landfilling waste reduces the quality of water, air and soil, with significant health consequences for those nearby.

• Waste incineration has a significant impact on air quality and carbon emissions, which affects the environment and public health. This process, while reducing the volume of waste, releases greenhouse gases and toxic pollutants, which requires rigorous control measures and technological advances.

• Poorly managed waste, in particular plastic pollution, damages fisheries and associated livelihoods and contributes to food insecurity.

Dumps and landfills release pollutants into the soil, water and air. Pollutants from landfills enter the soil and groundwater through rainwater that enters the landfill cell. Rainwater can be contaminated when it comes into contact with chemicals such as volatile organic compounds, chloride, nitrogen, solvents, phenols, trichloroethylene and heavy metals seeping into groundwater.

While protections are often put into place to prevent this contaminated water, known as leachate, from escaping landfills, these protections are prone to failure. They can endanger the water supply of nearby communities.

Landfills also release greenhouse gases such as CH_4, CO_2, N_2, NH_3, H_2S, produced by the decomposition of organic waste by bacteria. The amount and type of gases emitted depend on the landfill’s age, composition, temperature and moisture content.

Landfills create gases and toxins that pose a cancer risk at high exposure levels and can be inhaled or ingested by workers or people living near the site. Studies have indicated that elevated levels of hydrogen sulfide commonly emitted from landfills can lead to increased eye, throat and lung irritation, lung cancer, nausea, headaches, nasal blockage, sleeping difficulties, weight loss, chest pain and asthma aggravation.

Although incinerators often produce energy from waste, the process, like landfills, releases pollutants and gases into the environment, which negatively impact human health. These findings further highlight the need to focus first on reducing waste at source, in order to limit the use of landfills and incinerators.

2.1. Introduction

Development and rapid industrialization have led to the production of enormous waste. Waste disposal has a negative impact on the environment, such as land use, resource depletion, and the amplification of global warming due to emissions of methane, carbon dioxide and other greenhouse gases, waters intoxication due landfilling, as well as acidification and toxic effects from emissions to air in the case of incineration.

Waste management, one of the branches of applied rudology, includes the collection, trading and brokerage, transport, treatment (processing of waste), reuse or disposal of waste, usually those resulting from human activities. This management aims to reduce their effects on human and environmental health and the living environment. For several decades, emphasis has been placed on reducing the effect of waste on nature and the environment and on its recovery in a circular economy perspective. All waste is concerned (solid, liquid or gaseous, toxic, hazardous, etc.), each with its own specific sector. Management methods differ depending on whether one is in a developed or developing country, in a city or in a rural area, whether one is dealing with an individual, an industrialist or a trader. Non-hazardous waste is usually managed under the responsibility of local authorities, while waste from businesses and industry tends to be managed under their own responsibility.

From a material resource-efficient perspective, disposal options such as landfill and incineration do not represent best practice for separately collected recyclables and mixed municipal solid waste, it is important to quantify the impacts associated with such disposal operations, in order to quantify the environmental, economic and societal benefits achieved through proper waste management.

This chapter will allow you to develop a further understanding of what goes into waste management and should a low you to grasp the full potential benefits of waste management, across different commercial, industrial, and residential applications.

2.2. What is waste management?

Waste management includes the collection, transport, recovery and disposal of waste and, more broadly, any activity involved in the organization of waste management from its production to its final treatment, including trading or brokerage activities and the supervision of all of these operations.

Waste management is an essential task to protect the environment, and more specifically our planet. The harmful impacts of waste on the environment are numerous: soil and water pollution, greenhouse gas emissions, energy production from waste, etc. Waste management must therefore be adapted to the needs of each community in order to reduce these harmful impacts as much as possible.

Waste management aims to minimize the negative environmental impacts of waste at all stages of its life cycle. This includes treatment, recycling and disposal of waste. The main objective is to prevent any form of contamination of soil and water, as well as to avoid the production of substances harmful to the environment and human health.

Waste management is essential to protect the environment and minimize the negative environmental impact associated with the life cycle of waste. Measures must be put in place to improve waste management: reduction, recycling, collection, transport, treatment and management of hazardous materials. These measures will ensure better control and protection of the environment.

Figure 2.1. Waste management processes (Bhusan, 2016)

2.3. Principles and procedures of waste management

In this section, we will start with identifying the phases of waste management, starting from its generation up until disposal, this will include:

- Generation, Collection and Storage
- Transport, Treatment, and Disposal
- Monitoring and Evaluation

2.3.1. Generation, collection, and storage

Waste prevention processes shall be designed to prevent or minimize the quantities of waste generated and the adverse effects associated with such waste in accordance with the following strategy:

1. Use less toxic and less hazardous materials to minimize the volume of waste produced. An example of this would be the replacement of toxic cleaning materials with sustainable and safe ones. For example, Using Certified Green Seal products, which is a labeling for environmentally friendly cleaning products.

2. Secondly, we can also minimize hazardous waste generation by implementing strict waste segregation to prevent the mixing of non-hazardous and hazardous waste during storage. Contact between the two types of hazardous and non-hazardous waste causes contamination which increases the amount of hazardous waste that must be managed and treated properly. Which is surely considered a losing bargain.

3. Applying manufacturing process that convert materials efficiently, providing higher product output yields, including modification of design of the production process, operating conditions, and process controls. An example of this would Be in the form of reducing wasted materials in production line for fabric cutting through certain design solutions.

4. To reduce the amount of waste resulting from materials that are out of date, off-specification, contaminated, damaged, or in excess of facility requirements, good maintenance and operating practices, including inventory control, must be implemented.

5. In order to avoid over-ordering of materials and reuse packaging materials and containers for compatible materials, procurement measures must be put in place that recognize the possibilities of returning usable materials such as containers.

With respect to storage, wastes must be stored in a manner that prevents mixing or contact between incompatible wastes and allows inspection between containers for spills and leaks. Examples include physical separation such as containment walls or curbs or sufficient space between incompatible wastes. When designing storage plans, there are a few guidelines to keep in mind:

1. Waste should be stored in closed containers, protected from direct sunlight, wind and rain, and take into account the wind profile of the storage area in case it is exposed.

2. To avoid any loss to the environment, secondary containment systems must be constructed with materials that are suitable for the waste contained and adequate.

3. Where liquid waste is stored in volumes greater than 220 liters, secondary containment must also be provided. It should be kept in mind that the available volume of secondary containment must be either at least 110% of the largest storage container or 25% of the total storage capacity.

4. Provide adequate ventilation where volatile (hazardous) wastes are stored. Hazardous waste storage activities should also be subject to special management actions, which should be conducted by employees who have received specific training in handling and storage of hazardous wastes.

The waste management plans should also take into consideration the following parameters whenever hazardous waste streams are present in a facility:

1. Information on chemical compatibility and labeling of each container to identify its contents must be provided to employees.

2. Limit access to hazardous waste storage areas, allowing access only to properly trained employees, while clearly identifying (labeling and warning signs) the area, including documenting its location on a facility plan or site map.

3. Waste storage areas must have periodic inspections with documented results.

4. To deal with any accidental release in the event of a spill, response and emergency plans must be prepared and implemented.

5. Due to the high risk of contamination by hazardous waste, underground storage tanks and pipelines should be avoided.

2.3.2. Transport, treatment and disposal

Waste transportation, either on-site or off-site, must be carried out in a manner that allows for treatment and prevents or minimizes spills, releases, and exposures to employees and the public. All waste containers intended for shipment off-site must be secured and labelled with the contents and associated hazards, properly loaded onto transport vehicles before leaving the site and accompanied by a shipping document identifying the load and its associated hazards. Transportation begins with municipal waste collection in conjunction with the waste collection levels inside facilities.

In this regard we see that Municipal waste handling is mostly

based on 4 main levels, they are:

- Collection Center.

- Distribution Center.
- Treatment.
- Disposal.

These levels should be taken into consideration when monitoring the transport of waste from handling services.

Next, waste treatment, this could be in the form of Recycling and Reuse. The implementation of recycling plans helps to reduce the total amount of waste produced and this of course after the implementation of waste prevention strategies. Waste treatment should take into account the following elements:

1. Evaluation of waste production processes and identification of potentially recyclable materials

2. Identification and recycling of products that can be reintroduced into the manufacturing process or into industrial activities in the operating area.

3. Products that may be reintroduced into the manufacturing process or into industrial activities in the operating area must be identified and recycled.

4. Establishing recycling objectives and formal tracking of waste collected for processing.

5. Provide training and incentives to employees to achieve proper treatment and disposal targets if waste is still generated.

6. Finally, we need to ensure that the waste handling service should be properly equipped to treated and dispose of waste in a manner that ensures meeting sustainable goals set in our plans.

For the waste handling service provider, we need to keep in mind that Selected management approaches should be consistent with the characteristics of the waste and local regulations, and may include one or more of the following:

− To render waste on-site or off-site non-hazardous prior to final disposal, it must undergo biological, chemical or physical treatments.

− Treatment or disposal at permitted facilities specially designed to receive the waste.

Several known methods for the safe and final disposal of waste include composting operations for non-hazardous organic waste; properly designed, licensed and operated landfills or incinerators designed for the type of waste concerned; or other effective methods such as bioremediation.

Commercial or Government Waste Contractors, as waste managers we need to validate that they represent the best option for us to achieve our waste management plan goals, this is done by ensuring that they have two main things, they should:

1. Have the technical capacity to manage waste in a way that reduces the immediate and future impact on the environment.

2. Have all required permits, certifications, and approvals, of applicable government authorities.

Finally, waste managers should consider Installing on-site waste treatment or recycling processes in case no proper waste handling service is available and as a final option, construct facilities that will provide for the environmental sound long-term storage of wastes on-site or at an alternative appropriate location up until external commercial options become available. One example is the storage of waste from nuclear energy production.

2.3.3. Monitoring

There are several guidelines that you need to be sure to follow during the implementation of any waste management plan, and most of them will be greatly utilized in the assessment stage for existing waste management plans.

There are many steps in monitoring active waste management operations that need to be included in monitoring activities related to hazardous and non-hazardous waste management. Among these operations, we can cite: inspection, audits, tracking and characterization of waste management operations. These include:

1. To detect any evidence of accidental release and to verify that waste is correctly labelled and stored, regular visual inspection of all waste collection and storage areas is required.

2. Regular audits of waste segregation and collection practices as seen in our plans.

3. In order for us to assess the achievement of different targets, it is necessary to monitor trends in waste production by type and quantity of waste generated, preferably by department of the establishment.

4. Characterize waste at the beginning of the generation of a new waste stream and periodically document the characteristics and proper management of the waste to adapt to new inputs.

5. Keep manifests or other records that document the volume of waste produced and its destination, to allow for assessment and comparison between different conditions of operations.

Accordingly, whenever significant quantities of hazardous wastes are generated and stored on site, monitoring activities should include:

1. Inspection of vessels for leaks, drips, or other indications of loss.

2. Identification of cracks, corrosion, or damage to tanks, protective equipment, or floors

3. For ease of use, check locks, emergency valves and other safety devices and lubrication if necessary and practice of keeping locks and safety equipment in the standby position when the area is not occupied.

4. Documenting results of testing for integrity, emissions, or monitoring stations (air, soil vapor, or groundwater).

5. Documenting any changes to the storage facility, and any significant changes in the quantity of materials in storage.

As for Monitoring records for hazardous waste collected, stored, or shipped should contain Name and identification number of the material(s) collected, stored, or shipped. This includes three things:

1. Name and identification number of the material(s) composing the hazardous waste, including:

   a. physical state (be it solid, liquid, gaseous or a combination of one).
   b. Quantity (in kilograms or liters, and number of containers).

2. Strict Waste shipment tracking documentation that includes:

   a. quantity and type.
   b. date dispatched, date transported.
   c. date received.
   d. record of the generation facility.
   e. handling and processing service provider.

3. Method and date of document storage, repacking, processing or disposal at the facility, cross-referenced to specific WMP manifest document numbers.

You may feel that these administrative guidelines are not tailored to the specific needs of your institution and therefore you should keep in mind that at the end of this manuscript you may be able to design the appropriate waste management plan for your specific institution and from there decide on the proper regulation with regard to each stage of the hierarchy from generation to disposal.

2.3.4. Products Recycling and Labeling

As waste managers, labels are a great way to communicate information, and this extends to information related to our work. In this chapter, we will overview some of the most significant labels that can be stamped on products and will allow you to understand them to make use of them in the future. a separation of components, a resin identification code (RIC) to differentiate the quality of plastic, a company's perspective on recycled products or certain disposal warnings are instructions that may include these labels.

a) The Mobius Loop

The Mobius loop is a triangle made up of three arrows looping back on themselves in a clockwise direction. This symbol is used as a general reference for the recyclability of a product, to convey several messages regarding the conditions and possibilities of recycling for different types of products. It is also used to indicate that a product can be recycled as well as the presence of recycled content in a specific product.

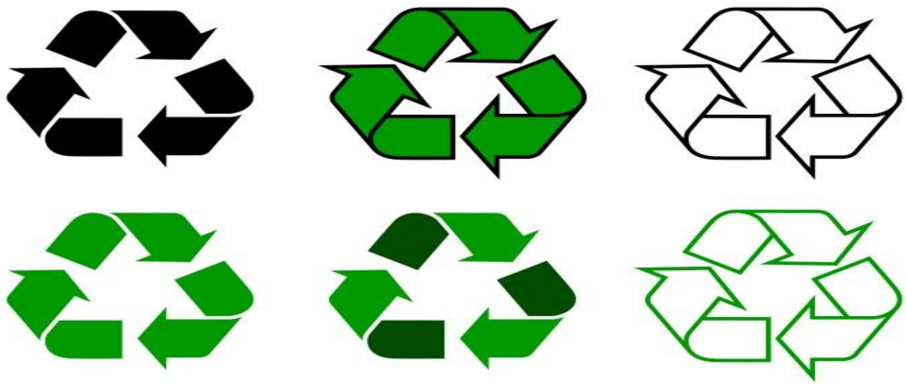

Figure 2.2. Illustrations of the Mobius Loop (Ameer Mubaslat, 2021)

b) The Green dot Symbol

The green dot, which represents two arrows looping into one another, is mostly used as a reference for consumers that the manufacturer contributed resources towards package recycling at some point.

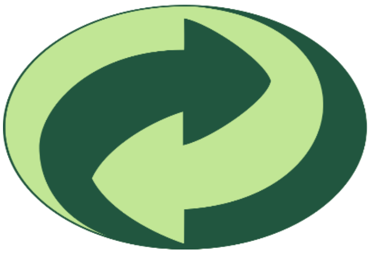

Figure 2.3. Green dot Symbol (Ameer Mubaslat, 2021)

c) The Wheeled Bin Symbol

The wheeled bin symbol indicates that the product cannot go in a normal waste or recycling bin, most likely because it is electrical or hazardous.

Figure 2.4. Wheeled Bin Symbol (Ameer Mubaslat, 2021)

d) The Forest Stewardship Council (FSC) logo

We also have the Forest Stewardship Council logo identifies the product as wood-based from well-managed forests in accordance with FSC rules and regulations.

Figure 2.5. Forest Stewardship Council (Ameer Mubaslat, 2021)

This resembles a brief of product labels which relate to our managerial needs. Keep in mind that These labels help us identify different opportunities for handling the waste their products generate, thus contributing to our waste management plan.

2.4. Waste management plans for facilities

This section will tackle the design and assessment for facilities waste management plans (WMP).

2.4.1. Design

The design of the waste management plans for facilities mainly focuses on the generation, collection and storage of waste which was covered previously, we will put each of these stages into implementation and show you how you can utilize them to design your own waste management plan. Beginning with major requirements for your waste management plan and moving into the administrative steps to design it.

Before designing our plan, there are certain parameters which we need to identify in order to help us manage the waste and recycling needs of our facility. these are 7 parameters, which should help make our design adaptive to the region we are implementing it in as regulations, infrastructure and waste management services defer from region to region. They include:

a. Land use details

Identify land use details, including the facility's land and building specifications. This involves documentation of the land size, building's number of floors, operation of the facility (industrial, residential and commercial), as well as the number of units and their specification (apartments by size, stores, offices or production zones).

b. Waste systems

Define waste handling systems. Including the different technologies for handling waste, would they be mandatory or not. This could include chutes, compactors (They are mainly used when waste volumes exceed 25,000 litres per week and help to compress the waste into smaller sizes), and also automated waste management systems, onsite food processing systems and glass crushers.

c. Frequency of collection

Next to the establishment, identify the collection frequency and include the collection times by the relevant municipality or collection service provider.

d. Collection location and bin storage

Design collection location and bin storage, through identifying the location of level 1, 2, and 3 collection spots throughout the facility. This is always based on the major locations for waste generation with relevance to different types of waste.

e. Waste management drawings

Drawing Up to Scale waste management designs by overlaying schematics of preliminary waste handling plans over building blueprints. This is meant to show the path that the waste would travel throughout the facility's levels of waste handling.

f. Collection contractors

Define waste contractors which are represented by municipal waste handling services in most countries. This is done by identifying the service provider's capacity, scope of operations as well as the present options for waste processing and set the goals for recycling and reuse.

Now, after finishing the initial screening for our design, we begin the design for our plan by following the below eight steps. Following these steps will help to accelerate your work, this is what you will need to do:

1. Create tables that define the following elements (source of production, type of waste, quantity of waste, treatment and handling requirements based on their type) to determine the type and volume of recyclable waste and waste that will be produced on site.

2. Determine reduction, reuse and recycling opportunities and targets. this begins by substituting materials purchased where treatment produces lower volumes of waste as well as instituting procurement measures that recognize opportunities to return usable materials such as containers and packaging material. This process involves identifying recycling opportunities based on service availability and manufacturer specifications. It then involves looking for possible options for reusing the items, either internally through the facility or externally. This ends with documenting the data in tables containing the type and quantities of waste, in addition to their reduction, reuse and recycling possibilities.

3. Calculate the number and type of containers required. Your WMP must include the number of bins and their sizes. It is preferred to collect larger bins as this decreases the number of bins to be stored or collected and reduces truck movements and the time taken for collection.

This is usually done by using benchmark values for waste produced by different industries.

Example: suppose we have a restaurant, it is safe to build the baseline for our level 3 waste storage around 860 liters (representing 660 mixed and 200 recyclable) and then move on to breaking down each type into its source of generation. From there we move down to level 2 collection bin sizes depending on the zones we have, and these would range from 120l to 200l for a commercial facility and could go up to 500 l for an industrial facility. As for level 1 collection, we usually focus on waste generated from the station itself and these translate into 20-60 liter bins for commercial facilities.

4. Calculate level 3 and level 2 collection and storage space required. In Calculating the space for level 3 collection and storage. we use the following equation:

$$Collection\ Space = NContainors \times Acontainor \times fmaneuver$$

$NContainors$: Number of containers.

$Acontainor$: Individual container footprint.

$fmaneuver$: Maneuver factor, and represents the space required to move the

containers inside the storage zone and is between (2-2.25).

Example: if we have 6 containers for our facility and a 3*1m footprint for each, and a limited space so we utilize a maneuvering factor of 2, we are left with needing a level 3 collection area of 36 square meters.

5. Determine access route for collection vehicles and turning radius.

Using your municipal or waste collection service provider’s guidelines which should be included in the plan. You should Design entry and exit scenarios for an easy and proper access and loading environment for the waste, and this depends on the facility’s activities and the dimensions of the collection vehicle.

For example, a facility with considerable customer interaction should consider concealing the loading and waste storage access points from the entrance. Additionally, the route design should be conducted as seen in the picture. As we said utilizing the available access points and the proper loading and storage location for each facility and waste.

6. Designate collection/loading area.

Choose final location and bin allocations for the level 3 collection area. taking into consideration its loading capability for our waste handling service's collection trucks.

7. Develop and submit a waste management overlay plan while keeping in mind that it contains the following from previous steps:

a. generic floor schematics showing garbage and recycling disposal points.
b. Chutes, carousels, compactors, bins, bin lifts, hard waste, charity bins and green waste areas are storage areas as well as waste infrastructure.
c. Make a clear diagram of the movement of each material from disposal, storage and collection points, including slopes or stairs.
d. Indicate the location of the bins presentation with the alignment of the bins, it is also necessary to indicate the size and type of material for each individual bin.
e. For all vehicles requiring collection from the facility, swept route diagrams must be created illustrating sufficient access to collection points.
f. You should finally keep in mind to check different requirements mentioned in section 4 regarding including the policies enforced in your area and taking them into account.

2.4.2. Assessment

Waste assessment usually begins with assessment visits and reporting to the facility in focus. These preliminary assessments should utilize checklists that are meant to navigate through the official assessment plan which will be demonstrated in this section.

Exemple: what we usually look for in preliminary assessments are:

- Definition of type, source and quantities of municipal waste generated.
- Presence of a well-defined waste management hierarchy
- Existence and identification of hazardous waste on site
- Existing waste collection schemes
- Readiness for new future waste streams

The assessment approach which will be proposed in this course relies on four key areas of assessment, which are:

Area 1: Compliance Assessment

Area 2: Assessment of Targets

Area 3: Viability Assessment

Area 4: Credibility Assessment

each of these areas for assessment will be demonstrated in the following sections:

2.4.2.1. Compliance Assessment

This section will introduce you to the Compliance check and the coherence check.

1) Compliance Check: In a compliance check we are looking to identify gaps between your existing control environment and what is required. We identify gaps and presence of definition, type and source of the following: municipal waste generated / waste amounts / future waste streams/ existing waste collection schemes / major disposal and recovery installations /waste shipments / special arrangements / assessment of the need for new collection schemes / additional waste handling infrastructure / capacity of future disposal and major recovery installations / location criteria for site identification / closure of existing waste installations / description of waste policies / planned waste management technologies or methods / policies for waste posing specific management problems and finally self-reporting of evaluation of WMP implementation.

2) Level coherence: Level coherence checks are well organized and purposefully designed to facilitate waste management without the need for modification or repetition. the term refers to the alignment of the WMP across all departments and areas of implementation. If waste management planning is carried out at different administrative levels, we examine in the consistency check which includes the general waste management policies which are: strategy / type, quantity and source of waste, estimation of waste quantities, developments and forecasts / existing waste collection systems and assessment of new collection systems / recovery or disposal facilities / planning of additional capacities and infrastructure for waste / closure of existing facilities / identification of the site by location criteria / waste shipments / special provisions (at least for waste oils and hazardous waste) / relevant waste streams which are covered at different administrative levels: municipal waste, packaging waste, biodegradable waste, hazardous waste, batteries and accumulators.

2.4.2.2. Assessment of Targets

We then move on into the second stage which is the assessment of targets, in this phase we look to identify the targets set in the waste management plan for reduction or waste prevention, as well as reuse, recycling and output to dumpsites. These targets can be additionally divided into their respective environmental, economic, and societal impacts while prioritizing one over the other, depending on the main goal of the assessment.

2.4.2.3. Viability Assessment

We look into the viability of each WMP being assessed in order to address any issues or areas which lack management and monitoring. Generally, viability assessments involve reviewing general information of the WMP, waste streams and policy instruments.

1) General information: What we mean by reviewing general information is that we evaluate whether the following basic information on the WMP are mentioned or not. These are: the application and legal adoption period / the examination period / the competent authority for drafting WMP as well as the competent authority for implementing WMP.

2) Waste streams: Through this criterion, we evaluate whether information on relevant waste streams is included or not:

a. For Municipal waste we review:

- the definition, type and source of municipal waste generated.
- waste amounts.
- trends in waste increase over last years.

b. As for All other waste streams including (packaging waste, biodegradable waste, hazardous waste, batteries /accumulators, waste oils, End of life vehicles, construction waste, industrial waste). They should be separately assessed, but share the same items mentioned in **a**.

3) Policy instruments assessment: Involves defining whether sufficient information on applied and planned policy instruments is included and documented or not. This includes identification of set of instruments (environmental, economic, and legal instruments which represent policies and regulations enforced in the area of operations) as well as the evaluation of usefulness and suitability of these instruments to the WMP.

2.4.2.4. Credibility Assessment

Our last area for assessing WMPs is the credibility assessment, which look at the credibility of the assumptions made, and targets set in the plan itself. In doing this we look into the waste model, the robustness of data, the inner logic of data and the waste prevention plan.

1) Waste model: Beginning with the waste model, this is done by conducting Comparisons between anticipated treatment infrastructure and targets as included in the WMP with a given benchmark such as the European Waste Modelling Tool on Waste Generation and Management scenarios or the US EPA’s estimations for waste generation and relevant impacts.

2) Robustness: Evaluating the robustness gives us an idea whether the WMP includes sufficient information on data sources and how assumptions were made. This includes:

timeliness of data on municipal waste generation / time-lines for waste generation / primary data and information sources on municipal waste generation and data and information sources for status-quo of waste collection and treatment facilities.

3) Inner logic: In this we evaluate whether conclusions (recommendations) and the future planning as laid down in the WMP are consistent and coherent with the data we mentioned in our robustness assessment. In doing the inner logic assessment we focus on: waste data / identification of main problems in connection with waste data provided in the WMP as well as the measures we propose to address these problems.

4) waste prevention plan: We conduct specific evaluation of the coherence of the waste prevention plan in the WMP by measuring consistency of baseline data and indicators with quantitative data collected through the waste management operations. Basically, comparing between data of waste without management with the data of waste managed before and after prevention policies. After establishing how each are of assessment is carried out, we combine the outputs to form the final shape of the overall assessment for a given WMP, as seen in the figure below:

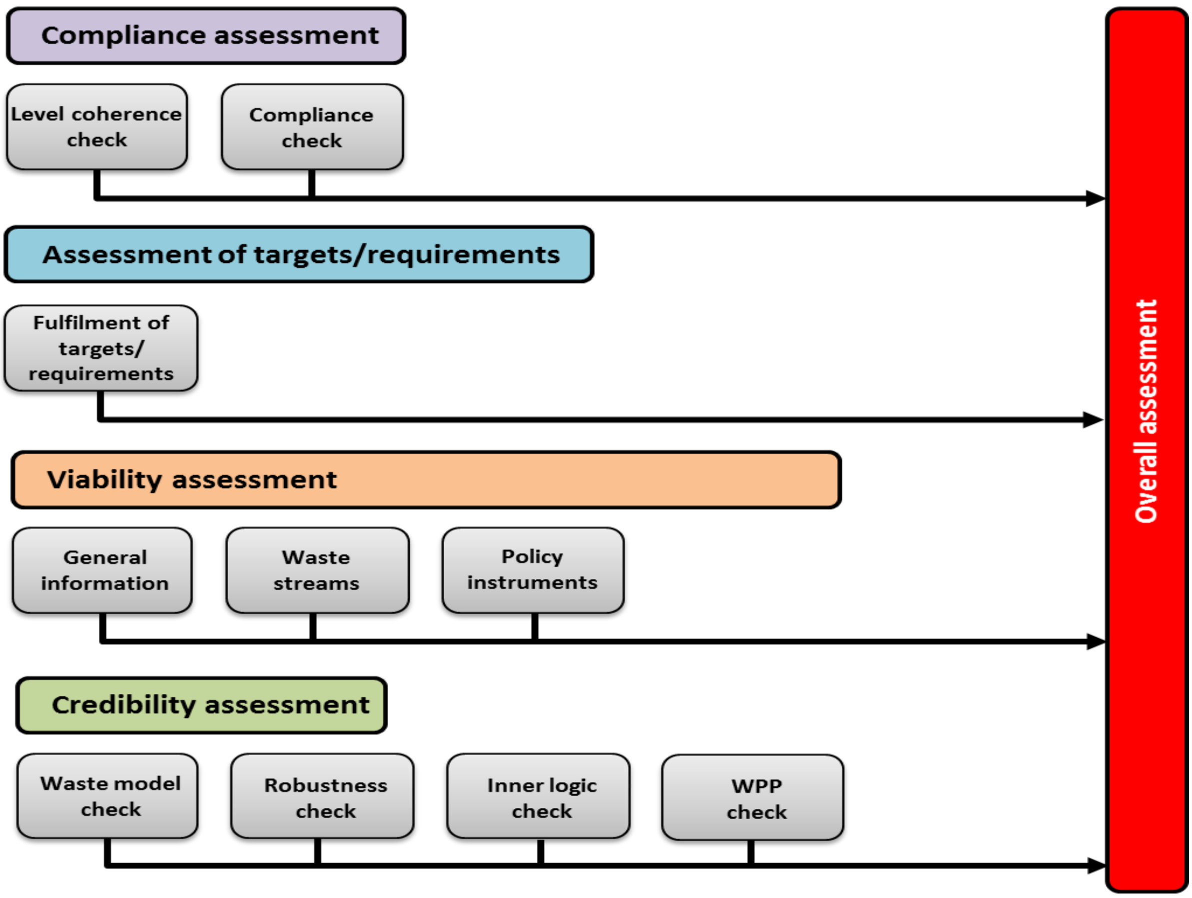

Figure 2.6. Areas and criteria for assessment of WMPs (Ameer Mubaslat, 2021)

We begin by assigning marks for each criteria of assessment, representing the coherence check, compliance check, quality of targets, general information, waste streams, policy instruments waste model, robustness, inner logic and waste prevention plan. we then add each mark to make up the overall mark of each area of assessment representing. Compliance, targets, viability, and credibility. For the overall rating of the WMP, the final marks of each area provide a reference to the following approach to assess the result of the assessment. And the results must be categorized as follows:

− Substandard. If it does not pass the compliance assessment

− Adequate. If it passes only the compliance assessment, it is considered adequate.

− Satisfactory, Good or Exceptional. passes all for areas mentioned before, relative to its score.

2.5. Management of household and similar waste

2.5.1. Physico-chemical characteristics of household and similar waste

Knowledge of the physicochemical characteristics of waste is essential in the management (recovery, recovery, etc.) and treatment of discharges, and to predict potential pollution risks for the environment. It therefore makes it possible to set up procedures to control and reduce pollutant emissions in the receiving environment. These physicochemical characteristics are: particle size, volumetric weight, humidity rate, lower calorific value (LCV), C/N ratio, volatile and ash contents and heavy metal content.

I.4.1. Granulometry

Waste can be characterized by its particle size. These sizes are generally classified into three distinct particle sizes during sorting:

- ✓ fine (< 20 mm);
- ✓ medium (20 mm < size < 100 mm);
- ✓ and large (> 100 mm).

Fines are the most studied, particularly for their biodegradable character.

I.4.2. Volumetric weight or Density

In the literature, there is sometimes talk of volumetric mass which fixes the relationship between the weight and the volume of waste, some authors preferentially use the volumetric weight, or even the density. This characteristic has a great influence on the capacities of the means of collection and landfilling of waste.

We therefore determine a "density in a bin", a "density in a compacting bin", a "density in a landfill with or without compaction" ... It should also be emphasized that these are in any case apparent densities given the extreme heterogeneity of household waste.

Expression of the density of household waste:

$$d = \frac{\rho_d}{\rho_e}$$

$$\rho_e = 1000 \text{ kg / m}^3$$

where,

d: density of household waste.

d: volumetric weight of waste (kg/m^3).

e: volumetric weight of water (kg/m^3).

I.4.3. Moisture content or water content (Hu)

The water content by weight (Hu) of a given waste sample represents the ratio between the mass of water present in a sample and the dry mass of this sample. For fresh waste stored away from the elements, the humidity varies between (% by mass):

• (35-40) %: Europe, with a maximum in summer and a minimum in winter;

• (60-62) %: for a large Algerian city;

• (65-70) % and more: for tropical countries.

It should be noted that the percentage of water in waste is higher as it is richer in organic matter, the average humidity of which is around 80% by mass.

I.4.4. Lower calorific value (LCV)

The LVF (expressed in kcal/kg dry mass) of solid waste is the quantity of heat released by the complete combustion of the unit mass of the fuel assuming that all the water, originating from the latter or formed during combustion, remains at the final stage in the vapor state in the combustion products. Several methods are used to determine the LVF:

a. It can be calculated from the higher calorific value (HCV) measured using a bomb calorimeter. We then have under standard conditions:

$$PCI = PCS\ \left(1 - \frac{Hu}{100}\right) - Cv\ (Hu + 9H)$$

where,

PCI and PCS are in kJ/kg.

Hu: % by mass of the water content of the waste.

Cv: latent heat of vaporization of water equal to 583 kcal/kg.

H: % by mass of the hydrogen content of the waste.

b. Other methods determine it from the elemental composition of the waste; they use simplified calculation formulas based on the contents of the waste in categories and the humidity.

Thus, for the calculation of the PCI, the following model was chosen and which takes into account all the fractions likely to have a contribution in the PCI:

$$PCI = 40.\ (P + T + B + F) + 90.\ R - 46.\ Hu$$

with,

Hu: average humidity of the waste (% dry weight).

P, T, B, F and R: contents respectively of the paper, textile, green waste, fermentable and plastic fractions (% dry weight).

The PCI is an essential parameter to define the authorization of waste for treatment by incineration. Without external energy input, waste can be incinerated when it has a PCI greater than 1200 kcal/kg. As a general rule, the PCI is inversely proportional to the humidity:

- ✓ If Hu ≥ 50%, then incineration of waste is not recommended.
- ✓ If 45% < Hu < 70%, then composting of waste is advisable (case of Algerian household waste).

Therefore, knowledge of the two parameters (PCI and Hu) are closely linked and their knowledge is essential for the choice of treatment method (incineration or composting, etc.).

I.4.5. Carbon/nitrogen ratio (C/N)

In order to calculate the carbon/nitrogen ratio (C/N), it is necessary to know the nitrogen and carbon contents. This parameter makes it possible to assess both the suitability of the waste for composting and the quantity of compost obtained (C/N < 12 in the solid phase indicates the maturity of the compost). A compost is valid from the C/N ratio < 35 at the start of aerobic and controlled fermentation and by obtaining a ratio of $18 \leq C/N \leq 20$ at the end of fermentation. In the case of Algeria, the C/N ratio rarely exceeds 15.

I.4.6. Volatile and ash content

In addition to the water content and calorific value of household waste, there is a determining physicochemical parameter in the interpretation of the combustion properties of the latter: their volatile content, which is transformed into gas during combustion (such as VOCs). This phenomenon is closely linked to the mineral portion of the waste, generally referred to as ash content. Since we are dealing here with non-combustible parts of the waste, the following mathematical relationship results between the volatile content (**V:** combustible components) and ash content (**C:** non-combustible components):

$$C + V = 100\%$$

Considering the proportion of water evaporated by drying (Hu), then the general formula will be:

$$C + V + Hu = 100\%$$

I.4.7. Heavy metal content

The 12 main fractions of household waste containing heavy metals are selected as follows: Plastics, Batteries and accumulators, Overcaps, Scrap metal, Paper, Cardboard, Wood, Rubber, Leather, Glass, Textiles, Fines < 20 mm, Special waste.

Heavy metal concentrations in household waste are measured in the laboratory using a flame atomic absorption spectrophotometer. The main sources of heavy metals in standard household waste are as follows:

- ✓ Batteries appear to be significant carriers of heavy metals: 90% of Hg, 45% of Zn, 20% of Ni.
- ✓ Scrap metal contains approximately 40% of Pb, 30% of Cu and 10% of Cr present in household waste.
- ✓ fines (< 20 mm) are pollution vectors with regard to Cu, Pb, Ni and Zn.
- ✓ paper is a significant source of Pb and Cr since respective percentages of 20% and 10% of these 2 metals can be provided by this constituent.

2.5.2. How can we minimize the production of solid waste?

The new concept to be applied in waste management is based on the principle currently known as the "3RV-E" with, in order of priority:

- reduction at source;
- reuse;
- recycling;
- recovery;
- elimination.

This new concept of waste management aims to save resources and use them with minimal impact on the environment and human health.

- **Reduction at source**

It consists of generating the least amount of waste during the manufacture, distribution and use of the product. The citizen can contribute to this reduction by reducing the quantity of waste produced by using bulk products rather than packaged products, durable products rather than disposable products, etc.

- **Reuse or reuse**

We now define reuse or reuse as "the repeated use of the product without changing its appearance or properties". It is a method that consists of extending the life of a product by using it several times. For example, returnable bottles that can be used again after cleaning.

- **Recycling**

The concept of recycling consists of reintroducing materials from waste into a production cycle or manufacturing process as a total or partial replacement for a virgin raw material

- **Valorization**

Waste valorization is defined as a treatment method which consists of “reuse, recycling or other action aimed at obtaining reusable materials or energy from waste”.

There are two types of valorization: material valorization and energy valorization.

Examples

a. Recycling of plastic waste materials

A plastic material is suitable for recycling depending on its nature and its physical and physicochemical properties. A recyclable plastic product is one that can be remelted and molded or injected again.

Thermoplastic products are suitable for this practice, unlike thermorigid or thermosetting plastics, such as polyurethane and polyester. Thermoplastic waste is treated and transformed into granules by sorting, grinding, washing, drying and melting in an extruder to be regenerated.

Among the widespread thermoplastic products found on the national market and which are recyclable, are:

- ✓ PET (PolyEthylene Terephthalate);
- ✓ PE (PolyEthylene);
- ✓ PVC (PolyVinyl Chloride);
- ✓ PP (PolyPropylene);
- ✓ and rubber materials

b. Energy valorization of plastic materials

- ✓ The PCI of plastic materials (in household waste) is around 36.5 GJ/T
- ✓ The PCI of household waste as a whole is around 8.5 GJ/T
- ✓ 10% of plastic materials provide 48.6% of recoverable energy.

- **Elimination**

Any operation or treatment that results in substances that can either be returned without harmful effects to the natural environment (air, water, soil), or reinserted into economic circuits for recovery purposes (case of solid waste).

Decontamination, removal, reduction of toxic power or storage.

2.5.3. Household and similar waste collection system

There are two ways of collecting household waste: Traditional collection and Selective collection.

a. Traditional collection: Collection of all mixed waste.

a.1. Characteristics of traditional collection

- Regular collection: weekly.
- Door-to-door collection.

- Specialized collection bins or trucks for:
  - ✓ compacting of waste;
  - ✓ or hermetic collection (using bins with a tight closure and exactly adaptable to the feed port of the transport bin);
  - ✓ or pneumatic collection.

The dump body is the part of the vehicle in contact with the waste. It consists of the following elements: a waste receiving hopper, a compaction system, a watertight compartment and an emptying device.

a.2. Pneumatic collection

This system of Swedish origin (CENTRALSUG process) consists of transporting waste from the garbage chute to the storage and treatment site by underground pneumatic pipes (by compressed air jet). This process excludes any human intervention: it has beneficial repercussions on hygiene and allows a reduction in inconveniences to road traffic. However, this process is obviously very expensive, and it is almost impossible to carry out in existing buildings.

a.3. Containers for household and similar waste

- ✓ Bulk waste.
- ✓ Disposable bags.
- ✓ Garbage bins.
- ✓ Wheeled bins from 120 to 1100 litres.

a.4. Volume and number of garbage bins

The volume V of the container required for the waste production of a building, for example, is given by the following formula:

$$V = \frac{N_H . Q}{\rho} .t$$

where,

N_H: number of people living in the building.

Q: quantity of waste produced per inhabitant per day (kg/inhab/d).

ρ: volumetric weight of the waste contained in the bin (kg/L).

t: time interval between two collections (d).

To know the number of containers, you just need to know the capacity of the bin (or container). Let **V′** be the volume of the chosen bin, the number **m** of bins required is determined as follows:

$$m = \frac{V}{V'}$$

b. Selective collection: Collection of certain recoverable waste previously separated (paper and cardboard, metals, glass, etc.), with a view to recovery or specific treatment.

Currently, there are two main types of selective collection: door-to-door (PAP) and voluntary contribution (AP).

b.1. Selective door-to-door collection

It is based on sorting at source by the resident and on the installation of specific containers (bags or bins). It is generally multi-material. It targets either clean and dry recyclable waste (blue bin) for material recovery,

or fermentable waste (green bin) for organic recovery.

b.2. Selective collection by voluntary contribution (or collection points)

This is a single-material collection: the user must deposit waste previously separated from the others in a container, or a metal box (case of a recycling center), specially designed for this purpose and installed in a public place. This is the case, for example, when a user comes to deposit their glass bottles in a glass container.

2.5.4. waste disposal center

A waste disposal center, or recycling center, is a space designed, guarded and fenced for the voluntary contribution of waste. This voluntary contribution makes it possible to sort recyclable waste, special waste and to avoid fly-tipping. The waste disposal center also allows residents to get rid of certain waste that is too bulky or cannot be put in the trash.

Being a selective and episodic deposit location, it plays a role in collecting, transiting and directing waste to a destination adapted to its nature: recovery, composting, incineration or treatment.

There are three types of waste disposal center:

- ✓ “small” rural waste disposal centers (750 m^2, 4 bins, for 10,000 inhabitants);
- ✓ “medium” waste disposal centers located on the outskirts of urban areas (1,750 m^2, 8 bins, for 15,000 inhabitants);
- ✓ “large” urban waste disposal centers created for a dense urban population (3,500 m^2, 12 bins, for 30,000 inhabitants).

- **Industrial waste disposal site**

Unlike a regular waste disposal site, an industrial waste disposal site resembles a "recovery site" where the space is open. Given the nature, volume and heterogeneity of industrial waste, the site is set up in boxes with a large maneuvering area for unloading and reloading materials. The industrial waste disposal site can also contain skips that will be directly removed by the collectors. The sizing of this type of waste disposal site depends closely on the expected quantities of waste, the needs and specificities of the geographical area covered.

2.6. Waste management and sustainability

Sustainability is defined by meeting our needs to complete a certain task or activity in an efficient and productive manner that benefits the implementer and does not negatively affect the environment around us, in an approach that allows us to better utilize resources in three key areas, they are: economy, environment, and society.

- Economic impact, is represented in the financial benefits of adopting different plans in the operations involved at achieving a certain task.
- Environmental impact, involves the effect outputted from the activities we perform, this comes in the form of emissions, non-natural or non-native products outputted to the planet’s ecosystem.
- The impact of our activities on the quality of life of humans has a societal effect. This means their access to employment, resources and the presence of a healthy environment in which they can live.

Sustainability is deeply rooted within waste management as some consider it to be the basis on which it is built on. This relationship is part of the concept of the 3Rs of waste management and what will further be introduced as part of the environmental pyramid. The three Rs of sustainability are reduce, reuse and recycle, and they can be utilized across our waste management operations by follow three key recommendations, which are:

- Waste Reduction, is most preferable to us as it provides the best sustainable outcome of the 3 R's of waste management.
- Waste Reuse, whenever we find an inevitable source of waste, we look at opportunities to reuse, either for the same purpose or for another. this provides us with moderate sustainable payback.
- Waste Recycling, is the least preferable as it provides the least sustainable returns.

These three represent positive areas of investment. And should not be confused with the profitability of these approaches, for example, recycling some materials could require up to ten times the energy needed to create them, but at the same time it can be very beneficial and cost-effective for a business. At the same time, reducing the need for waste, if possible, would have saved the initial cost in addition to the cost of recycling.

Figure 2.7. Sustainable waste management hierarchy (Zhang& al. 2022)

2.7. Circular economy in waste management

All human activities produce waste. This is emitted both by our production methods and our consumption methods. Waste can cause pollution and nuisances for humans and the environment, particularly when it is classified as hazardous. The management of our waste production is therefore a crucial issue for the preservation of the environment but also constitutes an economic and societal issue. Better recovery of our waste will make it possible to optimize manufacturing and service production and reduce our dependence on raw materials and energy. The status of waste is therefore gradually evolving towards that of resources, by integrating it into a circular vision of the economy. The circular economy model gives a very special place to waste. It is no longer just a problem to be dealt with but becomes a new resource. This change, this transition is very concretely translated with waste-as-resource, a source of recycled raw materials and energy.

The circular economy in waste management focuses on reducing waste generation and promoting the continued use of resources. Instead of the linear approach that relies on waste disposal, the circular economy approach integrates waste reduction and sustainable practices at every stage of the product life cycle. This includes the design, manufacturing and end-of-life stages, ensuring that materials such as plastic waste, textiles and organic waste are reused, recycled or repurposed.

A key element of this approach is extended producer responsibility (EPR), which holds manufacturers responsible for the entire life cycle of their products, including post-consumer waste. By encouraging the use of recyclable materials and emphasizing material recovery, EPR policies aim to minimize waste and reduce carbon emissions.

In waste management systems, integrating circular economy principles can transform municipal solid waste into valuable resources. For example, a case study in a city could show how regulatory frameworks can be implemented to support a circular economy, focusing on improving waste management practices and reducing waste disposal. By leveraging these strategies, cities can significantly reduce their environmental impact, aligning waste management with broader sustainability goals.

This approach also benefits the textile industry, where innovative recycling techniques transform discarded fabrics into new products, closing the waste loop. Overall, adopting a circular economy approach to waste management not only supports environmental goals, but also boosts economic growth by creating new markets and reducing reliance on virgin resources.

Circular economy

The concept of circular economy has gained traction in recent years, inspiring environmentalists, governments and businesses. Once marginal, circularity is now recognized globally as the most promising solution to the sustainability challenges that threaten our planet. However, there are many divergent definitions and interpretations of circular economy.

Circular economy basically resembles an approach that identifies everything as healthy food for something else, the same way nature runs itself. plants use carbon dioxide and nutrients to grow and produce oxygen. while Animals use oxygen and create CO_2 and nutrients. Nothing is wasted in this closed loop system. Circular economy is usually opposed to linear economy which we have been running for many years and involves taking in inputs for processes and disposing of the outputs without acquiring any of their potential.

The shift to a circular economy goes beyond recycling and reusing materials (e.g. using old paper to make new paper). It is a call to assess the environmental impact of products and their components, from initial design to end use. In a circular economy, waste streams are eradicated through truly regenerative design.

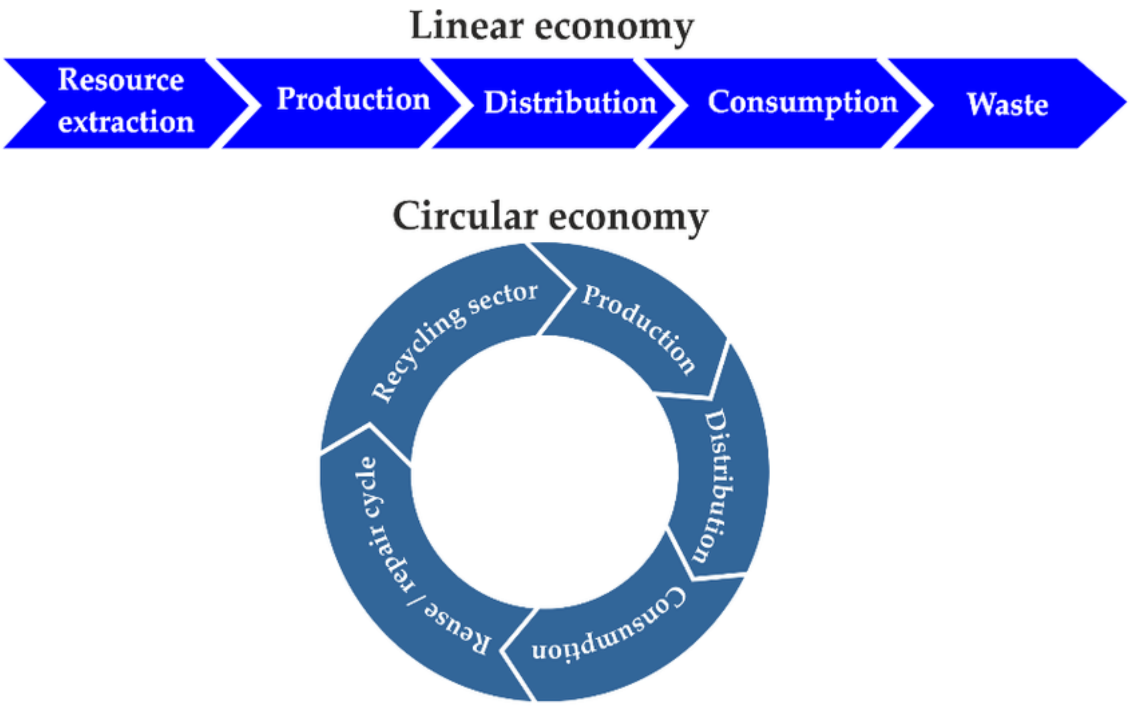

Figure 2.8. Linear and circular economy (Unterfrauner & al. 2017)

The circular economy is considered more sustainable because it aims to produce zero waste, reducing, reusing and recycling all kinds of materials and resources to ensure they remain in the loop. However, many people now believe that a circular economy can be more sustainable financially and environmentally, with benefits that also help build more sustainable societies.

Putting circular economy into perspective to sustainability and waste management. It handles economy as part of society, which is part of the environment, inside a closed ecosystem where the three influence each other. As shown in the following figure.

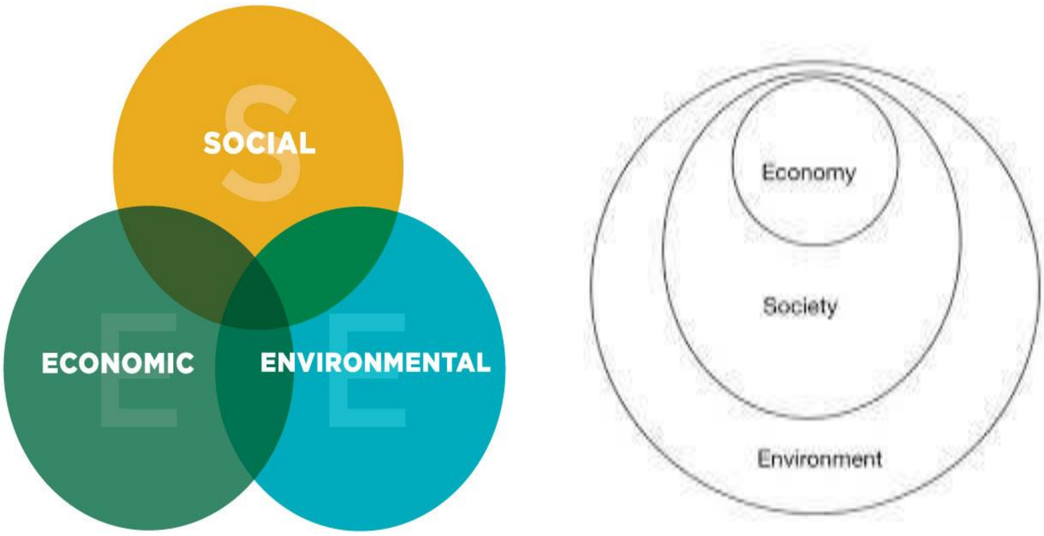

Figure 2.9. Green economy paradigm (Ameer Mubaslat, 2021)

We can divide material treated inside the circular economy into two categories: technical and biological.

- Technical materials are cycled like this (raw material is mined, product is manufactured and then it is used until the end of its life. And this is where the importance of waste management comes in as seen throughout the previous lessons in this course). For example, it is best to mine copper that is not used anymore (postconsumer copper) as opposed to mining new material from the ground, since copper is predicted to be mined out by 2040 and processing recycled copper takes 10-20 percent the energy it takes to process copper ore.
- Biological materials (farmed or collected to be processed and transported before being consumed. This cycle is completed by introducing biogas or biochemical extraction and composting operations to the consumed biological resources. Thus, making our output a healthy food for something else)

In this regard Circular economy and therefor waste management economics utilize two characteristics which are substitution and dematerialization.

− Substitution: using different resources to achieve the same goal.

− Dematerialization: using less of a resource to serve the same economic function in a society.

Finally, our utilization of Circular Economy will be based on its advantage to promote sustainable benefits throughout our activities as represents an integral part of sustainability alongside sustainable agriculture, energy and waste management.

2.7. Conclusion

Waste management represents a constantly changing field that is shaped by constantly changing technologies and approaches which rely on the many increasing regulations, requirements and benefits that surround waste generation and management. These could range from reduction of pollutants, risks on wildlife, or human discomfort and could extend all the way to building a whole business models around the financial benefits of the different resources that different types of wastes hold. Waste Management Systems which utilize sustainable designs represent the best method to realize the biggest impacts through daily operations both on the long term and short term.

3.1. Introduction

The economic The concept of uncompensated environmental effects of production and consumption which refer environmental externalities, that affect consumer utility and enterprise cost outside the market mechanism.

Private costs of production tend to be lower than their social cost because of negative externalities. The aim of the "polluter-user-pays" principle is to encourage households and firms to internalize externalities in their plans and budgets.

Usually Targets and regulations are either fixed through standards provided through legislative frameworks (such as in the European Union) or by the national law but they can also be determined by the strategic planners and decision-makers of a company. And in this process is where governments and international regulators come in.

Their contributions help us account for externalities and adopt environmental guidelines for waste management. In this lesson we will give a brief about two examples for entities which's work revolve around defining and regulating the waste management field. In specific, we will investigate the government's role as well as the work that the International Standardization Organization does for environmental management.

3.2. Government institutions and waste management

To begin with, the governmental roles which are involved in waste management for each country can be distributed across three levels: local government, government agencies, and national government.

3.2.1. Local governments

Waste management services must be provided by local governments. They include waste collection, storage and disposal services. This is mostly done through Municipalities which must work with industry and other stakeholders to extend recycling at municipal level. According to the regulations, municipalities may establish local waste management service standards for sorting, compacting, management and disposal of solid waste. Municipalities are responsible for diverting organic waste from landfills and composting it, they must provide additional bins for source separation.

3.2.2. Government agencies

Government agencies representing the environmental protection agency are the main authority to regulate waste-related activities, except for activities that must be approved by the national authority. They must ensure the implementation of national norms and standards. Their powers include declaring priority waste, registering waste carriers, listing waste management activities, requesting the preparation of industrial waste management plans, identifying contaminated land, and establishing provincial norms and standards.

3.2.3. National governments

Those responsible for the implementation of national waste management plans as well as the optimal and efficient functioning of the various local government bodies are the national governments which are mainly represented by the supervisory ministry. They are particularly responsible in terms of mandatory provisions for:

− Developing the national waste management strategy.

− Developing national norms and standards.

− Developing and maintaining a national register of contaminated land.

− Developing and maintaining a national waste information system.

− Implementing an integrated national waste management plan.

3.3. International standardization

The most prominent body that operates in the waste management policy creation is the ISO (International Organization for Standardization). Additionally, it overseas the accreditation of multiple organizations that operate in the fields of environmental and waste management. Its purpose is to facilitate and support national and international trade and commerce by developing standards that people everywhere would recognize and respect. ISO achieves this purpose through the participation and support of its members from 164 national standards bodies. In this chapter we will focus on the ISO 14000 family. It is developed by the technical committee ISO/TC 207. In this family we find the ISO 14001 standard which gives requirements and guidelines for environmental systems. There are also other standards in the family that focus on specific approaches such as communications, audits, labeling, life cycle analysis, as well as environmental challenges such as climate change. The main purpose of ISO 14001 is to define the requirements for the Environmental Management Systems and provides guidance for its implementation. Key elements of this standard include:

− Environmental policy

− Planning

− Implementation and Operation

− Checking and Corrective Action Management review

The application of ISO 14001 provides a systematic means of monitoring the environmental impact of an installation. It also provides the framework for an organization to achieve a high level of environmental performance that demonstrates an organization's total commitment to controlling the impact of waste, pollution and energy consumption. Other key outcomes of implementing ISO 14001 include:

• Through increased environmental efficiency, costs are saved

• Environmental liabilities are reduced.

• Environmental risks are reduced − Increased ability of the organization to compete in the global market.

4.1. Introduction

Waste generated by human activities during industrial, commercial, mining and agricultural operations. With the growth of population and industrial activities, solid waste must be properly managed and contained to avoid negative impacts on the environment and human health. Landfills have traditionally been used for waste management due to their ease of use, capacity to handle large volumes, and minimum operating costs. However, poorly maintained landfills and dumpsites with inadequate leachate collection systems become a potential source of contamination of soil, surface water, and groundwater. The composition of waste can alter soil chemistry and have a significant environmental impact by producing leachate and biogas. The most common contaminants found in solid waste leachate are chromium, dioxins, hydrocarbons, organochlorines, PAHs, PCBs, pesticides, radionuclides, TPHs, VOCs, persistent organic pollutants (POPs), and deadly pathogens. Therefore, it is mandatory to employ an adequate leachate monitoring program for safety and risk assessment.

Soil and groundwater contamination is closely linked to human society because of its direct impact on the health of the population and socio-economic activities. Toxic contaminants can enter the human body through the food chain, the water we drink and the air we breathe. Close to home, we have landfill sites, or open dump sites in the worst case, where toxic substances from organic waste, batteries, electronic devices, plastics, etc. seep into the soil and over time accumulate and end up in fresh water streams. Similarly, chemical fertilizers and pesticides in agriculture, dyes in the textile industry, additives and oils in the cosmetic industry, heavy metals, minerals and radioactive waste from the energy and transportation industry, antibiotics used in healthcare and food-producing animals have left a lasting mark on the environment. Plant Life: Contaminated soil adversely affects plant health. Plants absorb these toxins, leading to stunted growth, reduced yield, and even plant death.

So how do these substances once dump into the ground reach the water table? Let’s take an open dump as an example. The contaminants dumped are absorbed into the soil and when it rains, these compounds are flushed away by the rainwater, which either buries them deeper into the soil or carries them away to larger water bodies. In agriculture, fertilizers and pesticides are continually washed away during irrigation and enter the drinking water supplies of nearby populations, eventually making them sick. It is important to keep in mind that not everything that is dumped/spilled into the ground is washed away. Like a stain, it remains in the soil, accumulates, and continues to leak into the water.

4.2. Transport of pollutants in soil and groundwater

Controlling health and environmental risks related to industrial or nuclear activities requires controlling the "Source of danger – Transfer – Target" chain. In the event of soil contamination by heavy metals, radionuclides or organic compounds, the main route of potential harm to populations is through hydrogeological transfer to drinking or irrigation water resources. Water takes precedence over soil because, while users may be prohibited from accessing land, water resources, like the air we breathe, remain shared. Assessing this risk requires quantifying the migration of contaminants through the soil and underlying rocks, all the way to groundwater. To achieve this, it is necessary to adopt an integrated approach ranging from field operations to modeling, combining chemical and physical measurements, and simulations.

This approach is based on knowledge of water flow in natural systems but also of the transport of contaminants by these waters. Even for proven soil contamination, risk assessments on water resources are preventive in most cases and require projections into the future. The difficulty therefore lies in the validation of simulations and the analysis of associated uncertainties.

When contaminants settle on soil, they partially and gradually dissolve in rainwater, which transports them vertically through the soil and then the subsoil during its infiltration process. After passing through the unsaturated zone, these elements or chemical compounds can thus reach the groundwater table, several meters or several dozen meters below the ground surface. There, these different substances are once again diluted and then transported sub-horizontally according to the general flow of groundwater in the water table. The water table has rivers as its natural outlets, when it is not collected using wells or boreholes for drinking, domestic, agricultural or industrial water supply uses.

To identify the presence of a contaminant in one of the environmental compartments (soil, unsaturated zone, water table), it is necessary to be able to compare the measured quantity to a reference. We use efficient analysis methods capable of measuring these substances in trace amounts. Indeed, since contamination is very rarely massive, it is necessary to characterize its extent down to zero concentrations. Most of the substances are already found in the environment, including those of artificial origin. These substances come from contamination prior to the activity of interest on the site studied or from diffuse contamination, such as lead emissions from road traffic and fallout from global aerial nuclear tests.

Concerning the very large proportion of chemical elements and compounds also existing in a natural state, it is necessary to distinguish the proportion coming naturally from the ground (also called geochemical background) from that brought by contaminating activity. One way to achieve this is to measure the abundance of the different isotopes constituting the chemical element sought. This isotopic signature may differ between the geochemical background and the contaminant, particularly for depleted uranium. In the majority of cases, only the comparison between the concentrations measured on the site studied and the concentrations of the local geochemical background can highlight contamination. The detailed determination of the geochemical background, which depends on the nature and history of the soils and rocks, is therefore a major step in the environmental assessment of a site.

The solubility of contaminants deposited on the ground makes it possible to control the quantity potentially available for migration in aqueous solution. This thermodynamic equilibrium is often in addition to kinetic effects. Depending on the affinity of contaminants with the mineral or organic matrix of soils and rocks crossed by water, their transport occurs more or less quickly compared to the flow of water. Many chemical elements and natural compounds (in addition to pH and oxidation-reduction conditions) also contribute to modifying the quantity of chemical species under which the same contaminant exists in solution, and therefore, its interaction and transport properties. Risk control therefore requires understanding, modeling and simulating these physicochemical phenomena.

The transport of pollutants in water can occur under particulate or dissolved forms, either in surface or groundwater. In surface waters, soil particles can be introduced in streams and move under particulate form downstream (bed-load transport) by rolling, sliding, and saltation and further deposited downstream. This transport depends on flow velocity, turbulence, and grain size, shape, and density. In groundwater, particulate transport is not so expressive and occurs for very small grain size particles.

Simulating the migration of contaminants requires the association of two factors: water flow and the transport of substances of interest, from the soil to the water table, then within the water table to the outlets.

- To simulate vertical migration in an unsaturated zone, it is essential to know the water content at each depth level, and this as a function of the intensity of infiltration. The water content, which varies in the unsaturated zone, controls the permeability. This behavior is described using mathematical formulations whose parameters come from measuring the capillary water retention properties of rocks in the laboratory. The simulation of solute transport in an unsaturated zone makes it possible to estimate the flow of contaminant arriving in the water table, as a function of time, and for each point of a mesh representing the contaminated zone. This flow constitutes the input of the transport model in the water table, also called the saturated zone.

- Prior to simulating transport in a saturated zone, the flow of water in the water table must be simulated. This first part of hydrogeological modeling is based on determining the flow field of the groundwater table, a potential vector of contaminants in solution. The flow model is based on Darcy's law. Via a permeability coefficient serving as a parameter in the model, this law consists of linking the water speed to the hydraulic head gradient, i.e. to the variation in the space of the water level (called the piezometric level) that would be measured in a well. This piezometric field can be precisely defined from the available measurements and using geostatistical techniques that can include auxiliary information.
- Calculating solute transport in a saturated zone is the second part of hydrogeological modeling. The interaction between the solute and the rock plays a fundamental role here. This interaction, for transport in both a saturated and unsaturated zone, is most often represented by a delay term. This is based on the very simplifying hypothesis of adsorption proportional to the concentration in solution, and reversible, of the solute on the rock. A more complete modeling of this interaction can be carried out using calculation codes coupling with chemical reactions and transport.

4.3. Impact of soil and groundwater contamination on human health and environment

Soil is a finite resource, meaning its loss and degradation cannot be recovered in a human lifetime. Soil pollution impacts the food we eat, the water we drink, the air we breathe, our health, and the health of all organisms on the planet. Without healthy soil, we cannot produce our food. In fact, an estimated 95 percent of our food is directly or indirectly produced in our soil.

Healthy soils are the foundation of food security and our sustainable future. They help support food production, mitigate and adapt to climate change, filter water, improve resilience to floods and droughts, and much more. Yet an invisible threat is putting soils and everything they provide at risk.

Soil pollution causes a chain reaction. It alters soil biodiversity, reduces soil organic matter and the ability of soils to act as a filter. It contaminates water stored in soils and groundwater, and causes an imbalance of nutrients in soils.

Soil pollution has devastating effects on the environment and impacts all forms of life that thrive in it. Unsustainable agricultural practices that reduce soil organic matter can facilitate the transfer of pollutants into the food chain. For example: polluted soils can release contaminants that leach into groundwater, which then accumulate in plant tissues, which are then consumed by grazing animals, birds and ultimately by humans who eat these plants and animals. The presence of pollutants in soil, groundwater and the food chain can cause a multitude of diseases and lead to excess mortality in humans, from short-term acute effects such as poisoning or diarrhea to long-term chronic effects such as cancer.

In addition to the environmental impact, soil pollution also has a high economic cost due to reduced yields and crop quality. Preventing soil pollution should be a top priority worldwide. The fact that the vast majority of pollutants are the result of human action means that we are directly responsible for the changes needed to ensure a cleaner and safer future.

Soils must be recognized and valued for their productive capacities as well as their contribution to food security and the maintenance of essential ecosystem services.

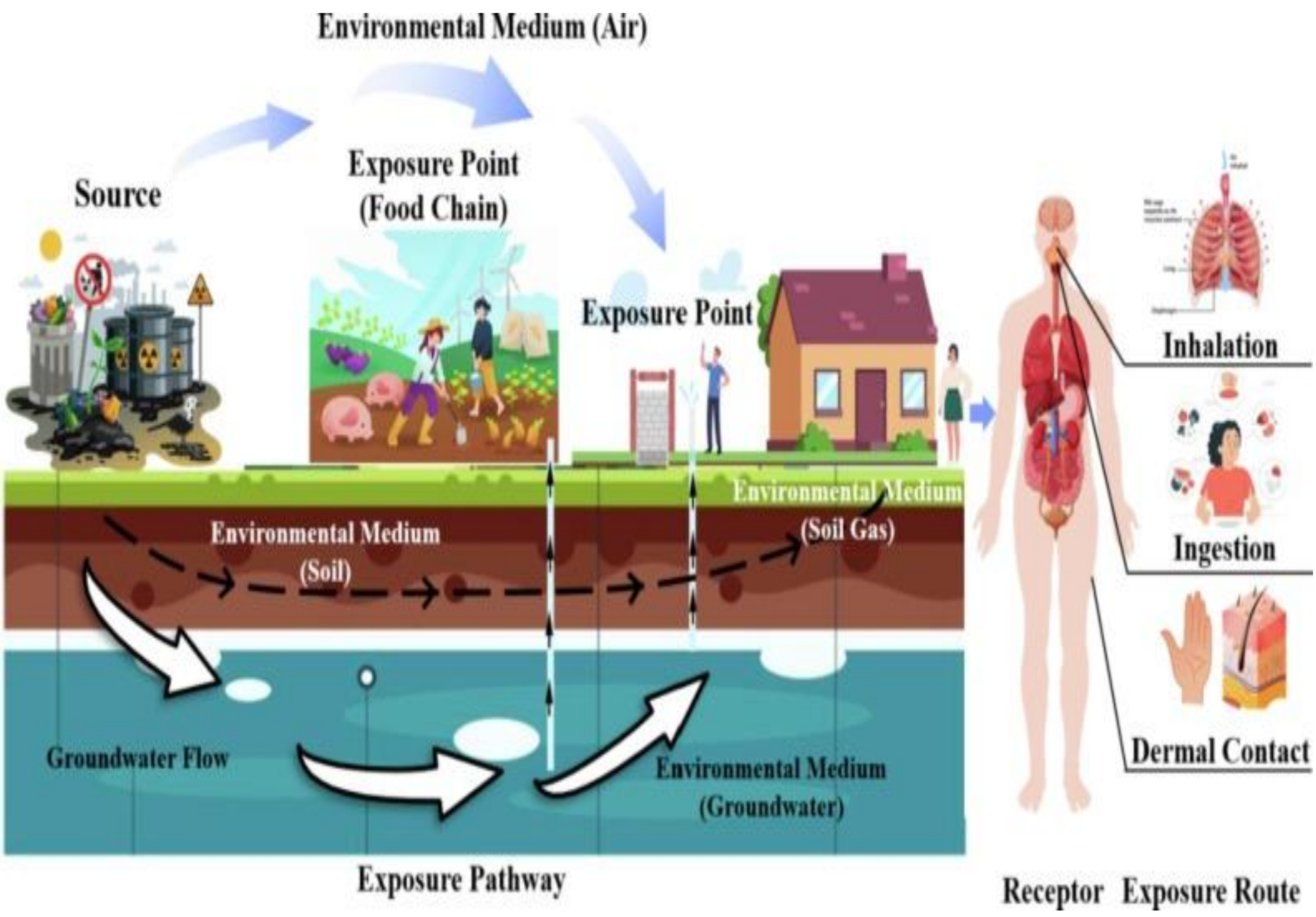

Figure 4.2. A conceptual model of the source-to-receptor process (Zhang &al. 2023)

4.4. Prevention of soil and groundwater pollution

Soil and groundwater pollution poses a significant threat to the environment, human health and the overall sustainability of our planet. To control this, rapid soil pollution prevention actions must be implemented immediately.

Many poor land use patterns, such as waste disposal, residential drainage, and industrial waste disposal practices, contaminate the soil and groundwater. The ecological system is damaged when soil is polluted because plants and microbes may have difficulty adapting to the changed soil chemistry. Some strategies for soil and groundwater pollution prevention methods:

- Existing records on land management, agricultural practices, and urban and rural planning should be updated to reflect the latest techniques for preventing and controlling soil and groundwater contamination.
- Reduce the doses of cleaning products as much as possible (dishwashing, laundry, floor scrubbing, etc.) and use the least polluting ones.
- Gather up any leftover toxic or dangerous products and take them to the heavy metals department. Never throw them in the trash or in the open air.
- Provide sealed enclosures for polluting products stored in barrels, tanks or cisterns in order to be able to recover any leaks.
- Avoid buried deposits of polluting materials. If this proves impossible, provide a system to quickly detect any leaks.
- Provide a sealed floor in places where harmful products are handled or delivered.
- Use the best technologies to limit the release of hazardous products.
- Carefully controlling mining and industrial pollution is the best strategy to reduce soil and groundwater contamination.
- It is also important to learn more about the basic quality of the soil environment.
- The practice of organic farming and good management of agricultural land.
- Solid waste should be disposed of properly by being treated before being released into the environment.
- The obligation to examine contaminated land areas for pollution.
- The government should strive to remediate and remove pollutants to improve soil and groundwater quality.
- Research on the prevention and management of soil and groundwater contamination should be furthered by strengthening technical research to ensure sustainability.
- Encourage all parties to assess situations objectively and accept their responsibilities.

How to solve soil and groundwater pollution? Here is a list of solutions:

- Decontamination: environmental decontamination consists of eliminating pollution from the soil, groundwater or surface water. Bioremediation (microbes) and phytoremediation (plants) can be used to transform pollutants into harmless products. These are natural solutions that must be supported by in-depth actions.
- Green agriculture: sustainable agriculture is essential because it aims to control the impact on the cultivated environment, by minimizing external inputs (plant protection products), diversifying crops and using biological treatments.
- Sustainable forest management: forest conservation is essential. Without the protection of trees, the land becomes dry and begins to erode. This is why sustainable forestry or logging is essential to preserve the soil from pollution.
- Proper Waste Disposal, whether industrial or household waste, is one of the most effective ways to combat soil pollution. This is especially true for the disposal of toxic and hazardous waste.
- The "3 R" Rule and Education: The "3 R" Rule: By reducing the use of non-biodegradable products, we reduce plastic pollution and ultimately have an impact on soil pollution. That is why it is very important to reuse and recycle all possible items. Education should also play a major role in efforts to protect the environment from soil pollution.

5.1. Introduction

Multiple human activities (industrial, mining, agricultural, military, urban, transport, etc.) are the cause of pollution of sites, soils and groundwater. Currently, awareness of this pollution, changes in industrial practices and the disappearance of certain activities have put a stop to the spread of pollutants in the soil and most of the cases treated are legacies of the past. Many sites are affected by multiple pollutions, of various natures (organic and/or mineral), superimposed or geographically separated. These polluted sites can then present risks of transfer of pollutants to sensitive targets, such as water resources, ecosystems and therefore human health. They can also disperse over time in the environment, thus increasing the size of the polluted surfaces…. The decision to decontaminate or not is based on different criteria, including the health risk, the location of the site, the planned future use as well as the cost and time. These same criteria guide the choice of techniques to be implemented.

Among these techniques, some aim to immobilize pollution, others to extract or destroy it. They are generally classified into three families: physical and/or chemical, biological and thermal treatments.

- Physical treatments consist of either immobilizing pollutants or providing energy mechanically or electrically to degrade or extract them and possibly provide surface treatment. They include in particular confinement, stabilization, incineration, thermal desorption, pumping, volatilization (or venting), etc.
- Chemical treatments involve a reagent to degrade or extract pollution. Examples include oxidation, reduction, washing with solvents or surfactants, etc.
- Biological treatments, on the other hand, are based on the action of living organisms (microorganisms, plants, etc.) that aim to either degrade pollutants or immobilize them, depending on optimal conditions.
- Thermal treatments use heating to volatilize and then extract semi-volatile and/or strongly adsorbed compounds. An example of such methods is thermal desorption.

Depending on the case, treatments are carried out on-site or off-site. On-site, the soil can be treated "in situ" without excavation or "ex situ" after excavation.

Off-site, it is transported to a fixed treatment center. “In situ” treatment is attractive in principle, but sometimes difficult to implement and control.

On-site treatment is effective, insofar as it homogenizes concentrations, but it consumes time and space. Off-site, treatment in a specialized center is very effective in terms of duration and very economical for small volumes.

For each specific case of soil contamination, it is essential to choose the most appropriate remediation technique as well as to plan its duration, cost and effectiveness.

5.2. Soil and groundwater remediation

Remediation is the process of removing contaminants from soil and water sites that have been polluted by industrial, manufacturing, mining, or commercial activities, thereby removing or reducing our exposure to the contaminants. The end goal is to eliminate the contamination sources and protect people and the environment against potentially harmful pollutants.

Soil remediation is the method of purifying and revitalizing contaminated soil. Untreated soil pollution can present various risks either through direct contact (ingestion through consumption of food and beverages) or through introduction into the food chain. In order to protect human health and the environment, polluted soils must be remediated by removing their contaminants.

Remediation treats soil contaminants such as petroleum hydrocarbons, pesticides and heavy metals. It may also be used at sites where toxic materials have been deposited as a result of a natural disaster. Depending on the contaminant to be eliminated, several remediation techniques can be used: chemical, biological, physical or thermal.

Groundwater is water that is underground and found in large aquifers or water that is contained in the subsurface layer of rock and soil. The most well-known pollutants found in groundwater include arsenic, iron, chromium, selenium, and fluoride.

Groundwater deterioration that originates from the land surface(underground) could be due to the infiltration of contaminated surface water, wastes from land and water disposal, fertilizers and pesticides, accidental spills, and other airborne particulate matters.

Deterioration originating from above the water table (near the surface) may be caused by septic tanks, surface impoundments, landfills, leakage from underground pipes and storage tanks, sumps, and even graveyards.

Soil and groundwater remediation process refers to the stages of treatment aimed to effectively remove contaminants while turning the hazardous substances into less harmful form. The remediation measures using immobilization technique or isolation is taken to ensure safe groundwater source for drinking and containing the contaminants from intruding the surrounding area that are potential source of food owing to the bioaccumulation effect. Strategic remedial planning is crucial from the initiation phase of setting up any industrial site until the final phase of cleaning the area from harmful substances. Soil and groundwater remediation can be achieved by utilizing many different methods. Selection of appropriate remediation method is thoroughly determined based on the environmental assessment, resources available, policy involved and cost effectiveness analysis.

5.2.1. Types of soil and groundwater remediation

Contamination of soils and groundwater has tremendous impacts on the environment that brings the utmost concern in public health. The non-degradable characteristics of heavy metal contaminants explain the persistence in the environment which further contaminates the food chain. Long term contaminated food or water consumption poses serious adverse effects to the general wellbeing of human health, particularly the younger age group and during reproductive years. It is quite impossible to clean up the polluted site completely. However, prompt action is required to reduce the contamination risk to a level that is tolerable for both short- and long term environmental exposures. The reduction plan should return to a containment approach, taking into account land use policy controls and active soil and groundwater remediation efforts. The remediation procedure can be performed alone or in conjunction with additional actions. Similarly, when deciding on the optimal remediation strategy, the approach to dealing with soil and groundwater contamination should be holistic, weighing the benefits and drawbacks of a number of significant aspects such as time, location, cost, sustainability, and the severity of the condition.

Generally, there are two types of groundwater remediation, namely in-situ (in place or on-site) and ex-situ (off-site). Instead of removing and transferring it to another location for treatment, in situ remediation entails treating areas where it is currently located. This kind of remediation is far less expensive than ex situ remediation, which often entails excavating and transporting the polluted site to another location while avoiding off-site contamination. Although the procedure can avoid future damage on site, transportation cost and eradication is extremely high. When the capacity of in-situ remediation is exhausted, ex-situ remediation is applied. Chemical, physical and biological remediation techniques been discovered as treatment strategies. Physical separation, source pump and treat, recycling, thermal treatment, solidification and stabilization, off-site incineration, aeration, and chemical and bioremediation procedures are examples of ex situ techniques. Out of all, most commonly used technique in ex situ treatment is physical separation such as screening, sieving, sorting of solid media to separate components, dehydration and decontamination. According to several sources, the optimum remediation strategy for leachate or liquid waste media is extraction and ex-situ treatment, which often includes carbon adsorption, neutralization, aeration, evaporation, or bioremediation during the process.

5.2.2. In-situ remediation technology

In-situ remediation involves removing contaminants on-site. When the remediation process involves a larger/ deeper contamination site with a lower cost than excavation, the in situ approach is recommended. This chosen remediation strategy is well-suited to other materials i.e. (i) Soil/ sludge/sediment treatment: Chemical extraction, flushing, thermal desorption, vitrification, bioaugmentation, biostimulation, phytoremediation, and electro-kinetic separation are examples of technology-based approaches; (ii) Groundwater/fresh water/leachate treatment: common techniques such as air sparging, dual phase extraction, bioslurping, natural attenuation and air stripping.; (iii) Other remediation containment: Physical barriers and reactive treatment walls; (iv) Hazardous gas emission treatment: Chemical oxidation, membrane bioreactors and bio filtration.

The risk management application, the physicochemical characteristics of contaminants, the available remedial approach, the location of the process to take place, the strategic system to be applied with, implementation, and outcome are factors to consider when selecting the most suitable remedial approaches for remediation technique. The vast majority of today’s soil and groundwater remediation approaches are driven by the development of an integrated approach plan that is implemented on site for cost savings and convenience.

In-situ remediation is classified into two, existing technology, and emerging technology. Fracturing, soil flushing, heating, physical barriers, electrokinetic separation, multiphase extraction, soil vapor extraction, air sparging, biostimulation, natural attenuation, bioaugmentation, bioventing, and phytoremediation are examples of existing technologies. Microbial fuel cells, nano-remediation, genetic engineering, and phyto-hetero microbial systems are examples of new approaches including pump and treat technique, nano treatment technique, in-situ soil vapor extraction (SVE), in situ chemical treatment technique, in-situ thermal treatment technique (ISTT), permeable reactive barriers and bioremediation treatment technique. The most prevalent in-situ approach has been SVE, ISTT, bioremediation, and chemical treatment including in-situ chemical oxidation (ISCO) and in-situ chemical reduction

(ISCR). Frequently, more than one techniques have been utilized according to the site and type of contaminants.

- **Heating**

The heating procedure includes methods for raising the temperature, lowering viscosity and adsorption, and increasing solubility to promote the recovery of volatile organic compound (VOC) and semi-volatile compound (SVC). Heating is suitable to remediate those non-aqueous phase liquid (NAPLs) and dense-non-aqueous phase liquid (DNAPLs). The contaminants can be easily remediated by soil vapor extraction, air sparging, and bioremediation by changing their density, viscosity, surface tension, and solubility. Electrical heating (hot air/ steam injection, thermal conductive heating, thermal decontamination) is commonly used. Throughout the heating stage, pneumatic and hydraulic control is essential for efficient treatment and a clear path must be provided for the generated vapours to an extraction system. Furthermore, heating is a procedure that improves other remediation technology, reducing the time and cost of the entire remediation process when used together. Electrical resistance heating is a technique for creating electrical resistance by placing an electrode in low-permeability zones. This method heats the soils and converts semi-VOC and VOC to steam. The steam would be condensed and extracted VOCs are then to be treated conventionally into granular activated carbon (GAC) or being oxidized. This type of technology improves the speed and efficiency with which contaminants are removed.

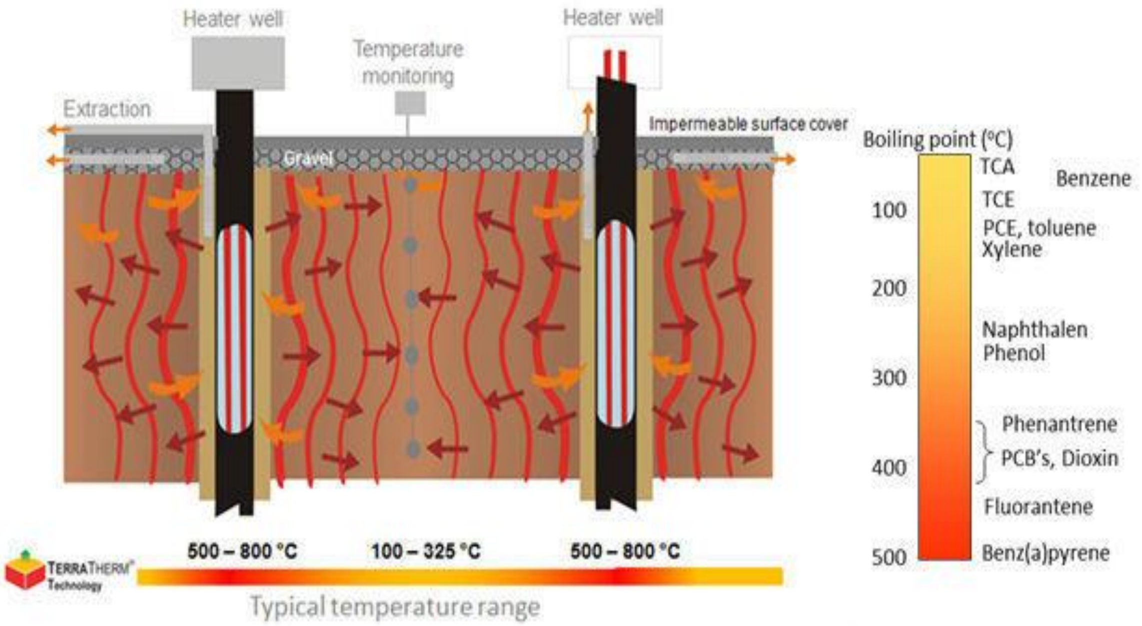

Figure 5.1. Thermal soil remediation (Ploug, 2018)

- **Soil Flushing**

In situ soil flushing, also known as soil leaching or chemical extraction, includes in situ soil remediation technologies that use a washing solution (e.g., solvents, acids, chelating agents, polymers) to mobilize organic or inorganic contaminants to a groundwater recovery system.

In situ soil flushing involves the continuous injection of the flushing solution into the saturated zone upstream of the contamination and its pumping downstream, in order to promote its migration through the contaminated zone and allow recovery of contaminants and the washing solution. In the case where the contamination is located in the vadose zone, the flushing solution can be injected directly from the ground surface above the contaminated area. Soil flushing is generally used to supplement the treatment or improve the performance of conventional groundwater pumping and treatment techniques.

Soil flushing solutions can be water, surfactants, co-solvents, acids, bases, chemical oxidants, chelating agents, or organic solvents. Surfactants and co-solvents, or a mixture of these, are most commonly used. The flushing solution is selected based on the physical properties of the contaminants present, the geochemistry of the groundwater, and the nature of the soils in place.

In situ soil flushing requires the installation of several elements allowing the injection and then recovery of the flushing solution. Thus, wells or trenches must be built upstream of the contamination zone in order to allow the injection of the flushing solution by gravity or under pressure. The equipment necessary for this injection (tanks, pumps, piping, etc.) must also be installed nearby. Wells or trenches must also be built downstream of the contaminated zone in order to be able to pump the groundwater and recover the solution that will have migrated through the contamination. Pumping and treatment equipment for the pumped water will be installed nearby. In some cases, the washing solution is separated from the extracted water and reused, while in others, the water is simply treated and then discharged.

The location, depth and quantity of injection and extraction wells depend on geological, hydrogeological and engineering considerations. Some equipment, such as the treatment system, will need to be transported and built on site.

The characteristics of the contaminants as well as the properties of the soil to be treated and the geochemistry of the aquifer must be known to determine the type and concentration of the optimal flushing solution.

In situ flushing is mainly applied with water, mixed with extracting solutions such as:

- ✓ acids to lower the pH and mobilize certain metals,
- ✓ bases, for example sodium hydroxide in aqueous solution to induce surfactants favorable to their mobilization by action on hydrocarbons (e.g.: alkylbenzene sulfonate),
- ✓ surfactant (to desorb pollutants from the soil matrix),
- ✓ aerated water, oxygenated water or water with added hydrogen peroxide to increase biological stimulation.

The implementation of in situ soil flushing treatment may include:

- ✓ preparation of the site for the installation of the equipment;
- ✓ development of injection and extraction wells, trenches or drains;
- ✓ installation of the mixing, holding and distribution systems for the flushing solution;
- ✓ construction of the containment system (physical or hydraulic) or extraction;
- ✓ installation of the treatment system for the extracted water, on the surface; (separation of the rinsing solution and treatment of groundwater)
- ✓ discharge of the treated water.

In situ soil flushing is applicable to:

- ✓ treatment of dissolved and residual contamination as well as non-aqueous phase liquids (light and dense);
- ✓ Allows the treatment of residual contamination present in the vadose and saturated zones;
- ✓ Effective for a wide variety of organic and inorganic contaminants, such as volatile and semi-volatile organic compounds, polychlorinated biphenyls, pesticides and heavy metals;
- ✓ Allows the treatment of organic and inorganic compounds simultaneously;
- ✓ The flushing solutions remaining in the soils following treatment can promote the solubility and bioavailability of contaminants for eventual bioremediation;
- ✓ Soil flushing is effective in permeable sandy or gravelly and homogeneous soils.

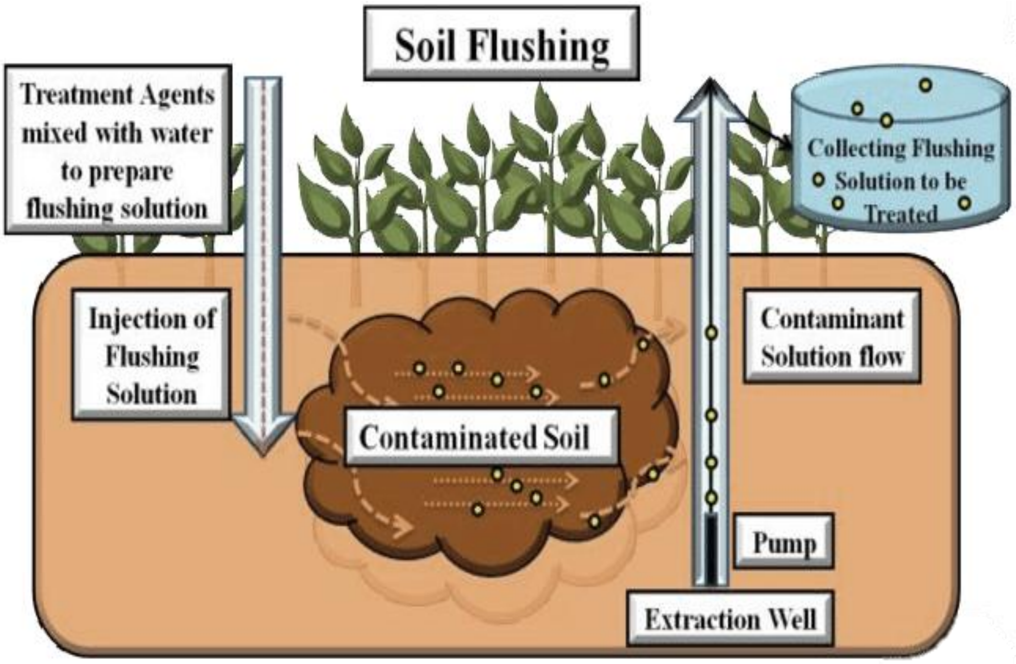

Figure 5.2. Soil flushing process (Ramanlal & al. 2022)

- **Physical Barriers: Treatment Walls / Reactive Permeable Barrier**

A Reactive Permeable Barrier (RPB) consists of a vertical permeable zone of reactive materials (electron acceptors or donors, adsorbents, bacterial bed, etc.) located on the passage of a plume of polluted groundwater. By natural convective flow through the barrier, the pollutants present in the groundwater are degraded into non-harmful elements (organic) or adsorbed/complexed (organic, metals and metalloids) by the reagent.

RPB treatment is a passive treatment technique, which uses natural groundwater flows and does not require the use of a pumping system for the recovery of polluted water. The BPR consists of a permeable zone within which a plume of polluted groundwater flows under the action of a natural hydraulic gradient. This permeable zone consists of a reactive material that can degrade, modify or adsorb pollutants. The pollutant load present in the groundwater downstream of the barrier is reduced.

The basic principle of a reactive barrier is based on a trench whose length allows the entire plume of pollution to be intercepted and whose width gives rise to a sufficiently long contact time between the reagent and the pollutant to ensure the degradation or sorption of the latter. The barrier should preferably be oriented perpendicular to the direction of flow of the water table.

The two main types of configuration are:

- ✓ The continuous wall system (continuous trench, Continuous Wall, CW or Continuous Reactive Wall, CRW),
- ✓ The Funnel & Gate system noted F&G (literally, Funnel & Gate).

In the case of a "continuous wall" system, the barrier is reactive and permeable over its entire length. This configuration minimizes hydraulic disturbances. On the contrary, in the case of a "funnel-gate" configuration, the plume is channeled using sealed screens towards one or more gates that constitute the reactive zone. This second configuration causes the flow to converge. The limited extension of the reactive zone of the barrier offers the possibility of better controlling its performance in terms of pollution abatement. These two configurations cover the vast majority of industrial applications.

Regardless of the configuration adopted, the barrier is anchored in the underlying impermeable substratum so that the plume cannot flow under the barrier. The majority of RPBs are anchored at depths of between 10 and 20 metres. The volume of the reactive zones varies greatly (from a few m^3 to several hundred m^3). The volume of reagent used depends on:

- ✓ the size of the structure,
- ✓ the extent of the pollution plume,
- ✓ the flow rate of water to be treated,
- ✓ the reaction kinetics (which determines the residence time) of the pollutants and their by-products,
- ✓ and the adsorption capacity of the reagent (when this type of reagent is used).

In all cases, the thickness of the active treatment zone must allow sufficient contact time between the water and the reagent.

Contact times are higher for "continuous wall" type RPBs than for "funnel-gate" type RBPs where the entire water mass converges from upstream towards one or more passages. It should be noted that interventions on reagents are much more complex for "continuous wall" type RBPs than for "funnel-gate" type RPBs.

The selection of the reactive material(s) used in RPBs depends on the pollutant and the binding mechanisms of this pollutant (decontamination).

The main characteristics to be taken into account when choosing the reactive medium of the BPR are the following:

• **Reactivity**: the reaction rate and the equilibrium constant of the pollutant(s) with the reactive material are used to determine the necessary residence time, and therefore the dimensions of the RPB.

• **Stability:** the reactive medium must be effective for a sufficient period of time in order to achieve the set decontamination objectives. Once it has been set up, the reactive medium is difficult to handle in the event of loss of efficiency (clogging), in addition these additional

handlings lead to costs that had not been anticipated (except for RPBs with replaceable cartridges).

- **Availability and Costs**: The reactive medium must be available and at a reasonable cost to keep the technique economically viable.
- **Hydraulic Performance**: The permeability of the reactive material must be equal to or greater than that of the aquifer to minimize flow changes.
- **Environmental Compatibility**: The reactive material must be well understood to minimize interactions with groundwater. Undesirable by-products must not be created during reactions with the pollution plume.

The RPB reactive medium is the origin of one or more groundwater treatment mechanisms, the four basic processes for the treatment of inorganic pollution are as follows:

- ✓ pH control and precipitation;
- ✓ Oxidation-reduction;
- ✓ Adsorption and ion exchange;
- ✓ Biological activation.

The basic objective of RPB reactive media is to directly degrade or immobilize the target pollutant(s), or to modify groundwater conditions to destroy or immobilize the target pollutant(s).

Reactive barriers allow the treatment of many organic pollutants (VOCs, COHVs, SCOHVs) and certain metals (As, Cd, Cr, Pb, etc.). This technique is applied in low-permeability to permeable aquifers, preferably in homogeneous and porous media.

For the design of the RPB, investigations must be carried out to define the characteristics of the pollution and groundwater. The crucial parameters are the hydraulic properties, the type and concentration of pollutants, the total mass of pollutants and the geochemical composition of the groundwater.

Feasibility studies must necessarily take into account the following steps:

- ✓ choice of the decontamination method (pollutant fixation/degradation mechanism) and reactive medium;
- ✓ batch test experiments and/or column tests (and other studies to quantitatively determine the decontamination rate);
- ✓ estimation of the residence time;
- ✓ calculation of the thickness of the reactive zone.

The laboratory "treatability" test is essential because it evaluates the effectiveness of the reactive medium in a hydrogeological and hydrogeochemical environment comparable to the polluted site. Factors such as pH and ion concentration can affect the efficiency of reactive media (competition effects between ions, redox conditions, etc.) as well as the rate of clogging of the material by reaction with natural ions in groundwater. It is therefore essential to carry out laboratory tests before sizing the RPB.

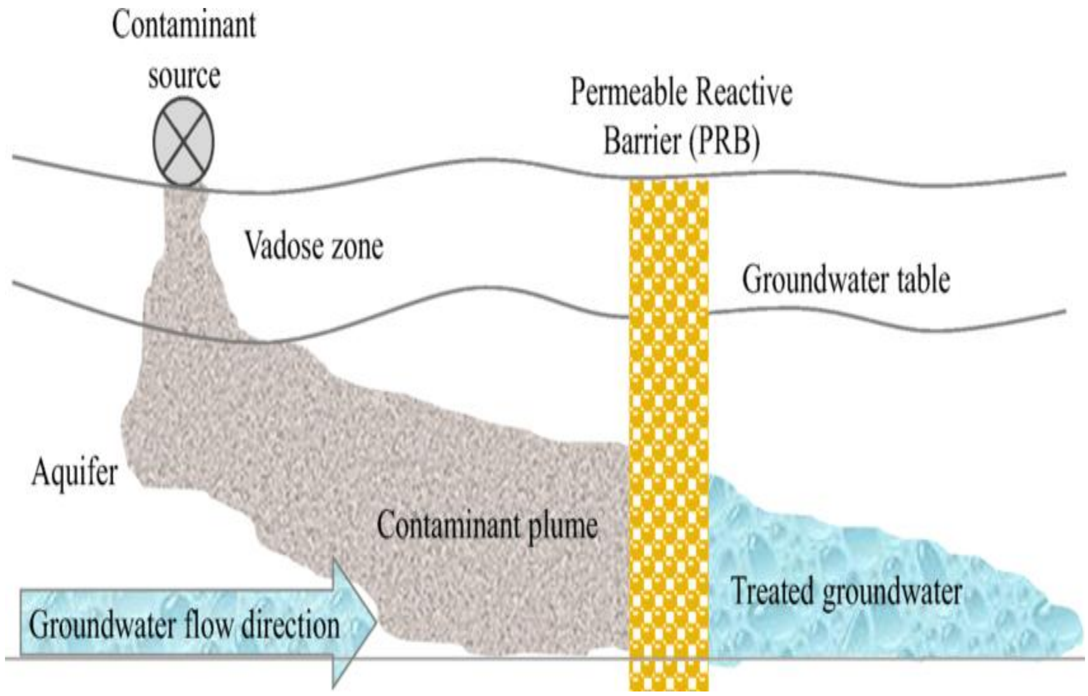

Figure 5.3. Schematic description of the reactive permeable barrier (RPB) (Medvidovic & al. 2018)

- **Soil Vapor Extraction (SVE) and Air Sparging**

The principle of SVE soil vapor extraction and air sparging is based on extracting vapors (volatile contaminants) from the subsurface to treat them on the surface. To extract vapors from the ground above the water table, SVE technology is used by applying a vacuum to extract them. Air sparging pumps air underground to help extract vapors from groundwater and moist soil below the water table. The addition of air to SVE technology accelerates the evaporation of chemicals making them easier to remove.

Soil vapor extraction uses vacuum to produce a concentration gradient, which causes gas phase volatiles to be extracted from the soil. The vapor of volatile elements will be removed using extraction wells and then treated with carbon absorption before being discharged into the atmosphere or reinjected into the subsurface. This method for treating contaminated groundwater has also been employed in air stripping and groundwater pumping. Petroleum residues, for example, can be treated by combining SVE with steam injections, bioventing, and radio frequency heating procedures, aided by the heavier contaminant's volatility, which is accelerated by hot air injections.

Soil vapor extraction has shown its ability to treat vast volumes of soil with little soil disturbances at a fair cost and in a short amount of time. However, it is only useful in areas with a low water table (>1 meter below ground level) and volatile chemicals. By restricting air movement through the soil pores, low permeability, high moisture content, and preferred flow in a layered pattern might prolong the restorative period. Other constraints include the requirement for air emission licenses the eliminated vapors released into the atmosphere require costly treatment, treatment of only unsaturated soil zones, and integration with other technologies that can lower contamination concentrations to more than 90%.

To speed up the process of contaminant volatilization, air sparging involves injecting gas under pressure into the saturated subsurface zone. Air sparging in groundwater raises the concentration of oxygen in the subsurface. The extracted air and pollutant vapor are referred to as "off-gases", which is another way of saying "contaminant removal". In order to eliminate any moisture that could interfere with the treatment process, the combustion gases are routed from the extraction wells to an air-water separator. To separate the steam from the air, it must be pushed through activated carbon cartridges. The chemicals are then trapped between the carbon while clean air will be emitted to the atmosphere. This strategy is more cost-effective and efficient, particularly when paired with other traditional remediation strategies (such as SVE or volatilization/biodegradation mechanisms).

To move volatile and semi-volatile contaminants in the underlying vadose zone through the air sparging volatilization process which involves injecting air into the contaminated groundwater is also beneficial in the treatment of VOCs. SVE technique is widely used in conjunction with air sparging to remove vapor phase contaminants generated from the vadose zone.

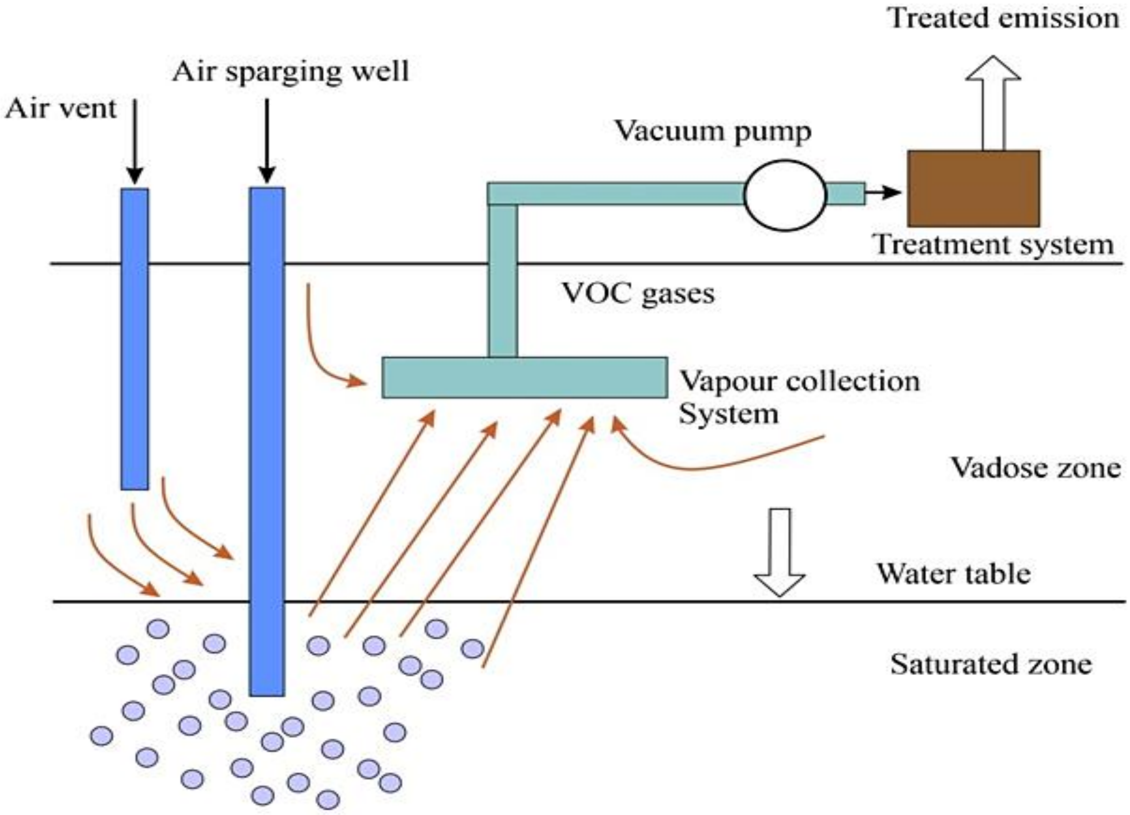

Figure 5.4. Air sparging with soil vapor extraction process (Shit & al. 2023)

- **Fracturing (Pneumatic/Blast enhanced/Hydro)**

Fracturing is a technology designed to increase the efficiency of removal and in-situ treatment techniques. It is used to widen existing cracks and introduce new fractures in soils with difficult conditions. For enhanced bioremediation, the new fractures occur in a horizontal direction and facilitate the extraction of soil vapours or methods that inject gases or fluids.

There are three primary fracturing technologies: hydraulic fracturing, pneumatic fracturing, and blast-enhanced fracturing.

These technologies are used for environmental applications in which suboptimal geological conditions at a site can be improved to enable greater efficiency in a site reclamation effort. Blast-assisted fracturing is performed exclusively in bedrock while hydraulic and pneumatic fracturing are performed in bedrock or in unconsolidated materials.

The three types of fracturing technologies are useful to assist in overcoming site-specific geologic constraints that limit application of a variety of in situ vapor, soil, and/or ground-water remediation technologies. A total of 86 cases of field applications of these technologies are documented in this report, with the distribution 43% pneumatic fracturing; 31% hydraulic fracturing, and 26% blast-enhanced fracturing.

By generating more new cracks, these fracturing strategies may improve contaminant mass transfer. The generated fracture will aid in increasing the efficiency and cost effectiveness of current in-situ technologies by increasing wall permeability and altering liquid flow. Aside from that, fracturing will help to reduce the number of extraction wells, manpower, and material expenses associated with contaminated site treatment. In terms of blast-enhancing fracturing, the drilled boreholes create additional fractures, which are subsequently filled with the explosion and detonation. In the presence of fractured bedrock formation, this in-situ approach can be used. Furthermore, the use of SVE technology in conjunction with hydraulic fracturing systems will improve overall contaminant recovery.

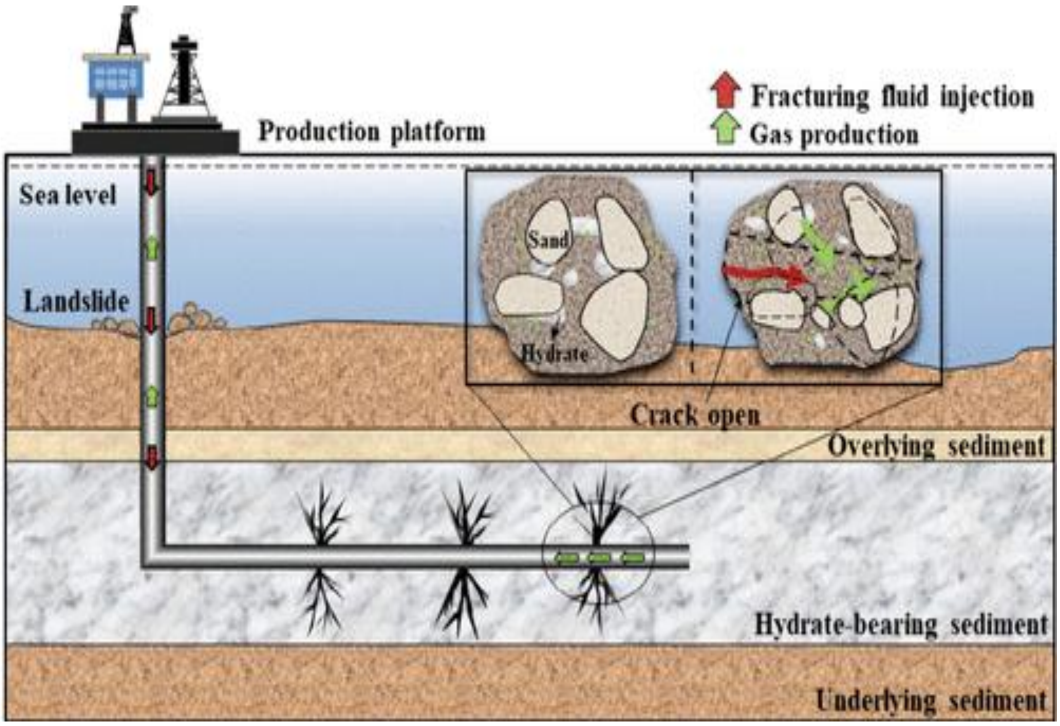

Figure 5.5. Fracturing process (Song &al. 2024)

- **Electrokinetic Remediation**

Electrokinetic treatment is a technique for decontaminating fine soils that is attracting increasing interest. It consists of moving various chemical species in soils under an electric field. This extraction technique, called electrodecontamination, electrokinetic technique or electroremediation, uses an electric current flowing between electrodes in an aqueous medium, cathode (–) and anode (+), respectively bathed by the catholyte and the anolyte, generating for fine soils an electrical gradient of the order of ten volts per meter and a current density of the order of mA/cm^2.

The application of this electric current generates several phenomena. At the electrodes, which are in an aqueous medium, the passage of the electric current causes chemical reactions at the electrode-water interface known in electrochemistry, such as electrodeposition and electrolysis of water with gas formation. The oxidation of water at the anode generates protons which, carried by the current, cause the advancement of an acid front, while its reduction at the cathode produces hydroxides resulting in the displacement of a basic front. The application of an electric field to the ends of a negatively charged porous material on the surface, here the clay phase of the soil, induces a flow of the aqueous phase towards the cathode. This phenomenon is called electroosmosis. Finally, for the entire electrode-soil system, the electric field causes the cations to move towards the cathode and the anions towards the anode, this is electromigration. These movements lead to changes in the chemical balances of the environments (soil and electrolytes), which result in chemical reactions and adsorption and desorption phenomena.

In this technique, the problem is to intervene on the adjustable factors acting on these phenomena in order to promote the extraction of a target component, considered undesirable compared to the other components of the soil. The current is applied in the pairs of electrodes that have been implanted in the soil on each side of the mass of contaminated soil. During electromigration, positively charged chemical species, such as metals, ammonium ions and some organic compounds, move towards the cathode, while negatively charged ones, such as chloride, cyanide, fluoride, nitrate, and some organic species, migrate towards the anode.

In fine-grained soils, electric current also causes electroosmosis. This flow can transport neutral species. Charged suspended colloids and miscelles can also move electrokinetically in the electrophoresis process. Electrophoresis, in this case, is similar to electromigration, except that the mobile species are not single molecules. This technology can be applied to contaminant concentration ranges from a few ppm to over 10,000 ppm, but may not be effective in treating multiple contaminants that have significantly different concentrations. Target contaminants are either extracted to a recovery system or deposited at the electrode. Surfactants and complexing agents can be used to increase solubility and aid in contaminant movement, but care must be taken when choosing between charged (anionic/cationic) and neutral surfactants.

Electrokinetics has been developed primarily to treat low permeability soils, particularly those with high clay content. This process works particularly well for soils with low cation exchange capacity (CEC) and low salinity. Electrokinetics has achieved efficiencies of:

- ✓ 75 to 95% for lead, cadmium and uranium (initial concentrations of 2,000 mg/kg);

- ✓ 85 to 95% for phenol (initial concentrations of around 500 mg/kg);
- ✓ 98% for TCE (initial concentrations of 100 to 500 mg/kg).

While the low permeability of a soil is often an obstacle to conventional in situ decontamination techniques, it corresponds to the best situation for the application of electrokinetics (hydraulic conductivity < 10^{-5} cm/s). There is currently no other viable solution for in situ treatment of metals in the unsaturated zone. Existing ex situ techniques are applied for small areas and depths.

The electrokinetic process is limited by the solubility of the contaminant and its desorption. Some heavy metals in the zerovalent state could not be dissolved or separated from the soil. The heterogeneity of the treated soil area can result in lower currents in certain parts. The decontamination of these poorly conductive areas will therefore be slower or even non-existent. Heating the soil is recommended in this process since it involves drying out the heated area and therefore a loss of conductivity.

pH control is critical to avoid precipitation of contaminants and thus their immobilization. The precipitation problem is commonly encountered in the vicinity of the cathode.

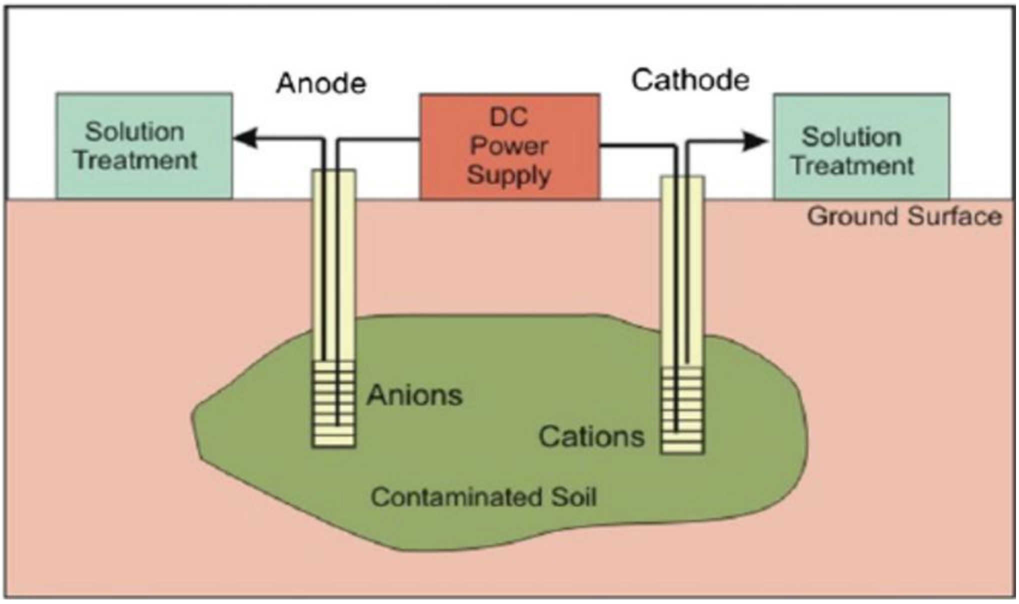

Figure 5.6. Schematic of electrokinetic remediation (Hashim &al. 2011)

- **Natural Attenuation**

Natural attenuation (NA) is a natural process, or combination of natural processes, that results in the reduction of the mass, toxicity, mobility, volume, or concentration of contaminants and their degradation products in soils and groundwater.

Natural attenuation is defined as a set of active processes, of physical, chemical or biological nature, which, under favorable conditions, act without human intervention to reduce the risk of dispersion linked to contamination. Natural attenuation in soil and groundwater occurs in three ways:

- ✓ Transformation of contamination;
- ✓ Reduction in the mass or concentrations of contamination;
- ✓ Reduction in the mobility and bioavailability of contamination.

Due to the absence of any human intervention (except monitoring), Natural Attenuation is not strictly considered a pollution control technique but rather a pollution management measure.

It is important to consider that natural attenuation must include at least one of the following processes:

- ✓ A process that destroys pollutant molecules,
- ✓ A process that sequesters pollutant molecules (e.g. adsorption).

Natural attenuation processes are diverse and can be divided into two broad categories, namely destructive and non-destructive:

- **Destructive:** The transformation of contaminants results in a reduction in their total mass. These are usually biological and chemical processes, including aerobic and anaerobic biodegradation by endogenous (naturally occurring) microorganisms, radioactive decay, and abiotic degradation (photolysis, hydrolysis, chemical reduction).
- **Non-destructive:** The reduction in the concentration, state (dissolved or solid), or mobility of a contaminant, without reducing its total mass. These are usually thermodynamically reversible reactions (such as solid-phase precipitation), or other physical processes affecting the transport and mobility of contaminants, such as advection, dispersion, diffusion, sorption, dilution, and volatilization.

Natural source area depletion (NSD), a term used to describe the natural collective processes of dissolution, volatilization, and biodegradation that lead to mass losses of contaminants over time, is a concrete example where NA processes are at play.

A good understanding of NA processes is important to be able to predict the fate of various contaminants and assess potential exposure pathways for receptors.

Natural attenuation only makes sense if it is accompanied by:

- ✓ appropriate monitoring of the environment,

- ✓ ongoing vigilance on possible future changes in use and systematic information of the various stakeholders.

Natural attenuation, to be validly considered as the equivalent of a rehabilitation technique, must meet a certain number of technical criteria. These criteria can be explained as follows:

- ✓ effective achievement of rehabilitation objectives,
- ✓ limitation of the spatial footprint,
- ✓ compliance with deadlines compatible with risk management.

Since natural attenuation concerns water tables that are characterized by a movement of groundwater, a notion of space comes into play: to treat a groundwater table by natural attenuation, it is necessary to be able to “freeze” the uses of the water table not only for a certain period, but also in a certain area (hence the establishment of easements). The natural attenuation process is deployed over large areas and volumes around the source of pollution. It is only considered if the extension of the pollution plume is reasonable in relation to the existing uses of the surrounding environments.

Natural attenuation needs time to be effective, and this time must be compatible with the level of risk to be managed, any projects concerning the site (land use) or its surroundings (water or even air uses), and the socio-political perception of the approach. The time scale varies from one case to another, and depends on the nature of the pollutant, whether or not source treatment is implemented, and the extent of the pollution. It is measured in years, decades, or even more for certain plumes that can then develop in a large volume of the aquifer for which usage restrictions will have to be instituted.

Natural attenuation is mainly applied in the saturated zone. The most convincing results have been obtained on light hydrocarbons, VOCs, SCOVs and certain COHVs. In some cases, interesting results have been obtained with certain pesticides, explosives (trinitrotoluene), phenols and certain inorganic compounds. In the latter case, natural attenuation essentially consists of changing the valence of the elements and therefore their mobility Cr(VI) and Cr(III); As(III) and As(V).

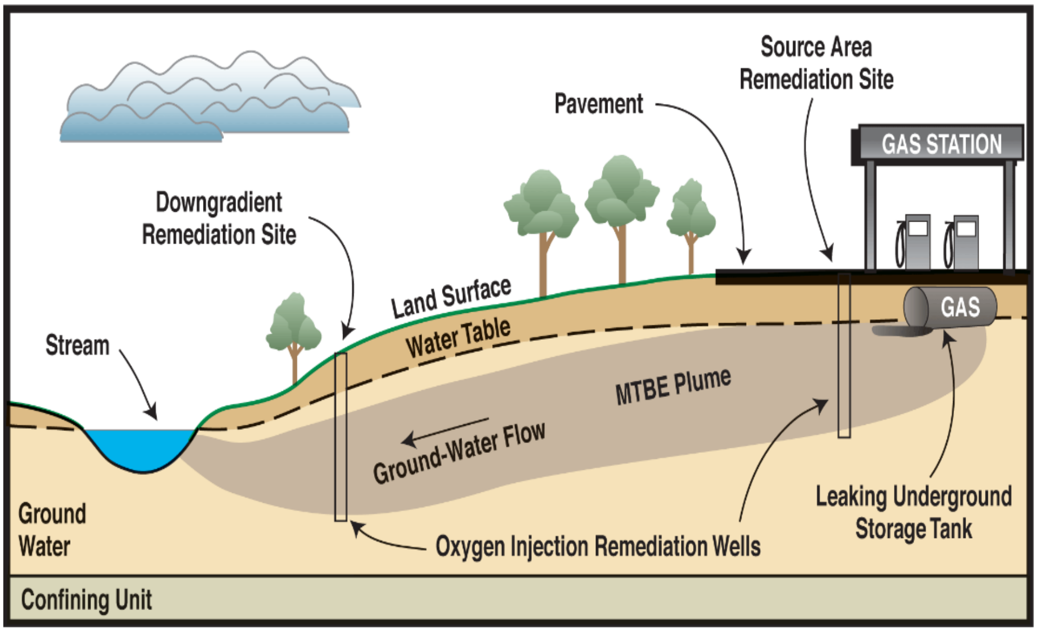

Figure 5.7. Natural Attenuation Process (McIntosh & Pontius, 2017)

- **Phytoremediation**

Phytoremediation is an emerging technology that uses various plants to degrade, extract, contain or immobilize contaminants from soil and water. This technology has received recent attention as an innovative, more cost-effective and therefore alternative to more established treatment methods.

Specific plants are planted in the area to be treated, either directly in existing soil or on deposits of materials (cured sediments, excavated soils, etc.) or in a special unit through which effluent or contaminated water will pass. The families of pollutants concerned are primarily heavy metals and hydrocarbons. Plants can act directly by absorbing the pollutant or indirectly by activating its degradation in the rhizosphere.

Applications of phytoremediation can be classified based on the fate of contaminants: degradation, extraction, or a combination of these. They can also be classified based on the mechanisms involved. These mechanisms include extraction of pollutants from soil or groundwater, concentration of contaminants in plant tissues, degradation of contaminants by various biotic or abiotic processes, volatilization or transpiration of volatile contaminants into the air through plants, immobilization of contaminants in the root zone.

Existing or commercially available technologies include:

✓ **Phytoextraction:** Phytoextraction is the absorption of contaminants by plant roots and their translocation into plants. This technology is used for heavy metals that are literally pumped by plants (which must be chosen from species that are able to grow on contaminated soils) and thus transferred from the soil (provided that they can be accumulated in sufficient quantities by plants without becoming toxic). Phytoextraction uses hypertolerant and/or hyperaccumulating wild plant species capable of taking up toxic metals from the surface horizons of soils and accumulating them in their aerial parts and root tissues. These hyperaccumulating plants are endemic to metalliferous sites and have the capacity to accumulate metals at concentrations that can reach and in some cases exceed 2% of the dry matter of the aerial parts. After cultivation, the biomass would be harvested and incinerated in order to reduce the volumes to be treated and to concentrate the metals in the ashes. These could, for example, be landfilled or recycled in metallurgy.

- ✓ **Phytodegradation:** Like phytoextraction, phytodegradation involves the uptake of contaminants, but the contaminants are then broken down by metabolic processes within the plant. Phytodegradation also includes the breakdown of contaminants in the soil by the effects of enzymes and other compounds produced by plant tissues (other than roots).

  Phytodegradation is applicable to organic contaminants. Their uptake is affected by their hydrophobicity, solubility, and polarity. Moderately hydrophobic and polar compounds are more likely to be “pumped” after being absorbed by plant roots. Contaminants with potential for phytodegradation include: chlorinated solvents, herbicides, insecticides, PCP, PCBs, and munitions.

- ✓ **Rhizodegradation**: Rhizodegradation, sometimes called phytostimulation, rhizosphere biodegradation, or plant-assisted bioremediation/degradation, is the enhanced breakdown of a contaminant, by increasing bioactivity using the immediate environment of plant roots ‘’the rhizosphere’’ to stimulate microbial populations.

  This technology is used to increase the degradation of organic contaminants (such as petroleum hydrocarbons, PAHs, pesticides, BTEX, chlorinated solvents, PCP, PCBs, and surfactants) in soil. The term comes from "rhizosphere", which is the area of soil influenced by plant roots. This zone extends about 1 mm from each root.

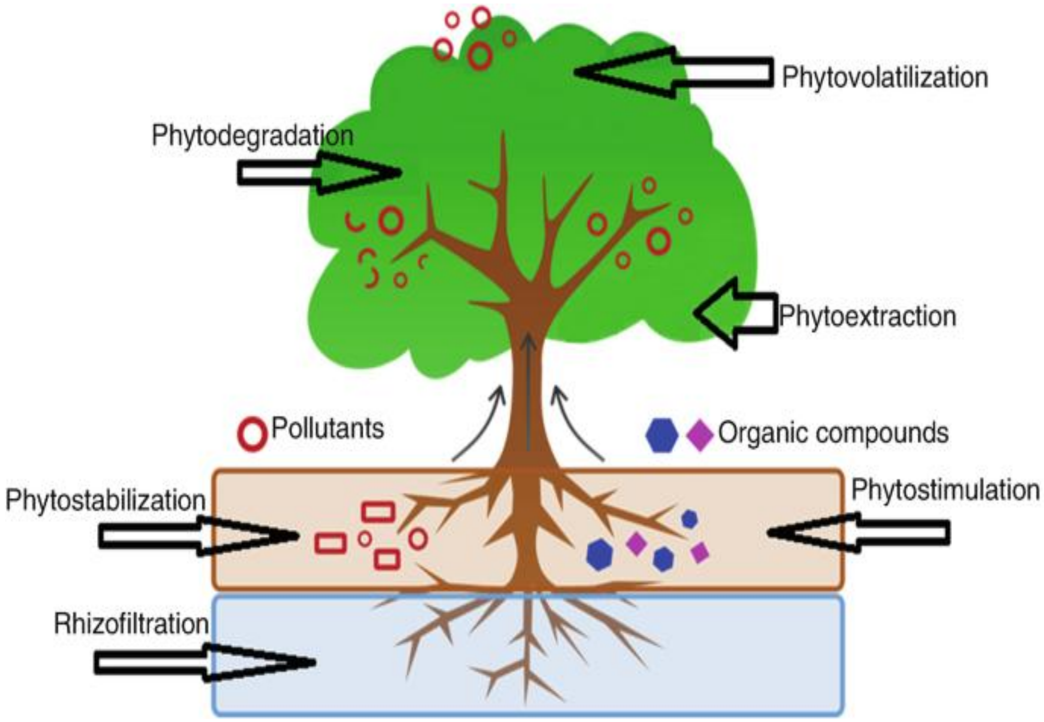

Figure 5.8. Phytoremediation technique (Abdel-Shafy & al. 2018)

- **Nanoremediation**

Nanoremediation techniques use reactive nanomaterials that allow the detoxification of pollutants in situ, by deep injection. Nanoremediation therefore has the potential to not only reduce the overall cost of contaminated site remediation processes, but also to reduce clean-up time. By eliminating the step of treating excavated soils and almost completely reducing the concentrations of certain organic contaminants in soils, without resorting to pumping groundwater, this process represents a gain in both time and efficiency.

Several nanomaterials have been explored for remediation purposes, such as nanozeolites, metal oxides, carbon nanotubes and nanofibers, enzymes, and various noble metals (mainly bimetallic Fe/Pd or Fe/Pt nanoparticles) and titanium dioxide. Among these nanomaterials, nanoscale zero-valent iron (nZVI*) is currently the most widely used. nZVIs have important redox properties, as well as special physicochemical properties: for example, their specific surface area is larger and their composition and structure are more homogeneous than those of their micrometric counterparts.

Preliminary results associated with this technology based on redox processes suggest a faster, cheaper, and more efficient remediation method. This is why this technology is increasingly used for environmental remediation, whether in the treatment of contaminated soils and waters or, more recently, in that of sewage water/sludge. Thus, nZVI-based technologies offer low-cost solutions for some of the most important environmental challenges.

This approach uses reactive materials with a size range of $1x10^{-9}$ meter to $1x10^{-7}$ meter. Through catalysis and chemical reduction, this procedure will aid in the detoxification and transformation of contaminants.

Despite the fact that many other reactive chemicals, such as titanium dioxide, metal oxides, nanotubes, and noble metals, have been studied, nanoscale zero-valent iron (nZVI) is often used in groundwater remediation.

Furthermore, in-situ nanotechnology applications such as nano-sized oxides have been shown to aid in the reduction of non-aqueous phase liquid NAPLs from subsurface oil tanks.

Although this emerging technology seems at first glance to be an obvious step forward in the remediation of contaminated sites, the potential risk it represents is still poorly understood.

The introduction of nanometric ZVI into the environment can pose a risk to microorganisms that are the basis of the food chain.

The factors and processes affecting ecotoxicity are complex and the potential impact of manufactured nanoparticles on the environment and human health remains poorly described.

Many socio-economic issues are therefore directly linked to the use of nanomaterials for the remediation of contaminated sites.

In order to prevent any negative impact of nanoremediation on the environment, it is essential to conduct an appropriate assessment, including studies with these nanoparticles at the ecosystem scale.

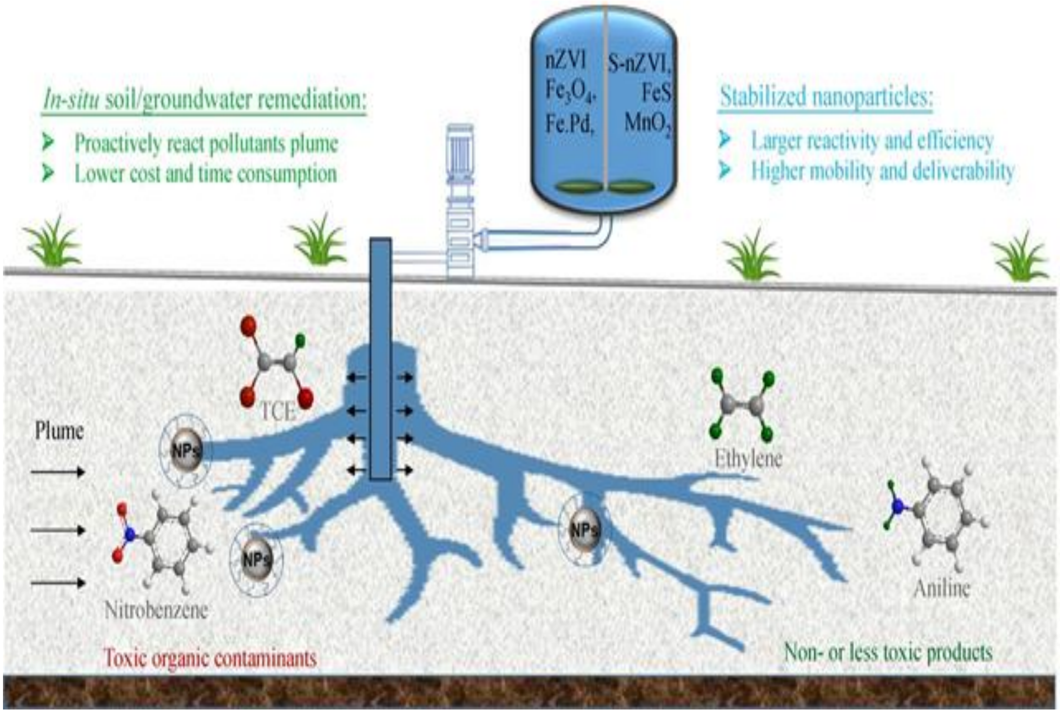

Figure 5.9. Nano-remediation technique (Cai et al. 2020)

- **Pump and Treat Technique**

Pump and treat systems are among the most commonly used systems for the remediation of contaminated groundwater. These techniques are practical for treating a wide range of contaminants, provided that the contaminants are, to some extent, soluble. These technologies involve increasing the hydraulic gradient in the saturated zone, using a pumping system, to promote the migration of contaminated water to the pumping well(s). The contaminated groundwater is pumped and treated at the surface before being disposed of or returned to the aquifer. This technology is often used to control the migration and spread of the contaminant plume.

Site remediation can be a difficult and lengthy process, taking years to decades to complete. In some cases, pump and treat techniques are used when no aqueous liquids (NAPLs) are present on the site, particularly when NAPLs are associated with dissolved contamination. Further information on the use of pumping and treatment technologies for the removal of LPNA is available in the fact sheets “Pumping and Recovery System for Non-Aqueous Phase Liquids” and “Pumping and Treatment of Dense Non-Aqueous Phase Liquids”.

The effective use of pumping and treatment technologies requires a thorough knowledge of the physical properties of the contaminant(s) and the geological and hydrogeological conditions of the contaminated site in order to allow the installation of the most effective pumping system.

Pumping and treatment is one of the most widely used techniques in groundwater treatment. Water extraction is usually carried out using wells equipped with pumps and may be combined with the installation of an impermeable barrier or other containment method. At the surface, the water thus extracted is subjected to physical treatment, chemical treatment or biological treatment. After treatment, the water is discharged or reinjected into the source site through injection wells.

This technique treats the plume rather than the source of pollution. It is therefore advisable to treat the source of pollution beforehand, if possible. The circulation of water induced by pumping generates a renewal of water in the pores of the saturated zone. The phase equilibria are then shifted, which implies that: the water passing through a polluted zone will become loaded with pollutants, the concentrations of pollutants adsorbed on the solid matrix (in the capillary zone and the saturated zone) and present in gaseous form (vadose zone) will decrease slightly. Before setting up the treatment, it will be necessary to find an outlet for the pumped water. The choice of the discharge point is essential. Depending on the environmental context, the pumped flow rates and the administrative authorizations, discharges may be carried out: at certain concentrations, in wastewater networks, rainwater networks, surface water, the water table (reinjection), in certain cases in approved disposal centers. In practice, given the volumes pumped, disposal in an approved center is infrequent; it is limited to low and concentrated discharges.

The variants of Pumping and Treatment are:

Hydraulic Containment: Pumping and Treatment can be used as a temporary containment solution to stop the spread of the pollution source and/or its poorly soluble pollution plume.

The drainage trench: Positioned perpendicular to the direction of flow of the water table and along the entire length of the pollution source (or the pollution plume), the drainage trench allows the temporary trapping of hydrophobic pollutants due to the difference in permeability. Low flow rate pumps positioned inside these trenches allow the recovery of pollutants. In order to facilitate the recovery of pollutants, geo-membranes are often positioned immediately downstream of the filter bed. This is close to pseudo-confinement.

The ‘pump and treat’ method offers several distinct advantages that make it a preferred choice in many environmental cleanup projects. First, the ‘pump and treat’ method stands out for its remarkable efficiency in removing a wide range of hydrocarbon contaminants from groundwater. This method proves its versatility by being able to handle different types and concentrations of pollutants, making it a reliable solution for various remediation scenarios. ‘Pump and treat’ offers controlled remediation, which is particularly advantageous for preventing the spread of contaminants to unaffected areas. By extracting and treating groundwater in a controlled manner, the method minimizes the risk of further contamination, making it suitable for environmentally sensitive sites. Another key advantage of this method is its potential for customization. Remediation teams can tailor the pump-and-treat process to meet the unique requirements of each contamination site. This adaptability ensures that the method can be optimized for diverse geological and hydrogeological conditions.

Pumping and treatment is a relatively universal technique since it applies to organic and mineral pollution, whether in free or dissolved form: (semi-)volatile organic compounds, (semi-)volatile organic halogenated compounds, PCBs, certain metals/metalloids. This technique is mainly applied in relatively permeable (sandy-silty to gravelly) and homogeneous aquifers.

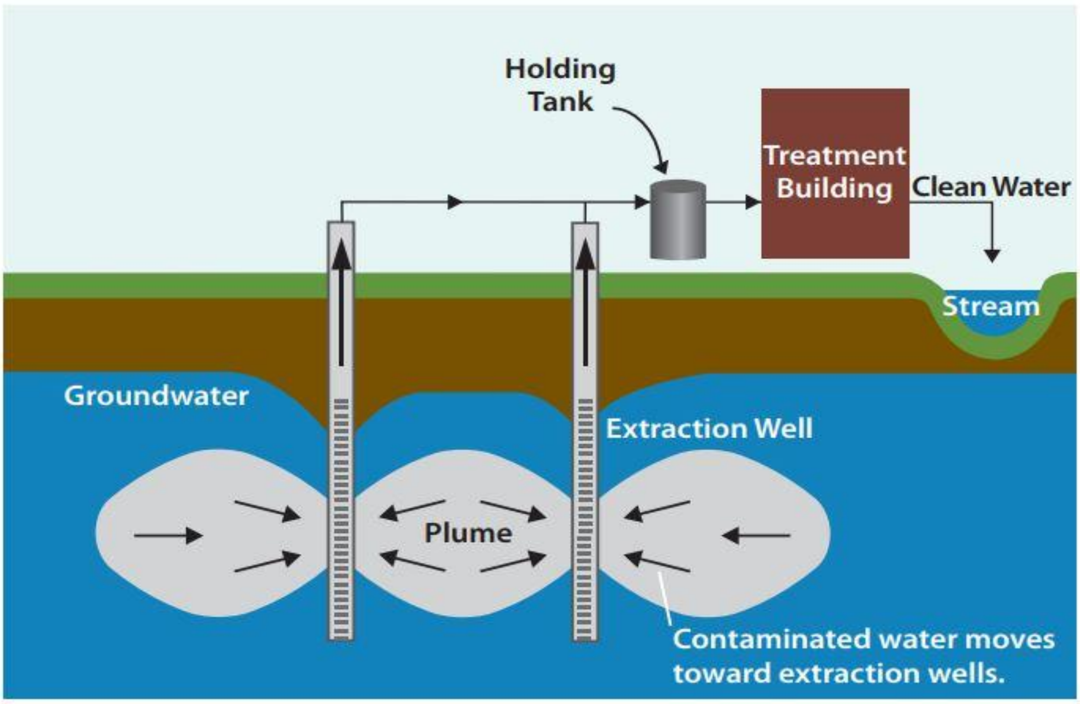

Figure 5.10. Pump-and-treat method (Carver & Mitchell, 2019)

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