Chapter 03: Heavy Metals and Algerian Standards:

1.Definitions:

1.1. Concept of materials:

A material is any substance used to make an object in the broad sense. It is therefore a substance selected initially because of its specific properties and processed for a particular use. The chemical nature, physical form and surface condition of the various raw materials that form the basis of materials give them their specific properties. Materials can be classified into:

- **Metallic materials**: Hard, rigid materials that can undergo plastic deformation. Metals and their alloys are generally good conductors of heat and electricity, and are opaque to visible light, which they reflect. They include pure metals (iron, copper, aluminum, gold) and alloys (steel, bronze, brass). They are essential for their strength and durability in construction, automotive, electronics, and aerospace industries.
- . **Ceramic materials**: Ceramic materials are inorganic, non-metallic, often crystalline oxide, nitride, or carbide compounds. They are created from minerals and elements primarily clay, silica, and feldspar that are shaped and hardened by high temperatures
- **Polymer materials**: large, chain-like macromolecules composed of repeating structural units (monomers), classified into natural (cellulose, proteins) and synthetic (plastics, rubbers, fibers) types
- **Composite materials**: combinations of at least two of the three types of materials mentioned above, which are not mutually miscible.

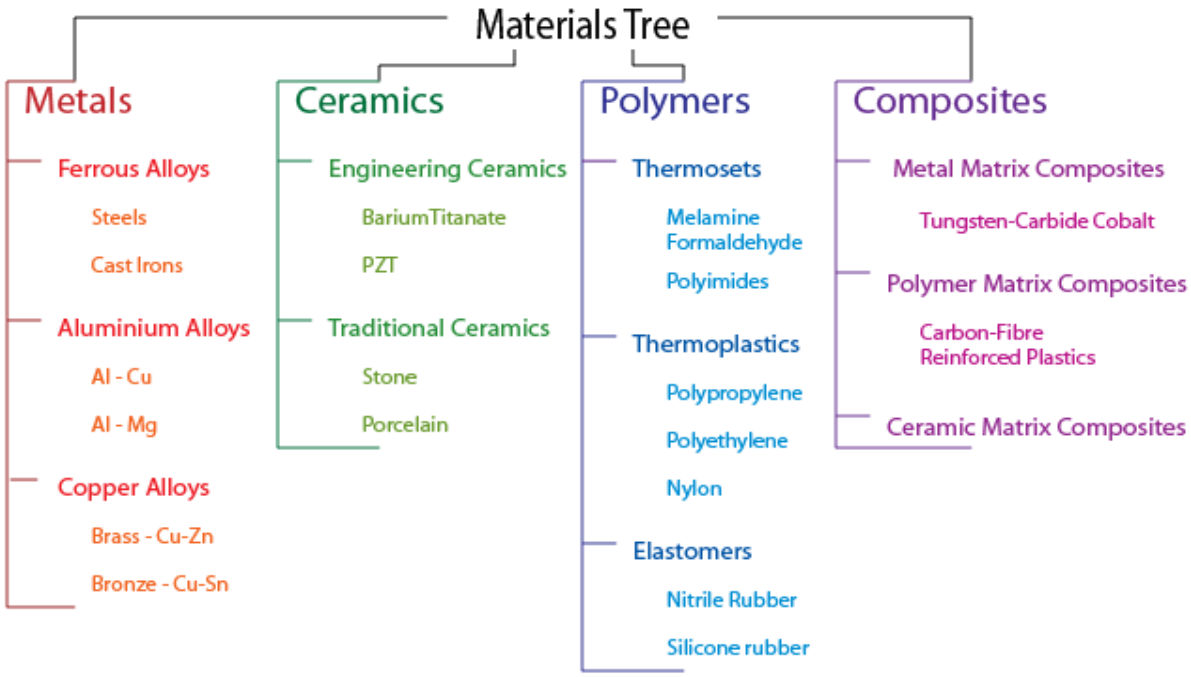

Figure 01. Materials 'classification in nature

1.2. Concept of metal:

A metal is a chemical element, compound, or alloy characterized by high electrical or thermal conductivity, luster (shine), malleability, and ductility. They readily lose electrons to form positive ions (cations) and are typically solid, strong, and opaque. Chemical elements present in nature play vital roles in biological processes, but they can become toxic when their concentration is too high.

1.3. Concept of heavy metal:

Heavy metals are a group of elements that are naturally present in the Earth's crust, but their concentrations in the environment can increase significantly due to human activities such as mining, industrial emissions, agriculture, and waste disposal. Common examples include lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), and nickel (Ni).

A metal is considered "heavy" if it has a high density, generally greater than 5 g/cm³. This purely physical definition includes metallic elements such as iron, copper, or zinc, although some of them are not toxic. From a toxicological perspective, the term heavy metals refer to elements that exhibit high toxicity even at low concentrations and have a tendency to accumulate in living organisms (bioaccumulation)

Table 01. Heavy metals according to their toxicity

Name	Symbol	Family	Density (g/cm³)	Toxicity	Origin
Lead	**Pb**	Post-transition metal	**11.34**	Highly toxic	Natural and industrial
Mercury	**Hg**	Transition metal	**13.53**	Highly toxic	Natural and industrial
Cadmium	**Cd**	Transition metal	**8.65**	Highly toxic	Natural and industrial
Arsenic	**As**	Metalloid	**5.72**	Highly toxic	Natural and industrial
Chromium	**Cr**	Transition metal	**7.19**	Toxic	Natural and industrial
Nickel	**Ni**	Transition metal	**8.91**	Toxic	Natural and industrial
Copper	**Cu**	Transition metal	**8.96**	Moderate toxicity	Natural and industrial
Zinc	**Zn**	Transition metal	**7.14**	Low toxicity	Natural and industrial
Cobalt	**Co**	Transition metal	**8.90**	Moderate toxicity	Natural and industrial
Antimony	**Sb**	Metalloid	**6.68**	Toxic	Natural and industrial
Bismuth	**Bi**	Post-transition metal	**9.78**	Low toxicity	Natural
Uranium	**U**	Actinide	**18.95**	Radioactive	Natural and industrial
Thorium	**Th**	Actinide	**11.7**	Radioactive	Natural
Plutonium	**Pu**	Actinide	**19.84**	Radioactive	Industrial
Silver	**Ag**	Noble metal	**10.49**	Low toxicity	Natural
Gold	**Au**	Noble metal	**19.30**	Low toxicity	Natural
Platinum	**Pt**	Noble metal	**21.45**	Low toxicity	Natural
Palladium	**Pd**	Noble metal	**12.02**	Low toxicity	Natural and industrial
Thallium	**Tl**	Post-transition metal	**11.85**	Highly toxic	Natural and industrial

Some of the heavy metals are having so much of biological importance in trace amounts. The biological importance of these metals is about enzyme functioning, hormone functioning, production (selenium), cellular growth (nickel), and metabolic growth (arsenic). But these metals are required for the human in trace amounts only if their amount in the body increases, they cause adverse effects on human health. They may damage the nervous system, kidneys, liver, and respiratory system, and some are carcinogenic.

From an environmental point of view, heavy metals are persistent pollutants because they do not degrade or disappear over time. Instead, they remain in soils, water, and sediments, where they can move through food chains. This leads to bioaccumulation in organisms and biomagnification at higher trophic levels, especially in fish and predators. Heavy metals can also disrupt enzymatic activity by binding to proteins and replacing essential elements like zinc or calcium in biochemical reactions. Even at very low concentrations, chronic exposure can have long-term health effects.

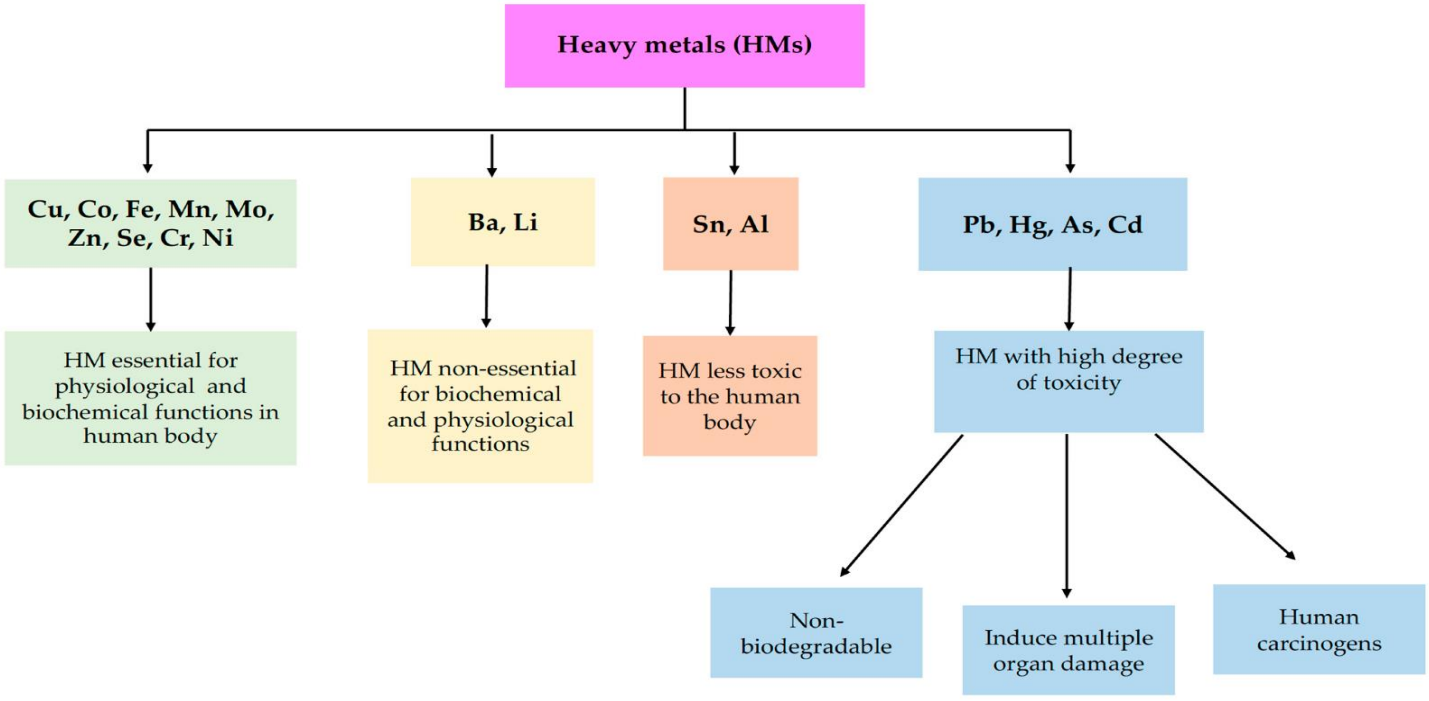

Figure 02. Heavy metals according to their toxicity in nature

2. Origin of heavy metals:

The sources of heavy metals in the environment are diverse and often linked to both natural processes and anthropogenic activities.

- Natural sources include weathering of metal-rich rocks, volcanic activity, and forest fires, which can release heavy metals into the air, water, and soil.

- However, the most significant contributors to heavy metal pollution are human activities. Industrial processes such as mining, metal smelting, battery manufacturing, electroplating, and chemical production release substantial quantities of heavy metals into the environment. Additionally, the extensive use of fossil fuels in power generation and transportation contributes to atmospheric emissions of metals like lead and mercury. Agricultural practices, including the use of phosphate fertilizers, pesticides, and sewage sludge, also introduce heavy metals like cadmium and arsenic into the soil and groundwater.

Table 02. Origin and effect of some heavy metals on human health

Heavy Metal	Sources	Health effects
Essential heavy metals		
Zinc (Zn)	Oil refining, Plumbing, Brass manufacturing	Gastrointestinal disorders, Kidney and liver abnormal functioning
Copper (Cu)	Copper polishing, Plating, Printing	Abdominal disorders, Metabolic activity abnormalities
Iron (Fe)	High intake of iron supplements and oral consumption	Vomiting, Diarrhea, Abdominal pain, Dehydration and lethargy
Cobalt (Co)	Hip alloy replacement case	Hematological, Cardiovascular, Hepatic, Endocrine
Chromium (Cr)	Steel fabrication, Electroplating, Textile	Lung disorders (bronchitis, cancer), Renal and reproductive system
Non essential heavy metal		
Lead (Pb)	Batteries, Coal combustion, Paint industry	Serious effect on mental health (Alzheimer's disease), Nervous system
Arsenic (As)	Atmospheric deposition, Mining, Pesticides	Highly effects dermal region (Cancer), Brain and cardiac problems
Mercury (Hg)	Coal combustion, Fish, Mining, Paint industry, Paper industry, Volcanic eruption	Blindness, Minamata disease, Deafness, Gastric problems, Renal disorders
Cadmium (Cd)	Plastic, Fertilizers, Pesticides	Osseo related problems, Prostate cancer, Lung diseases, Renal issues

3. Exposition of heavy metals to living organisms:

3.1. Bioconcentration:

A phenomenon by which an organism concentrates a contaminant (trace element, pollutant, radioisotope, etc.) at a level higher than that of the aquatic, aerial, or terrestrial environment, exclusively through respiration and dermal diffusion (transfer through the skin). Example of bioconcentration of heavy metals in fish refers to the process by which these contaminants are absorbed directly from the surrounding aquatic environment (water)

through the gills and skin, without involving dietary intake. This results in metal concentrations in fish tissues that are higher than those in the water.

3.2. Bioaccumulation:

A phenomenon by which an organism concentrates a substance at a level higher than that of the environment through all exposure pathways, including food intake. In the same organism, this capacity can vary greatly depending on age, health status, or external factors (season, nutrient content of the environment, pH, etc.). The bioaccumulation capacity in living organisms that absorb and store these pollutants (trace elements, pesticides, etc.) is expressed by a concentration factor (BCF):

$$\mathrm{BAF} = \frac{C_{\mathrm{organism}}}{C_{\mathrm{environment}}}$$

Heavy metal bioaccumulation in soil involves the persistent absorption and concentration of non-degradable elements such as lead, cadmium, and chromium by plants, microbes, and invertebrates

3.3. Biomagnification (or bioamplification):

A phenomenon by which a contaminant is found at a higher concentration in an organism than in its food. It refers to the cumulative increase in the concentration of a persistent substance as one moves up the food chain (trophic chain), from one level to the next.

4. Soil remediation:

It’s the process of removing, reducing, or neutralizing contaminants such as heavy metals, pesticides, and hydrocarbons from polluted soils to restore their quality and ecological function. It involves various techniques, including physical methods (soil excavation), chemical treatments (stabilization or oxidation), and biological approaches like bioremediation (Bacteria) and phytoremediation (Plants) , where these organisms are used to degrade or extract pollutants. These methods aim to protect human health, improve agricultural productivity, and prevent the spread of contaminants into water and the food chain.

As the soil is the natural repository for a variety of environmental pollutants, it is crucial to continuously monitor the levels of heavy metals in different environmental matrices, particularly the soil.

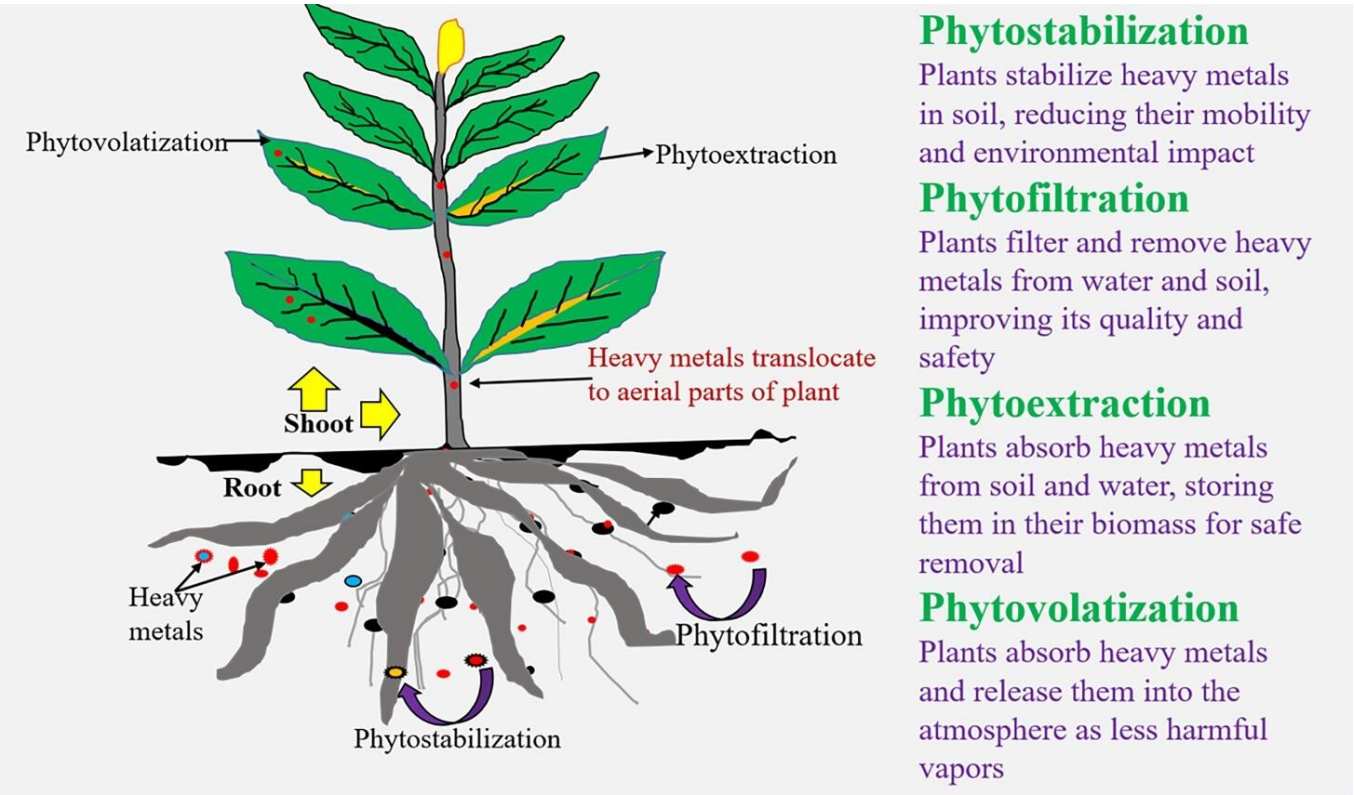

Figure 03. Various plant mechanisms for soil remediation

5. Algerian legislation for heavy metals:

In Algeria, regulations concerning heavy metals are part of a legislative and regulatory framework aimed at protecting the environment and public health. Heavy metals such as lead, mercury, cadmium, chromium, and arsenic are potential pollutants in air, water, and soil. Algerian standards, such as those defined by the National Agency for Nature Conservation (ANCN), as well as other legislative and regulatory texts, impose strict limits on the concentration of these substances in various products and environments. Algerian regulations regarding heavy metals rely on several mechanisms, such as

- **Law No. 83-17 of July 16, 1983 on the Water Code:**
- Defines standards for the discharge of industrial effluents, including those containing heavy metals, in order to prevent water pollution.
- **Executive Decree No. 05-12 of April 28, 2005 on the prevention and management of hazardous waste:**

  Establishes the conditions for managing hazardous waste and defines procedures for the treatment, storage, and disposal of such waste to minimize their environmental impact.
- **Executive Decree No. 09-209 of June 11, 2009:**
- Sets the maximum allowable concentration limits of heavy metals in industrial discharges. This decree aims to control and reduce metal pollution in the environment.

- **Interministerial Order of January 24, 2021:**
- Defines the permissible threshold limits of heavy metals in sugar intended for human consumption.
- **ISO 17025 Standard:**
- Applies to environmental analysis laboratories, as well as specific standards related to the quality of drinking water, air, and soil.
- **NF ISO 11885 Standard:**
- Defines methods for measuring heavy metals in water and sludge.
- **EN ISO 11212-1 NA 19385 Standard:**
- Specifies the method for determining arsenic content by atomic absorption spectrometry.

Table 03. Algerian standards for heavy metals in aquatic ecosystems

Element	*Symbol*	*Max Value (mg/L)*	*Industrial Sources*
Cyanide	CN	**0.1**	Metallurgy, gold processing, plastics
Cadmium	Cd	**0.2**	Batteries, pigments, electroplating
Chromium III	Cr^{3+}	**3.0**	Tanneries, textiles, metal treatment
Chromium VI	Cr^{6+}	**0.1**	Paints, anti-corrosion, electroplating
Manganese	Mn	**1.0**	Alloys, batteries, fertilizers
Mercury	Hg	**0.01**	Electronics, thermometers, chlor-alkali
Nickel	Ni	**5.0**	Stainless steel, batteries
Lead	Pb	**1.0**	Paints, batteries
Copper	Cu	**3.0**	Electrical cables, pesticides, mines
Zinc	Zn	**5.0**	Galvanization, alloys, paints