

EWCE 131
Ecology and Environmental Pollution

Lecture 13

Instructor

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Lecture outline

Heavy Metal Pollutants and Pollution Management

Topics

- ❖ **Heavy Metal Pollution**
- **Arsenic (As)**
- **Chromium (Cr)**

- ❖ **Heavy Metal Pollution Management**

Pollution by Heavy Metal

- The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations.

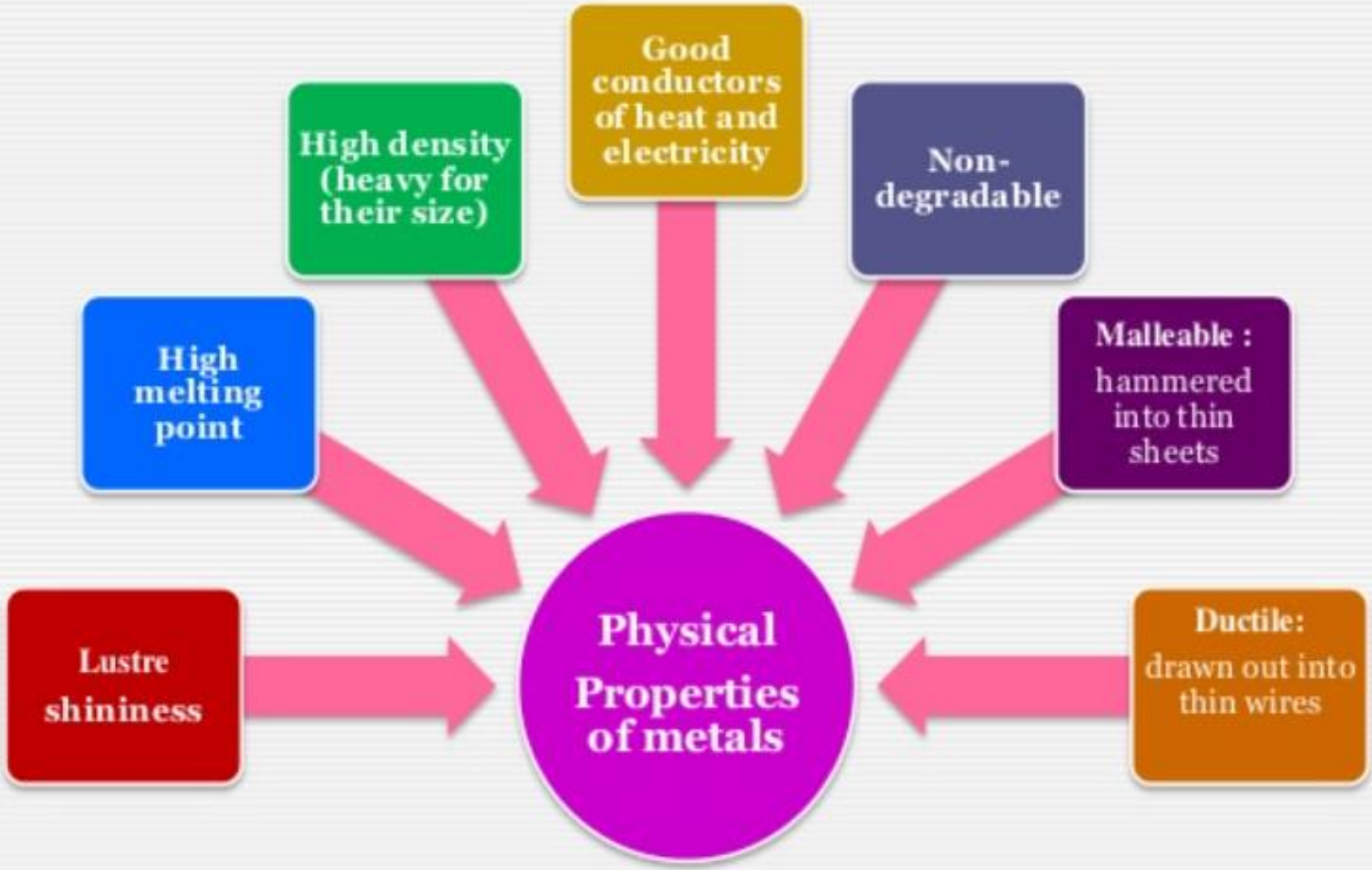
- Heavy metals are conventionally defined as elements with metallic properties and n atomic number >20.

- Heavy metals are those having densities five times greater than water, and the light metals are those having lesser densities.

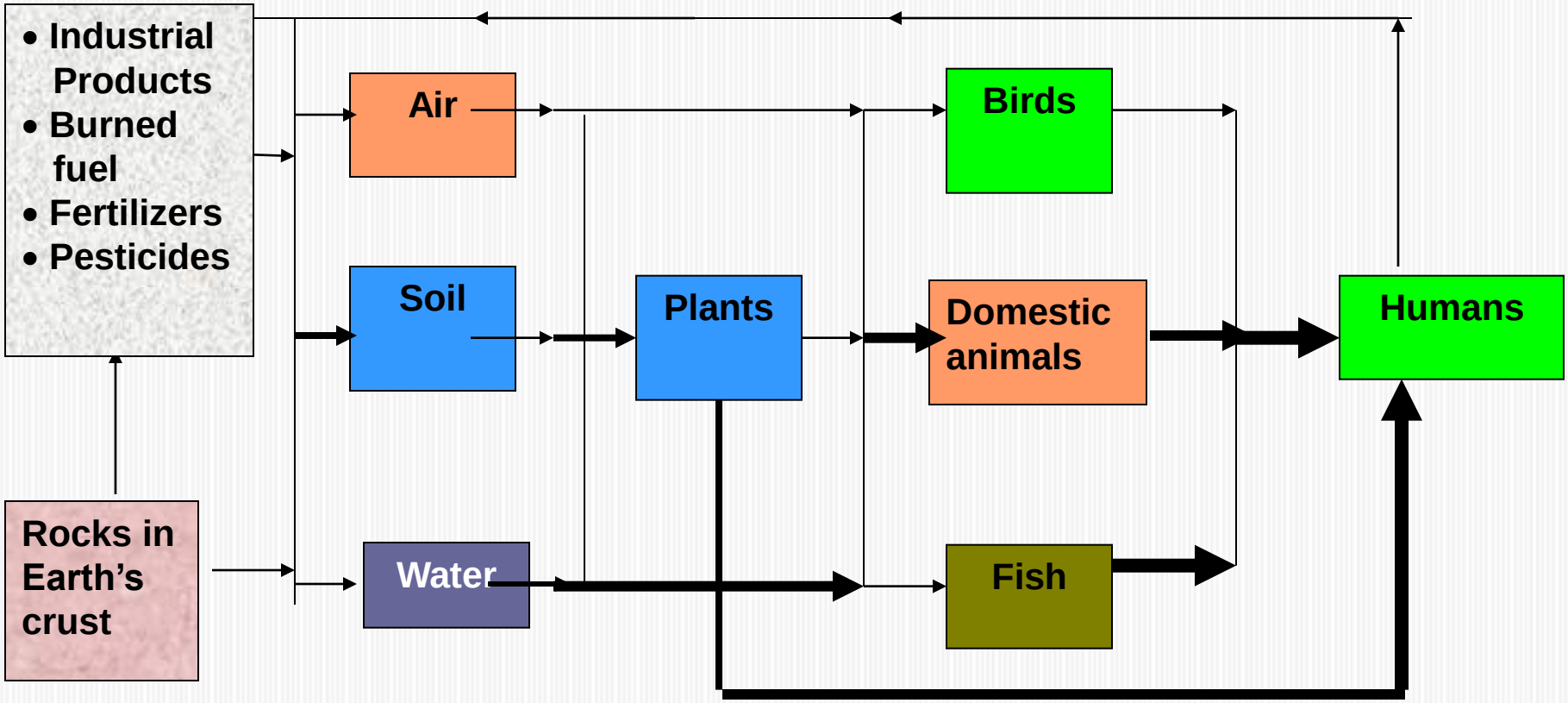
- The most common heavy metal contaminants are Cd, Cr, Cu, Hg, Pb, As, Zn etc.

- Humans consume metallic elements through both water and food.

Properties of Heavy Metal



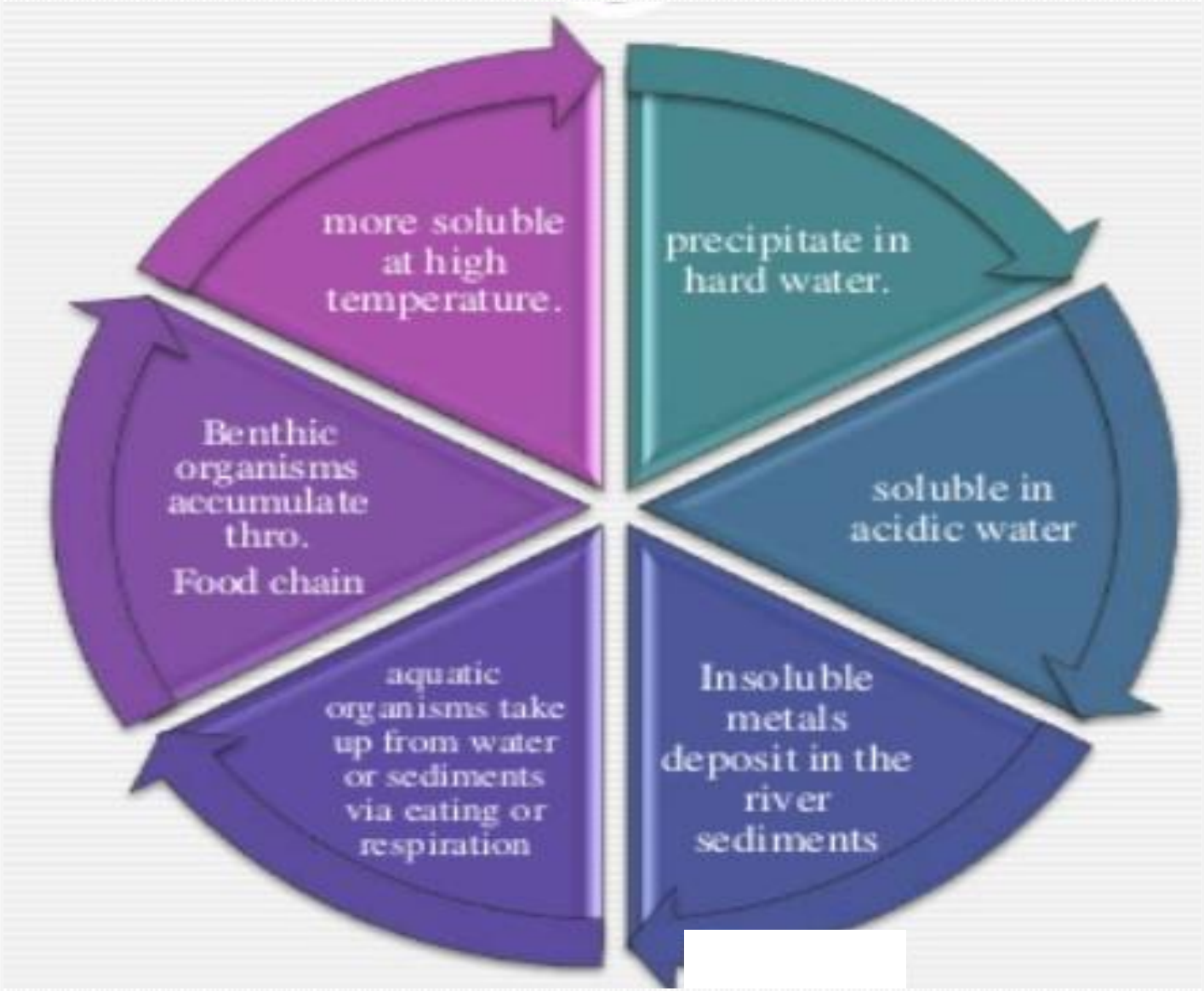
Sources of heavy metals and their cycling in the soil-water-air-organism ecosystem



It should be noted that the content of metals in tissue generally builds up (bioaccumulation) from left to right, indicating the increasing vulnerability of humans to heavy metal toxicity

Source: Brady, N. C. The nature and properties of soil, 1994

Fate of Heavy Metal in Aquatic Environment



Heavy Metal Toxicity

Cd, As

Hg, Pb, Ni

B, Cu, Mn, Zn



Extremely poisonous

Moderately poisonous

Relatively less poisonous

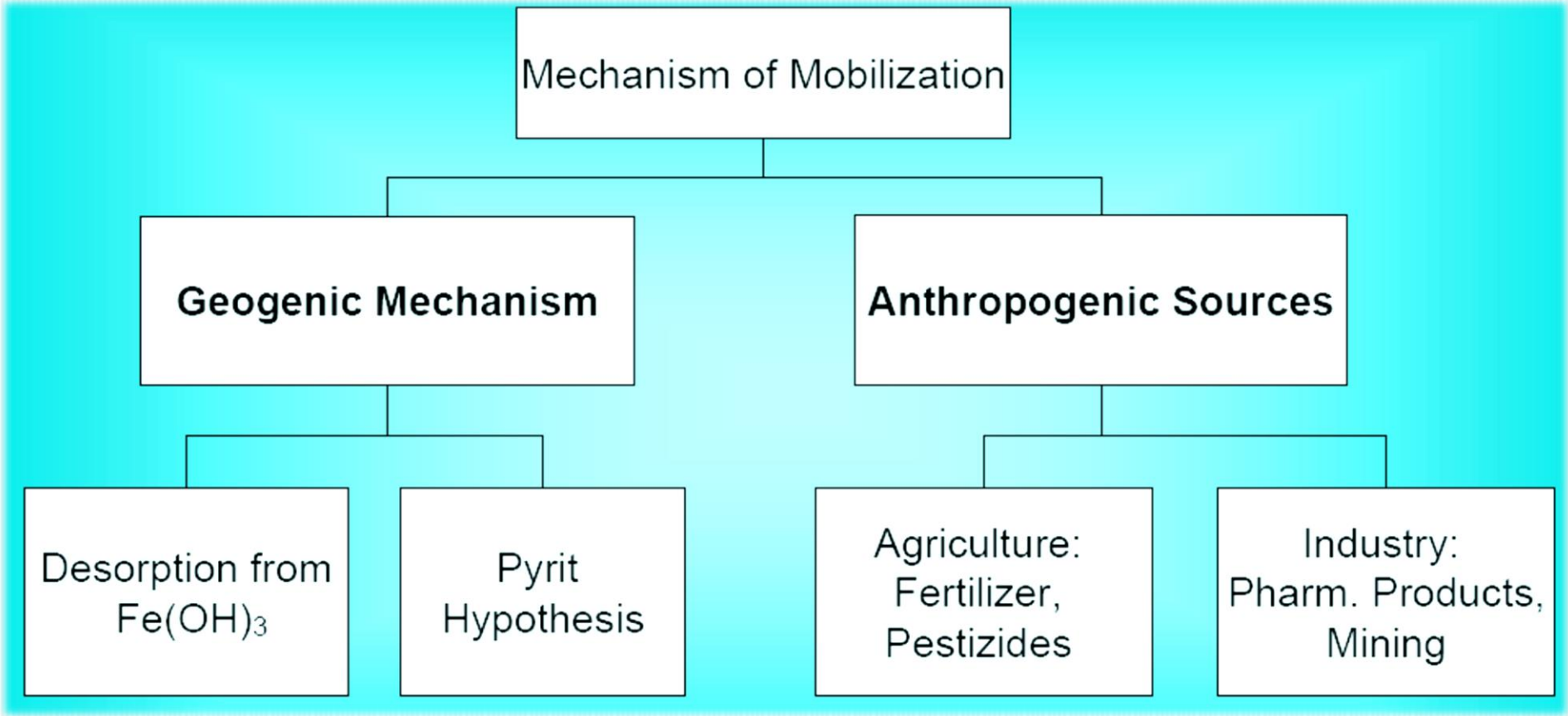
Heavy Metal Toxicity – **Arsenic (As)**

Sources of Arsenic Contamination

- Pesticides, herbicides
- Combustion of coal
- Mining, smelting of gold, lead, copper and nickel
- Production of iron and steel
- Leachate from abandoned gold mines
- Wood preservative
- Tobacco smoke

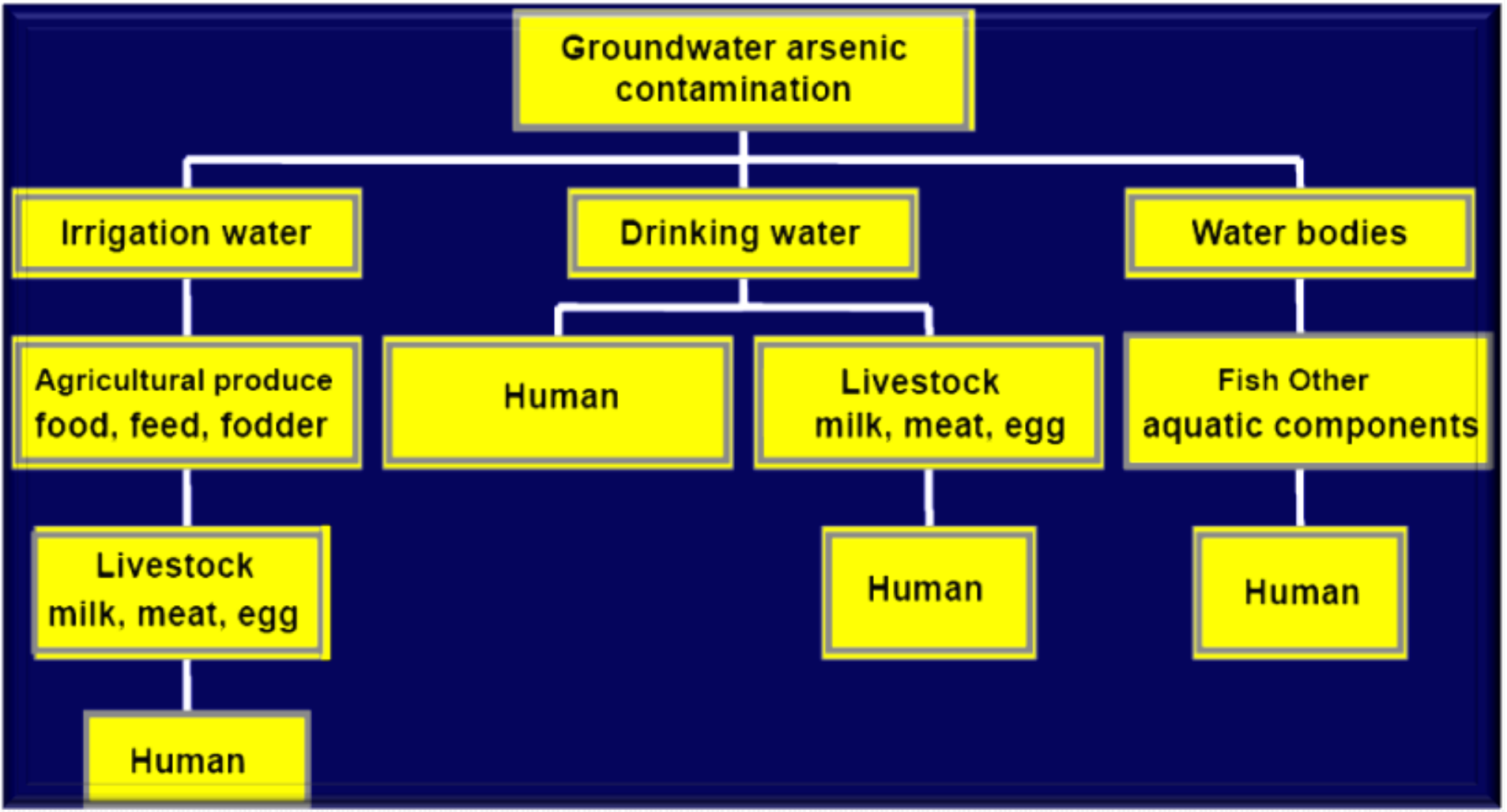
Heavy Metal Toxicity – **Arsenic (As)**

Arsenic Mobilization Theory



Heavy Metal Toxicity – **Arsenic (As)**

Pathway of Arsenic from Groundwater to Human Body



Heavy Metal Toxicity – **Arsenic (As)**

Mobility of Arsenic depends on –

- Oxidation/ reduction
- Precipitation/ dissolution
- Adsorption/ desorption

- ❑ Under oxic condition, As is usually bound to metal oxides in sediments (by adsorption).

- ❑ Under reducing conditions, As is released because oxides dissolve.

- ❑ The adsorption process is influenced by – concentration of As, redox potential, pH and presence of competing anios (e.g. phosphate).

Heavy Metal Toxicity – **Arsenic (As)**

Forms of Arsenic

- Inorganic – arsenite, As(III)
- Organic – arsenate, As (V)
- Elemental form

Characteristics of Arsenic

- Colorless, tasteless and odorless
- Small quantity may case death
- Can be easily administered with food or drink
- Symptoms simulate those of cholera.

Heavy Metal Toxicity – **Arsenic (As)**

Health Effects of Arsenic Contamination

- Inorganic As (III) is more toxic then organic As (V)
- Acute poisoning: Lethal dose is 1-2 mg/kg of body weight
- Chronic symptoms appear after 2-5 years of exposure
- Behavoir in body: bio-accumulation in liver, spleen, lungs, bones, skin, hair, nails etc.

Heavy Metal Toxicity – **Arsenic (As)**

Health Effects of Arsenic Contamination

- As (V) – binds to proteins causing a blockade of ATP synthesis

- As (III) – connects to enzymes hindering the profilation of tissue growth

- Arsenicosis: Symptoms are –

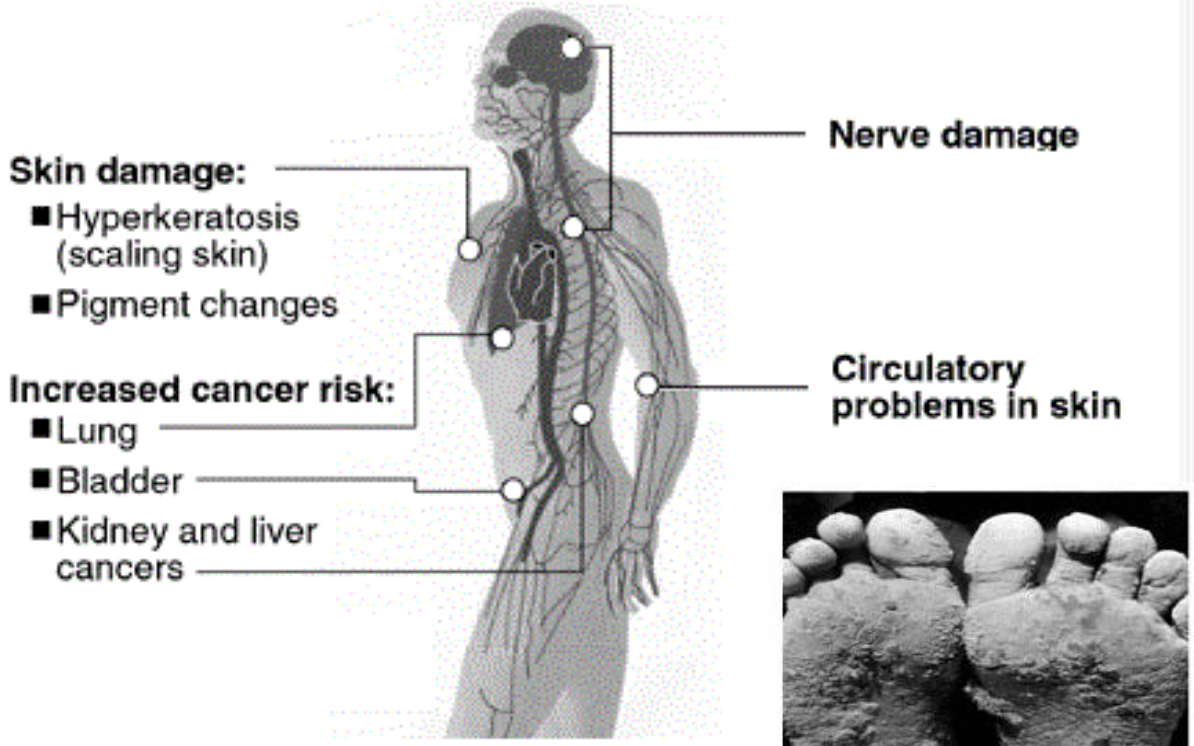
✓ Melanosis – thickening of the conjunctiva

✓ Keratosis (wart like growth) and hyperpigmentation

✓ Skin cancer and ultimately death

Heavy Metal Toxicity – **Arsenic (As)**

Health Effects of Arsenic Contamination





Mee's- lines



Skin lesions due to Arsenic Poisoning

Heavy Metal Toxicity – **Chromium (Cr)**

- Chromium is an abundant element of earth's crust.
- The trivalent (III) and hexavalent (VI) compounds of chromium are of great industrial importance.
- Chromium (III) is an essential nutrient.

Heavy Metal Toxicity – **Chromium (Cr)**

Human Health Effects of Chromium

- Acute chromium toxicity cause renal tubular necrosis.
- Chronic chromium toxicity cause cancer of respiratory tract.
- Upset stomachs and ulcers.
- Respiratory problems, lung cancer
- Weakened immune system
- Kidney and liver damage
- Teratogenic (disturbs the development of an embryo or fetus) and carcinogenic (causes cancer) action
- Death

Heavy Metal Toxicity – **Chromium (Cr)**

Environmental Impacts of Chromium

- Chromium in air will eventually settle and end up in waters or soils
- Chromium in soils adsorbs to soil particles and percolates to ground water.
- Chromium may adsorb on sediments and become immobile in water.

Heavy Metal Pollution Management

Phytoremediation

- Phytoremediation, which is derived from the words “phyto” (plant) and “remediation” (recovery) can be also defined as “bioremediation,” and “green remediation.”
- The concept has emerged from a broader philosophy of Bioremediation where besides plants, soil micro-organism are also used for amelioration of organic and inorganic contaminants
- Phytoremediation is a term which is related to ecological remediation technologies that use plants as the main source.
- The principle of this technology is to remove organic and inorganic substances from the contaminated area using plants.

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Phytoremediation

- The effects of this method can be observed in low polluted areas in a short time.
- The negative aspect is that in heavy contaminated areas the plants cannot be useful in a period of short time.
- The plants which are identified as metal hyper-accumulators and wild, are able to remove contaminant elements 10–500 times higher compared to the ones that are cultivated.

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Factors Influencing Phytoremediation

- Phytoremediation method is ecological, does not need special equipment during application and provides a re-usable land.
- The root depths and climatic conditions play an important role in the efficiency of the system.
- First of all, the soil must be appropriate to the needs of the plant for the removal of the contaminants from the soil by the plant.
- The pH of the soil is one of the most important parameters. The pH levels of the area must be between 5.8 and 6.5 for the nutrient elements to be taken.

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Phytoremediation Techniques

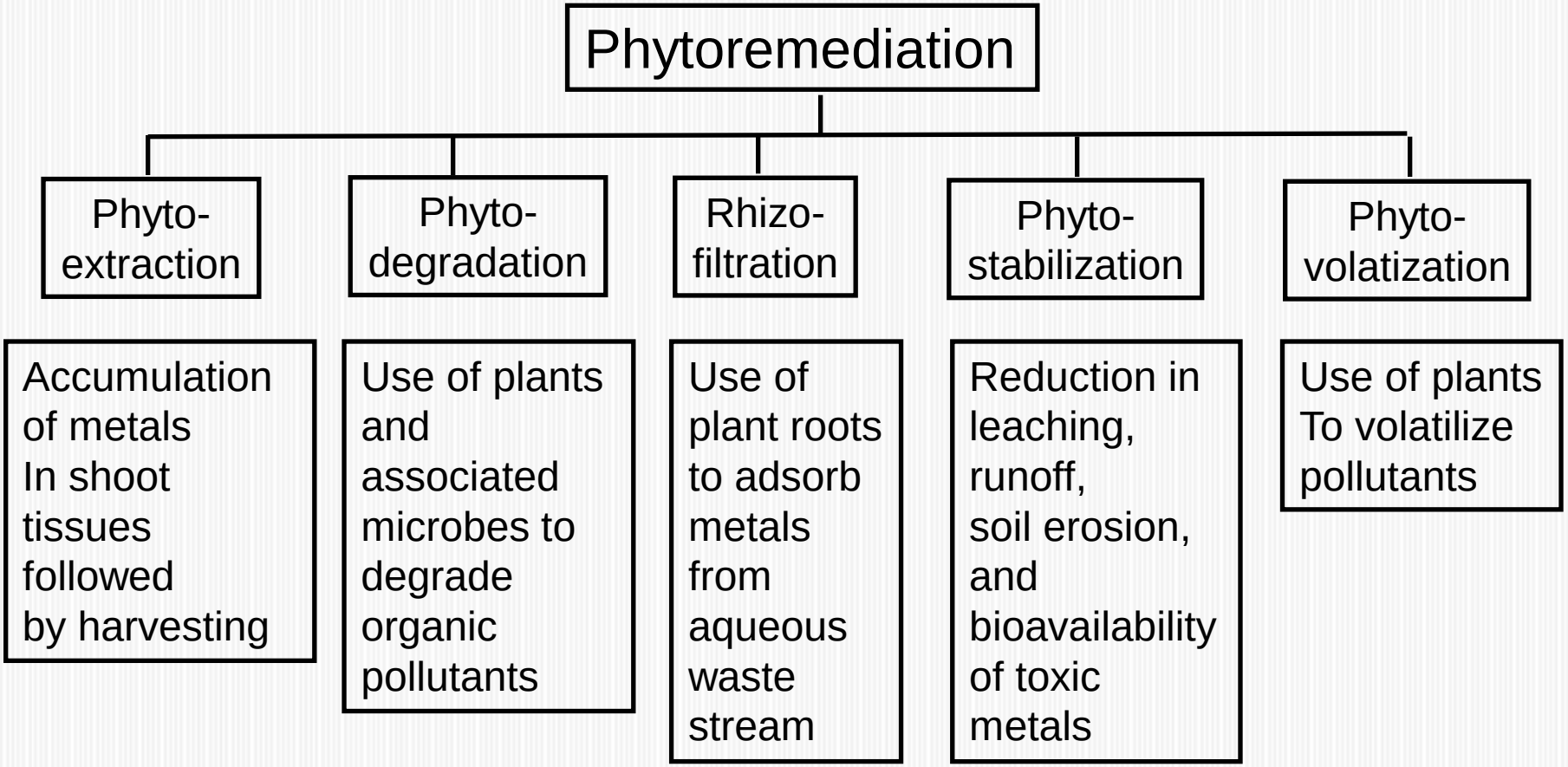
- Phytoremediation techniques can be subcategorized as -

  - ✓ phytoextraction
  - ✓ phytodegradation
  - ✓ rhizofiltration
  - ✓ phytostabilization
  - ✓ phytovolatilization
  - ✓ rhizodegradation

- Phytoremediation techniques are very effective in the sterilization of the areas that are medium-contaminated and have slight risk.

Heavy Metal Pollution Management - **Phytoremediation**

Approaches of Phytoremediation



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Phytoextraction (Vegetal Assimilation)

- This technique is used in the absorption of the organic and inorganic contaminants by the roots and the stems of the plant.
- It is a valid method for the recovery of the contaminated areas, in which the plants that are able to absorb metals are chosen and the contaminants are removed from the soil with the harvesting or removal of the plant.
- This technology takes more time compared to other techniques, hence its application on heavy polluted areas is very hard.

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Phytoextraction

- After the plants are harvested, they are burnt in an incinerator or exposed to another method.
- This method, which is called phyto-mining, provides the opportunity for obtaining the mineral ores whose cultivation process is not economic.
- With this method, gold and nickel are re-gained in the USA.

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Phytoextraction

- When the plants used in this method are compared to other plants, they are observed to accumulate contaminant elements 100 times more.
- In this method Brassicacea, Euphorbiacea, Asteraceae, Lamiaceae and Scrophulariaceae and 400 other types are identified which can accumulate heavy metals.
- The residues of the harvested plants can be isolated by drying, burning, composting and recycling to biological metal minerals.

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Phytoextraction



Brassicacea



Euphorbiacea



Asteraceae



Lamiaceae



Scrophulariaceae

Heavy Metal Pollution Management - **Phytoremediation**

Pteris vittata (Chinese brake) - a reported hyper-accumulator for Arsenic



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Phytodegradation (Vegetal Degradation)

- Phytodegradation is a method in which organic contaminants are degraded by the compounds that are produced by plants through metabolic processes.
- Vegetal degradation can be applied to soil, clay, sediment and underground waters.
- The most advantageous aspect of the method is that the reduction and degradation occur inside the plant as a physiological process, and do not depend on microorganisms.
- However, the emergence of toxic intermediate and end-use products, and the difficulty of their detection create a disadvantage.

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Phytodegradation

- The absorption of the organic compounds into the plant depends on the plant type, the residence duration of the contaminant element in the soil, and the soil's physical and chemical form.
- The easily dissolved compounds are difficult to absorb.
- Plant enzymes are known to be able to degrade hazardous substances such as herbicides, munitions wastes and chlorinated solvents (trichloroethane (TCE))

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Phytostabilization (Root Stabilization)

- Phytostabilization plants are able to tolerate heavy metal levels and immobilize the metals through sorption, sedimentation, complexation or reduction of metal valences.

- The contamination factors in soil occur as a result of the immobilization of the contaminants around the plant roots, their accumulation by the roots, cohesion or sedimentation around the roots.

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Phytostabilization (Root Stabilization)

- These plants can prevent contaminants' transportation by wind, water erosion, washing out or soil dissemination.

- In a system which is closely related to the plant's root environment microbiology and chemistry, the plant is able to modify the contaminant factor's form into non-resoluble or non-transported in water, thus making the contaminants stabilized.

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Phytovolatilization (Vegetal Evaporation)

- The most important aspect of this method is the transformation of the excessive toxic compounds (mercury contained compounds) into less toxic forms.
- However, the potential release of these hazardous and toxic materials into the atmosphere is a disadvantage.
- The contaminants can be removed from the plant by transpiration or evaporation.
- As a well-known fact, water is carried from the roots to the leaves with the help of vascular system; therefore, the contaminants are released to the air through evaporation or volatilization. Poplar tree can be an example for this mechanism.

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Phytovolatilization (Vegetal Evaporation)

- Some plants such as Brassica juncea and Arabidopsis thaliana can release heavy metals to the atmosphere with phytovolatilization by absorbing and transforming them into gas form.



Brassica juncea



Arabidopsis thaliana

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Phytovolatilization (Vegetal Evaporation)

- Some types of trees such as Populus and Salix are often used in phytovolatilization because of their capacity to take contaminants with phytoremediation.



Populus



Salix

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Rhizodegradation (the use of roots for degradation)

- Rhizodegradation is the decomposition of the organic contaminants in soil surrounding the roots of the plants as a result of microorganism activities.
- There are amino acids, sugar, organic acid, sterol, fat acids, growing factors, nucleotide, flavanone and enzymes which are released from the plant's roots and affect the microbial activities in the surrounding area of the roots.
- The most important benefit of Rhizodegradation method is the dissolution of the contaminants in their natural environment.

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Rhizodegradation (the use of roots for degradation)

- Pesticides (herbicide, insecticide), benzene, toluene, ethylbenzene, xylene (BTEX), total petroleum hydrocarbon (TPH), polycyclic aromatic hydrocarbons (PAH), surface active substances, chlorinated solvents (TCE, TCA), pentachlorophenol (PCP) polychlorinated biphenyls (PCB) are the contaminants that can be dissolved with Rhizodegradation.

- Mint (Mentha spicata L.), red berry (Morus rubra L.), lucerne (Medicago sativa L.), and reedmace (Typha latifolia L.) are used in Rhizodegradation method.

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Rhizodegradation (the use of roots for degradation)



Mint



Red Berry



lucerne



Reedmace

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Rhizofiltration (the use of roots for filtration)

- In Rhizofiltration method, contaminants cling to the roots or absorbed by the roots, where the contaminants may be taken or transported by the plant.
- It is important to maintain the immobilization of the contaminants in or on the plants.
- Later on, the contaminants can be taken from the plants with different methods.
- This method is applied to underground waters, surface waters and waste waters.

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Rhizofiltration (the use of roots for filtration)

- Rhizofiltration is used to remove the radioactive substances or metals from the contaminated waters.
- The plants which are used in this method are directly planted on the contaminated soil and the contaminant's adaptation is ensured.
- The plants are raised in clean water instead of soil until they have a wide root system.
- The rooted plants are transported to the contaminated water source in order to make them adapt to their new environment.
- When the roots become saturated the plants are harvested.

Heavy Metal Pollution Management - Phytoremediation

