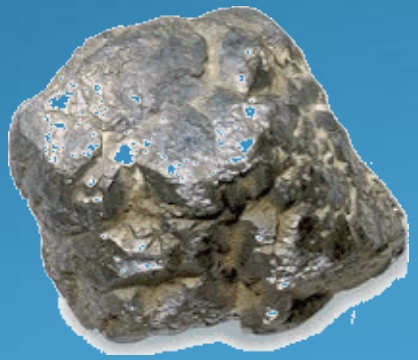
CBCS PG: Elective Paper - Environmental Science M. Sc., Semester-II

Heavy metal toxicity: Harmful effect on plants and humans and its management

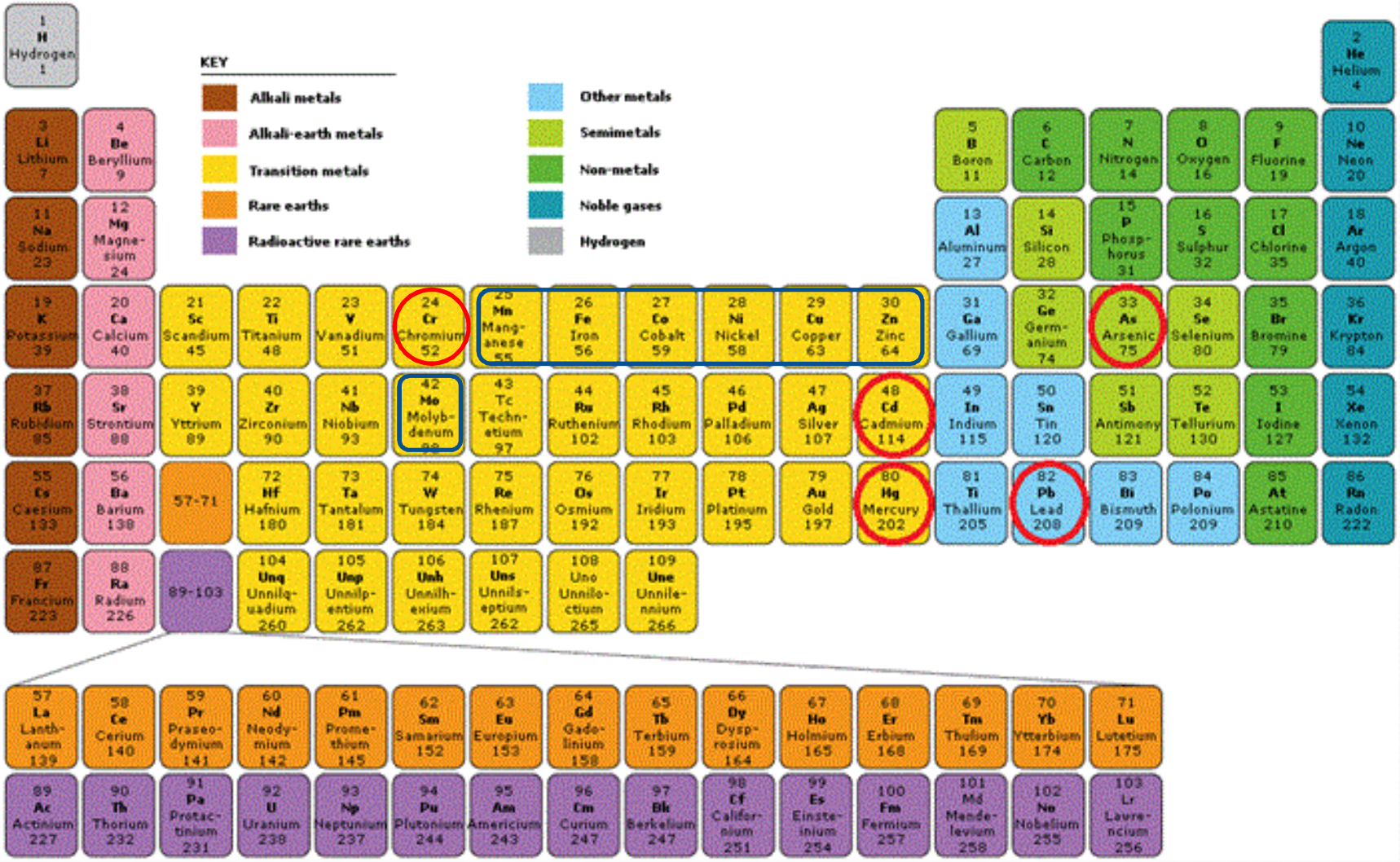


Toxic Metals/ Metalloids

Heavy metals

- A metal having an atomic weight greater than sodium, a density greater than 5 g/cm^3
- 'Metalloids' are elements with features intermediate between metals and non-metals. Example: arsenic.
- Heavy metals are usually associated with toxicity in plants (but some micronutrients produce toxicity symptoms as well) and animals including humans.

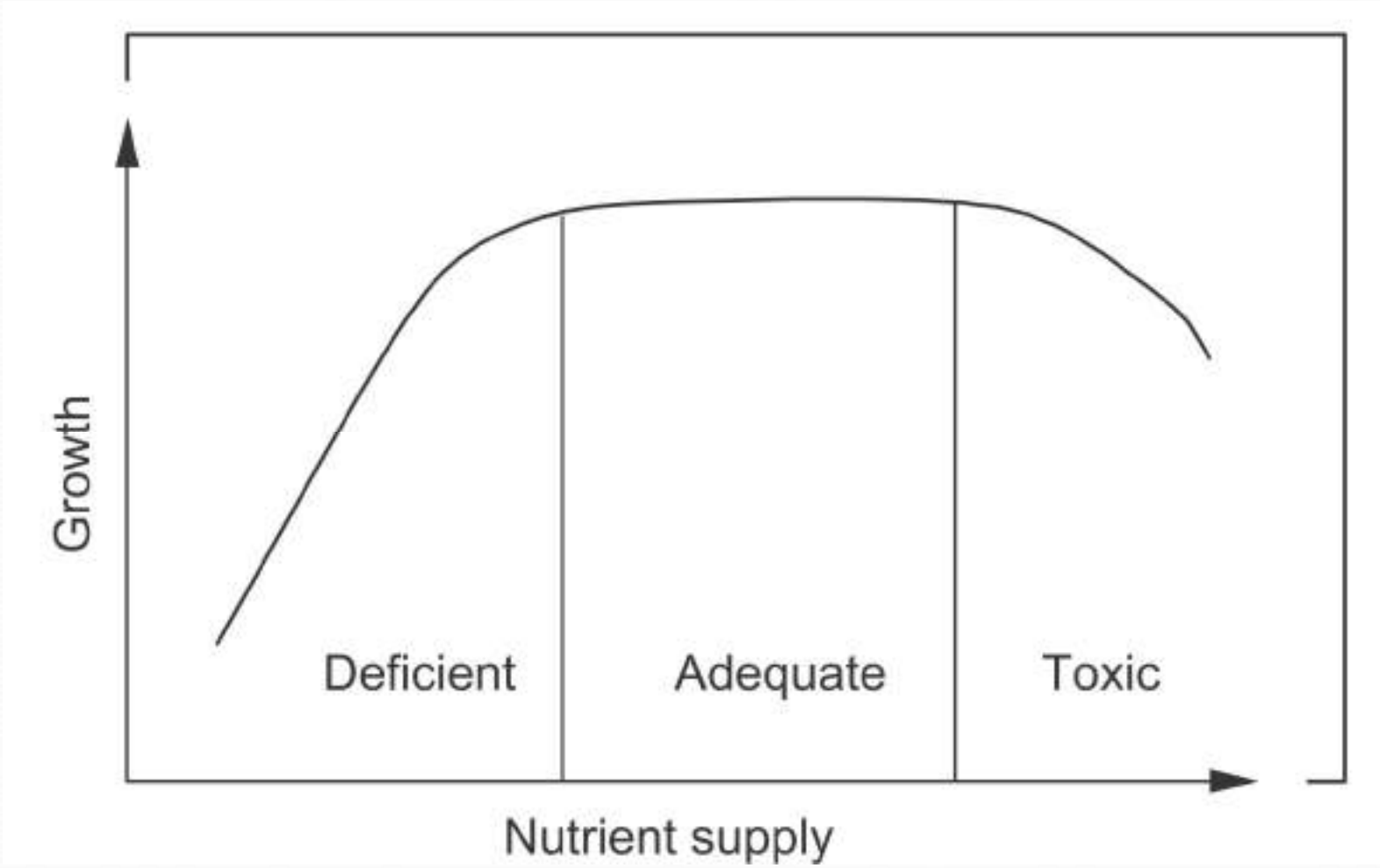
Periodic table



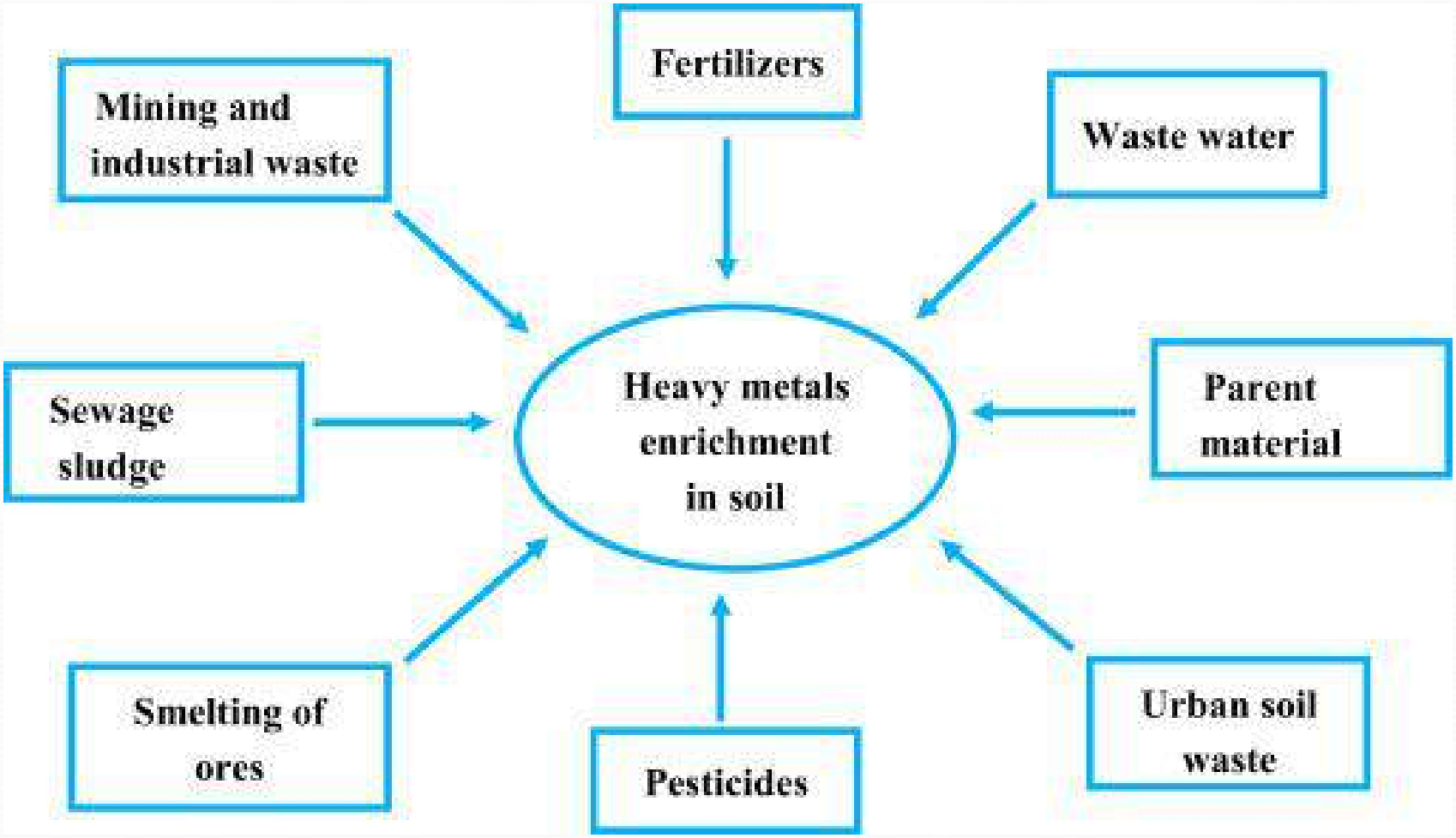
Heavy metals (HM)

- HM are natural components of the Earth's crust.
- HM cannot be degraded or destroyed.
- To a small extent they enter our bodies via food, drinking water and air.
- As trace elements, some heavy metals (e.g. copper, selenium, zinc) are essential to maintain the metabolism of the human body.
- However, at higher concentrations they can lead to poisoning.
- Heavy metal poisoning could result from :
  - drinking-water contamination (e.g. lead pipes),
  - high ambient air concentrations near emission sources, or
  - intake via the food chain

Relationship between nutrient supply and growth



Sources of heavy metal pollution



Sources of heavy metal

Arsenic (As)	• Pesticides, fungicides, metal smelters
Cadmium (Cd)	• Welding, electroplating, pesticides, fertilizer, batteries, nuclear fission plant
Chromium (Cr)	• Mining, electroplating, textile, tannery industries
Copper (Cu)	• Electroplating, pesticides, mining
Lead (Pb)	• Paint, pesticides, batteries, automobile emission, mining, burning of coal
Manganese (Mn)	• Welding, fuel addition, ferromanganese production
Mercury (Hg)	• Pesticides, batteries, paper industries
Nickel (Ni)	• Electroplating, zinc base casting, battery industries
Zinc (Zn)	• Refineries, brass manufacture, metal plating, immersion of painted idols

Concentration of metals

Metal	Surface Water (mg/L)	Soil (mg/kg)	Plants (mg/kg)
As	o.o5	1-50	
Cd	0.02	0.01-0.7	0.02
Cr	0.05	1-1000	1.30
Pb	0.10	2-200	2
Hg	0.002	0.01-0.3	-
Ni	-	5-500	10
Cu	1.0	2-100	10
Fe	0.3	7000-55000	250
Zn	5.0	10-300	0.60

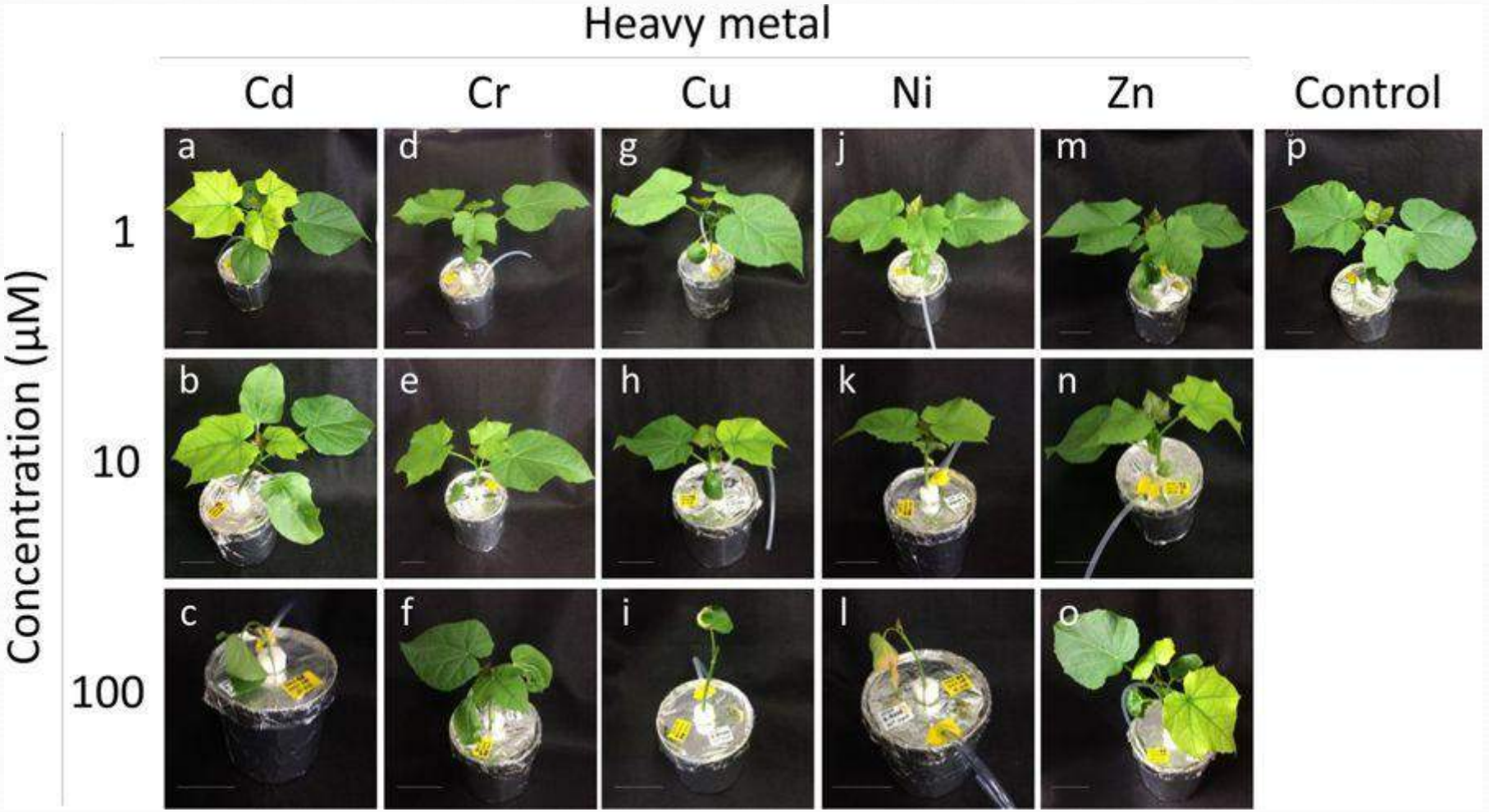
Effects of heavy metals in plants

- Reduced growth.
- Chlorosis (Loss of chloroplastic pigments) and scorching of leaves.
- Loss of turgor of tissue.
- Closure of stomata.
- Reduced rate of photosynthesis.
- Necrosis.
- Induction of programmed cell death
- Enhanced rate of senescence.
- Death of plants.

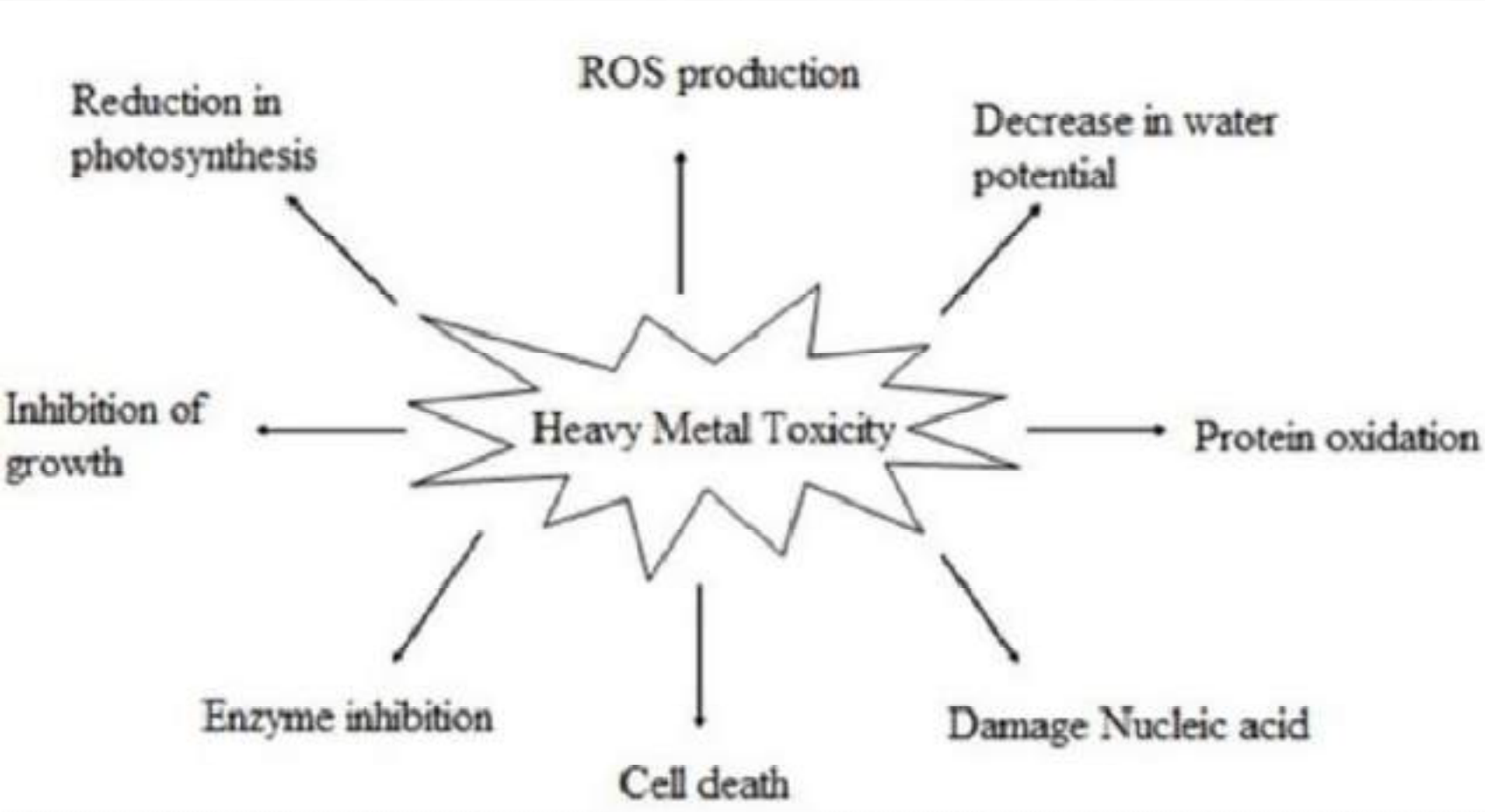
Effect of toxic metals: Plant

Metal(loid) species	Phytotoxicity symptoms	Reference
Cd	Chlorosis, necrosis, growth inhibition and browning of root tips	Wan et al., 2012
Pb	Reduction of root elongation and biomass production and inhibition of photosynthesis, chlorophyll biosynthesis and enzymes activities	Orcutt et al., 2000
Cr	Inhibition of seed germination and root elongation, foliar chlorosis, wilting and plant death	Vernay et al., 2007
Al	Inhibition of root prolongation and nutrients uptake, reduction in biomass, leaf chlorosis, yellowing and drying of leaf tips and reddening of leaf vein	Santos et al., 2014
Zn	Inhibition of plant growth and senescence and chlorosis of leaves	Garder-Torresdey et al., 2014
Ni	Chlorosis, growth reduction and alternations of photosynthetic and enzymatic activities	Pavlíková et al., 2014
Hg	Decrease of photosynthetic activity, antioxidant enzymes and water uptake and interference of mitochondrial activity	Sridhar et al., 2007a, b, Han et al., 2004b
As	Inhibition of seed germination, plant growth, decreases of plant yield	Rahman et al., 2007
Cu	Chlorosis, growth stunting as well as browning of leaves	Farooqui et al., 1995

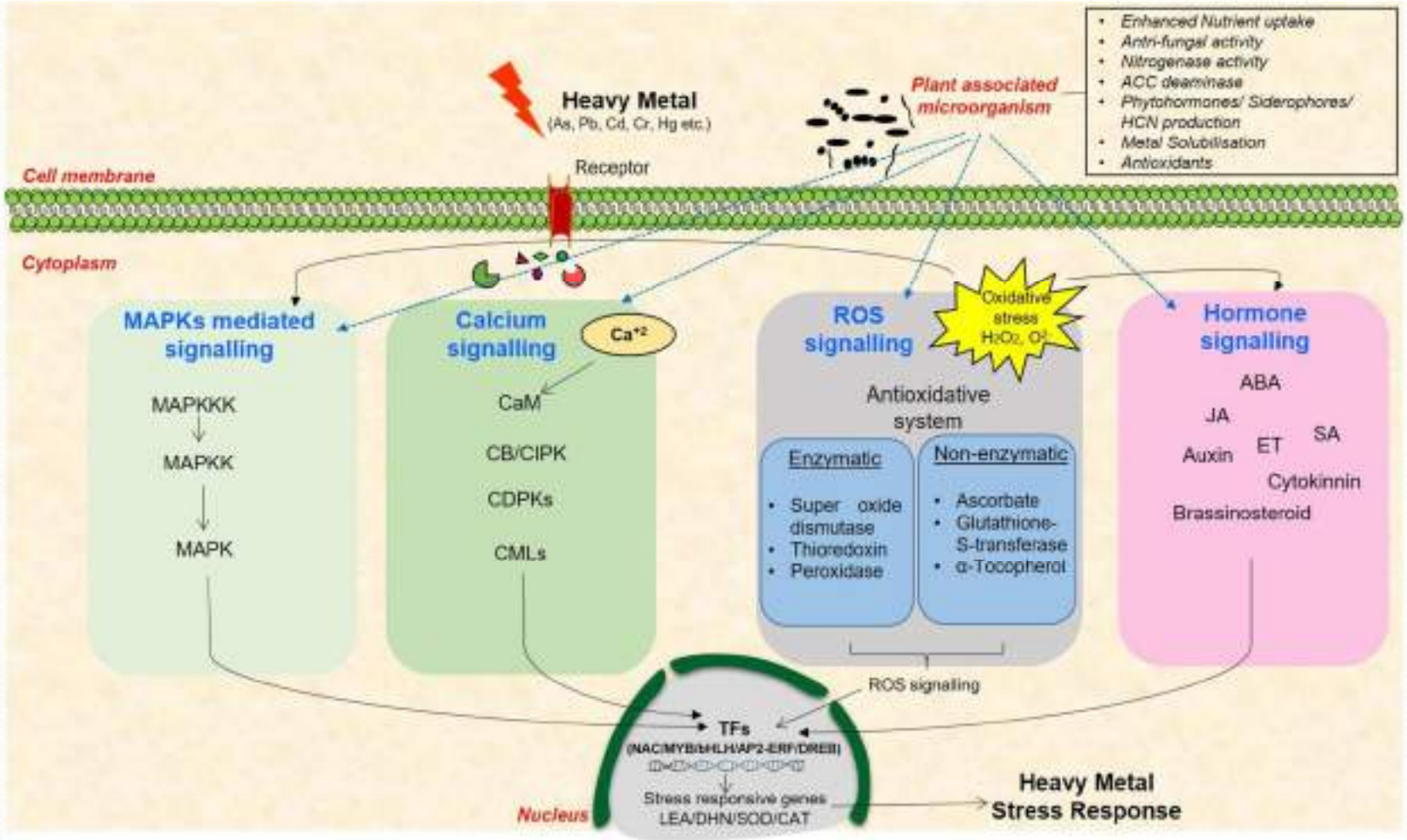
Symptoms of heavy metals in *Jatropha*



Consequences of heavy metal toxicity



Signalling under heavy metal stress



Effect of heavy metals: Humans

Pollutants	Major sources	Effect on human health	Permissible level (mg/l)
Arsenic	Pesticides, fungicides, metal smelters	Bronchitis, dermatitis, poisoning	0.02
Cadmium	Welding, electroplating, pesticide fertilizer, Cd and Ni batteries, nuclear fission plant	Renal dysfunction, Lung disease, Lung cancer, Bone defects (Osteomalacia, Osteoporosis), increased blood pressure , kidney damage, bronchitis, gastrointestinal disorder, bone marrow, cancer	0.06
Lead	Paint, pesticide, smoking, automobile emission, mining, burning of coal	Mental retardation in children, developmental delay, fatal infant encephalopathy, congenital paralysis, sensor neural deafness and, acute or chronic damage to the nervous system, epilepticus, liver, kidney, gastrointestinal damage	0.1
Manganese	Welding, fuel addition, ferromanganese production	Inhalation or contact causes damage to central nervous system	0.26
Mercury	Pesticides, batteries, paper industry	Tremors, gingivitis, minor psychological changes, acrodynia characterized by pink hands and feet, spontaneous abortion, damage to nervous system, protoplasm Poisoning	0.01
Zinc	Refineries, brass manufacture, metal Plating, plumbing	Zinc fumes have corrosive effect on skin, cause damage to nervous membrane	15
Chromium	Mines, mineral sources	Damage to the nervous system, fatigue, irritability	0.05
Copper	Mining, pesticide production, chemical industry, metal piping	Anemia, liver and kidney damage, stomach and intestinal irritation	0.1

THE BIGGEST DISASTERS WITH HEAVY METALS

1932-1952 Minamata

Sewage containing mercury is released by Chisso's chemicals works into Minimata Bay in Japan.

The mercury accumulates in sea creatures, leading eventually to mercury poisoning in the population.

In 1952, the first incidents of mercury poisoning appear in the population of MinimataBay in Japan, caused by consumption of fish polluted with mercury, bringing nearly 1000 fatalities.

Minamata

Mercury - Hg

- Mercury is the only common metal which is liquid at ordinary temperatures.
- It alloys easily with many metals, such as gold, silver, and tin - these alloys are called amalgams.
- Its ease in amalgamating with gold is used in the recovery of gold from its ores.

Health effects of mercury

- Disruption of the nervous system
- Damage to brain functions
- DNA damage and chromosomal damage
- Allergic reactions, resulting in
  - skin rashes,
  - tiredness and
  - headaches
- Negative reproductive effects, such as:
  - sperm damage,
  - birth defects and
  - miscarriages

Cadmium – Cd

- Human uptake of cadmium takes place mainly through food.
- Foodstuffs that are rich in cadmium can increase the cadmium concentration in human bodies (liver, mushrooms, shellfish, mussels, cocoa powder and dried seaweed)
- It cause Itai-Itai disease (term "itai-itai disease" was coined by locals for the severe pains in the spine and joints.

HEALTH EFFECTS

- Diarrhoea, stomach pains and severe vomiting
- Reproductive failure and possibly even infertility
- Damage to the central nervous system
- Psychological disorders
- Cancer development

Itai-Itai disease

Environmental effects of cadmium

- Cadmium can be transported over great distances when it is absorbed by sludge.
- This cadmium-rich sludge can pollute surface waters as well as soils.
- When cadmium is present in soils it can be extremely dangerous, as the uptake through food will increase.
- This is a potential danger to the animals that are dependent upon the plants for survival – Cadmium can accumulate in their bodies, especially when they eat multiple plants

Environmental effects of cadmium

- Cadmium can bioaccumulate in mussels, oysters, shrimps, lobsters and fish
- Salt-water organisms are known to be more resistant to cadmium poisoning than freshwater organisms

Chromium - Cr

- Chromium(III) is an essential element for organisms. Too low dose of Cr can disrupt sugar metabolism.
- Chromium(VI) is can alter genetic materials and cause cancer
- Chromium(VI) is a danger for people who work in the steel and textile and leather industry
- People who smoke tobacco also have a higher risk Cr toxicity
- Hexavalent Cr (VI) species is forbidden to use.

HEALTH EFFECTS

- When it is a compound in leather products, it can cause allergic reactions, such as skin rash
- After breathing it in, chromium(VI) can cause nose irritations and nosebleeds
- Upset stomachs and ulcers
- Respiratory problems
- Weakened immune system
- Kidney and liver damage
- Alteration of genetic material
- Lung cancer
- Death

Environmental effects of chromium

- Chromium in soils strongly attaches to soil particles and as a result it will not move towards groundwater.
- In water Cr may absorbed on sediment and become immobile.
- Only a small part of the Cr dissolved in water can cause Cr toxicity in aqatic organisms.

Lead Pb

- Foods such as fruit, vegetables, meats, grains, seafood, soft drinks and wine may contain significant amounts of lead
- Cigarette smoke also contains small amounts of lead.

Sources

- application of lead in gasoline
- fuel combustion
- industrial processes
- solid waste combustion

Health effects of lead

- Disruption of the biosynthesis of haemoglobin and anemia.
- A rise in blood pressure.
- Kidney damage.
- Disruption of nervous systems.
- Declined fertility of men.
- Diminished learning abilities of children
- Behavioural disruptions of children su as:
  - aggression,
  - impulsive behaviour
  - hyperactivity
- It can cause serious damage to the nervous system and affect the brains of unborn children.

Arsenic

- Arsenic is a metalloid element.
- Arsenic is a well-established human carcinogen,
- It severely affects plant growth and development
- As III and As V significantly inhibited seed rice seedlings' germination and growth.
- Its toxicity is very dependent on:
  - the concentration,
  - exposure time, and
  - physiological state of plants

- Sources
  - Groundwater
  - Arsenic containing mineral ores
  - Industrial processes : Semiconductor manufacturing (gallium arsenide), Fossil fuels,
  - Smelting (copper, zinc, lead), Glass manufacturing
  - Wood preservatives, Pesticides, Herbicides, Fungicides

Health effects

- Arsenic in drinking water can cause:
  - Cancer in the skin, lungs, bladder and kidney.
  - Thickening and pigmentation in skins.
  - Ingestion of Arsenic can lead to:
    - severe vomiting,
    - High BP and disturbances of the blood circulation,
  - heart attacks
  - damage to the nervous system
  - enlarged liver,
  - tingling and loss of sensation in the limbs
  - blackfoot disease (the blood vessels in the lower limbs are severely damaged and gangrene may develop)

Management/Remediation

Treatment/prevention of heavy metal poisoning

Treatment

- Chelating agents which bind to the metal and are then excreted in your urine
- Suctioning of the stomach to remove some ingested metals
- Use of diuretic
- Hemodialysis if kidney failure occurs

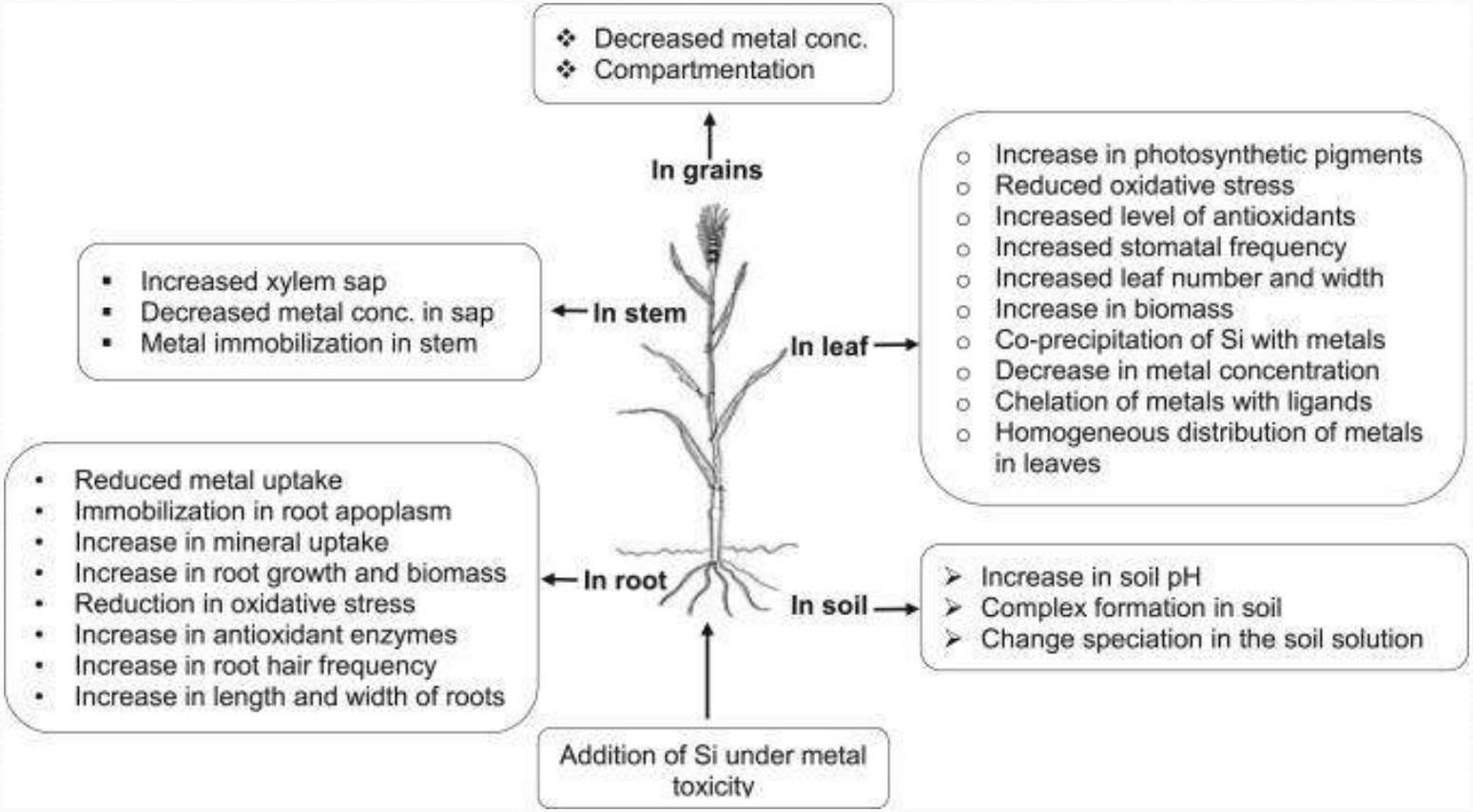
Prevention

- Wear masks and protective clothing if you work around heavy metals
- Since many metals accumulate in dust and dirt, keep these out of your home as much as possible
- Be aware of potential sources of metal exposure
- Check for any heavy metals listed on the labels of products you bring into your home

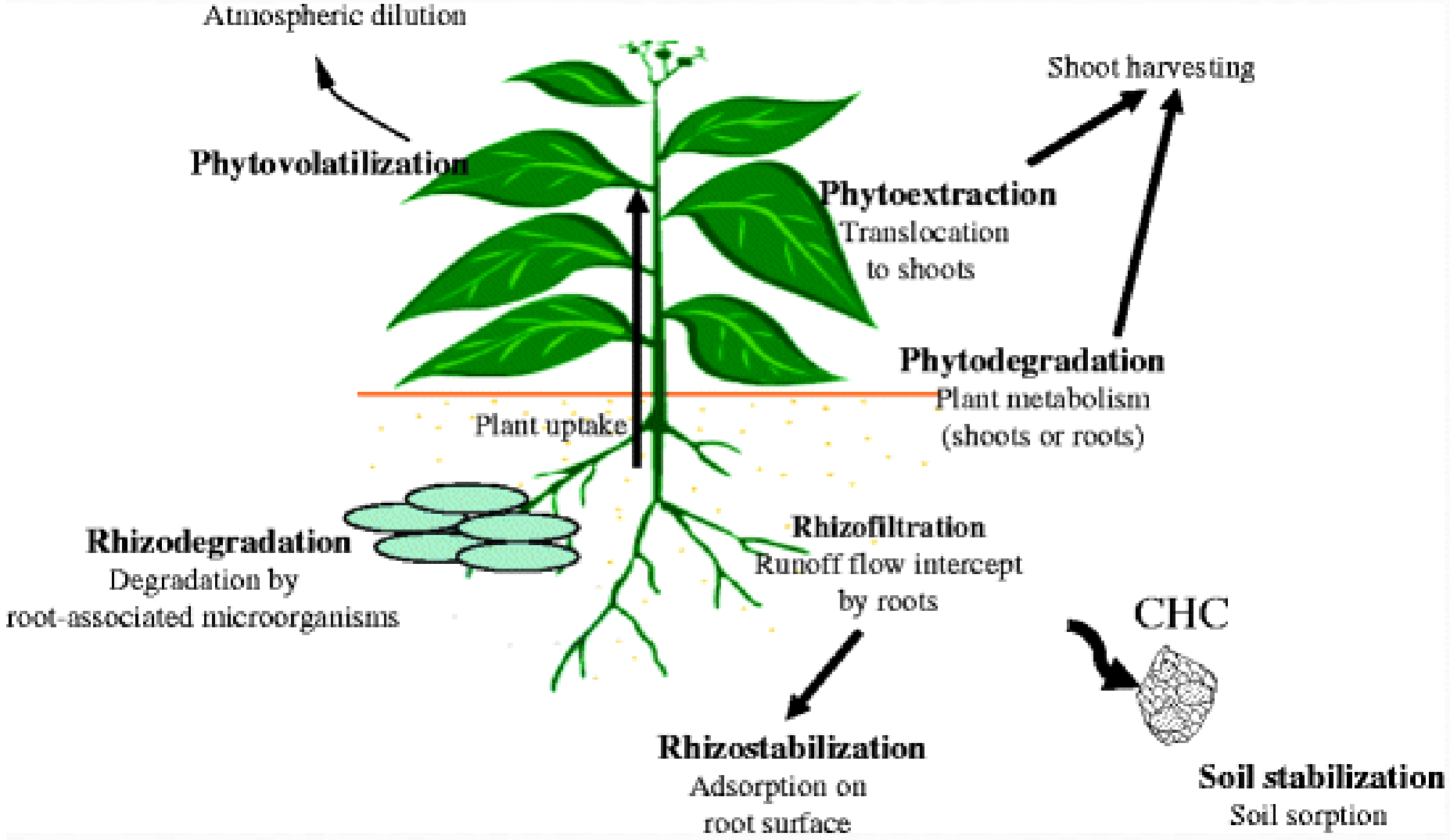
Remediation

- Soils contaminated by heavy metals can be remediated by one or more of the following technologies:
  - Isolation: involves the use of caps, membranes or below-ground barriers in an attempt to quarantine the contaminated soil.
  - immobilization: aims to alter the properties of the soil so as to hinder the mobility of the heavy contaminants.
  - toxicity reduction: attempts to oxidise or reduce the toxic heavy metal ions, via chemical or biological means into less toxic or mobile forms.
  - physical separation; involves the removal of the contaminated soil and the separation of the metal contaminants by mechanical means.
  - extraction: is an on or off-site process that uses chemicals, high-temperature volatization, or electrolysis to extract contaminants from soils.

Si-mediated tolerance

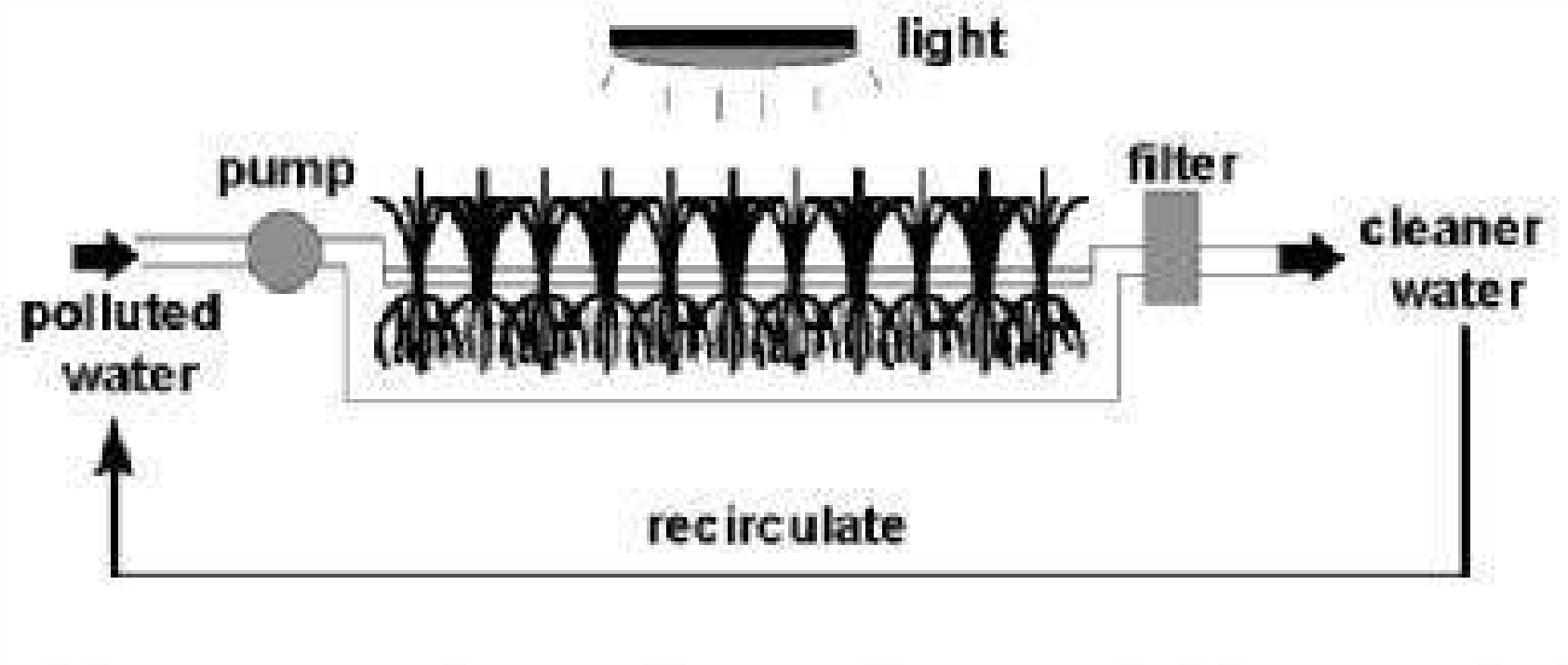


Phytoremediation

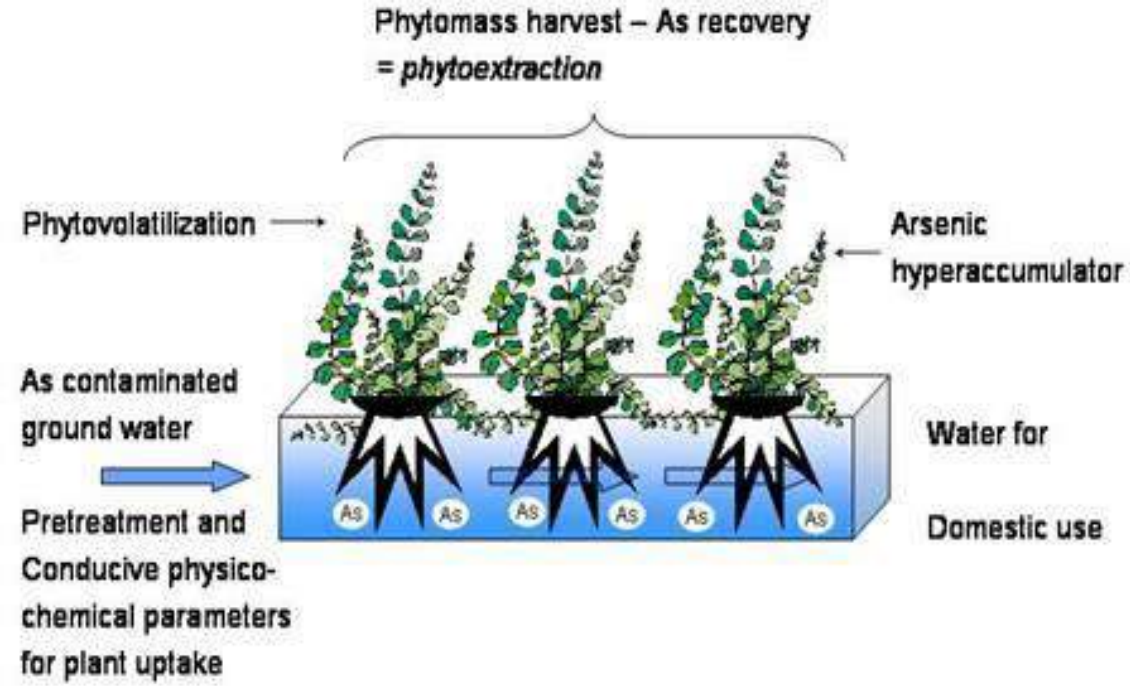


Rhizofilteration

1. Rhizofiltration is processes in which both terrestrial and aquatic plants are utilise to absorb, concentrate and precipitate contaminant from polluted aqueous sources in their roots.
2. Rhizofiltration approach is mainly used to remediate extracted ground water and waste water containing low concentration of contaminants.
3. This technique can be used for Pb, Cd, Cu, Zn and Cr, which are primarily retained within the roots.



Phytoextraction



- This approach is primarily used for the treatment of contaminated soils.
- This process uses plants to absorb, concentrate, and precipitate toxic metal from contaminated soil and loaded into shoots, leaves etc.
- Hyper accumulator plants are used for this purpose.
- (a) Plants must exhibit tolerant to high levels and the metal
- (b) Accumulate high levels of the metal in its harvestable parts,
- (c) Exhibit rapid growth and
- (d) Potential to produce a high biomass in the field.

Waste water forestry

Plant *Eucalyptus* trees all along sewage ponds (waste water forestry). These trees absorb wastewater rapidly and pollutants and release pure water vapor into the atmosphere and accumulate pollutants in their woods.

Metal accumulators

Allysum argentums (Copper)

Haumaniastrum homblei (Cobalt)

Festuca-rubra (Lead, Zinc)

Eichhornia crassipes (Zinc, Copper, Lead, Nickel)

Accumulators

Brassica juncea (Chromium 6+, Cadmium, Nickel, Zinc, Copper)

Populus (Cadmium, Nickel, Zinc)

Thlaspi-alpestre (Zinc)

Willow (Cadmium, Zinc,

Phytovolatization

- Phytovolatization is primarily uses the plants to take up contaminants like mercury and selenium from the soil.
- It convert them into volatile forms and finally release them into the atmosphere through transpiration as detoxified vapour.
- However, metal recycle back to the soil.

Phytostabilization

- Phytostabilization, also known as place-inactivation.
- Phytostabilization process involves plant root to prevent movement of contaminants and helps in bioavailability in soils.
- The utility of plants is to decrease percolation of water through the soil matrix, which may otherwise from hazardous leech out.

GMO in Bioremediation

Poplar trees remove groundwater contaminants

Scientists are engineering poplar trees and other plants that can clean up contamination sites by absorbing groundwater pollutants.