

*A major project report on*

STUDY ON PHYTOREMEDIATION POTENTIAL FOR REMOVAL OF  
TOXIC ELEMENTS

*submitted in the fulfilment of the requirement for the award of*

Degree of Master of Technology

(Environmental Engineering)

*By*

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2021

# *Certificate*

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# *Declaration*

*This is to declare that the report entitled "STUDY ON PHYTOREMEDIATION POTENTIAL FOR REMOVAL OF TOXIC ELEMENTS" has been submitted by me in the academic year 2021.*

*The work embodied in this report has not been submitted for the award of any other degree to the best of my knowledge.*

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*I earnestly express my deep sense of gratitude and implore God to continue showering His blessings on us.*

*Diya Pali*

# *Abstract*

There are numerous pollutants that pose threat to the environment on an unprecedented scale. It creates undesirable effects on water, soil, and air as well. It is furthermore an essential concern as the concentration of such elements goes on accumulating in the environment. Remediation of such pollutants by absorption and accumulation in plant or animal tissues is one of the most effective natural methods of waste treatment. The use of live plants for the removal of environmental pollutants is termed phytoremediation. Phytoremediation bears down to the capacity of plants to absorb, accumulate and store various elements from water and soil into their biomass. The physiology of plants plays a vital role in phytoremediation as not all plants can hyper accumulate contaminants. Remediation of contaminants includes several mechanisms involved for uptake of metals from polluted soils or waters for treatment and render them non-toxic. Along with phytoremediation, this project also studies the properties and health impact of various toxic elements in the environment that threaten human and animal health.

The project evaluates phytoremediation through an experimental study and a case study. Experimental study was accomplished by using kitchen wastewater generated from post-cooking washing of utensils as feed to plants for phytoremediation. It included testing of water quality parameters such as pH, electrical conductivity, total dissolved solids, biochemical oxygen demand, chemical oxygen demand total phosphate for water at the inlet and excess draining water from the outlet of the pot. The case study involved study on phytoremediation potential of twelve wild plant species for removal of toxic elements and assesses their

phytoremediation potential for removing toxic elements such as arsenic, cadmium, chromium, copper, nickel, lead, and zinc from contaminated soil. Plants remove elements by absorbing and binding various elements organically in their biomass. Hence, the phytoremediation potential of different species of plants shall be assessed for absorbing different elements.

The experimental study rather being of a short duration concludes that there is good scope for plants to absorb organic materials and stabilise kitchen wastewater. The case study reveals that, during the first year of growth, all the species of plants have absorbed and stored toxic elements in their biomass, especially in their shoot, leaves, and flowers. Still, a minimal amount was found to accumulate in the roots. Also, due to the photosynthetic activity, leaves contain the most concentration of the absorbed element. On the contrary, after the second year of growth, it is evident that roots are actively involved in storing toxic elements in them. The maximum concentration of toxic elements is found in roots. In contrast, the concentration of toxic elements does not seem to increase significantly in other parts of the plant.

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# *Introduction*

## 1.1 BACKGROUND

Studies in toxic elements are increasingly becoming important due to their toxicity level and impact on the environment. Most of the impact on the environment is due to the population rise globally. The emission of organic and inorganic substances such as minerals, oils, salts, acids and bases, pesticides, and toxic elements has held the environment's health hostage. The accrual of these pollutants in various segments of the environment creates a hazard. The threat becomes manifold as these pollutants degrade at a languid pace—toxic elements such as pollutants are pretty prevalent in the environment. Toxic element accumulation becomes a massive threat as they are non-degradable, persistent, toxic, and causes widespread consequences to aquatic life. Natural hydrological systems such as rivers, ponds, lakes, etc., are flooded with flows of the toxic element from natural and anthropogenic sources. These metals persist in water in aqueous form or get deposited on sediments. Hence, they become a priority in ecology as the water body's self-purification process cannot remove toxic elements. As a result, toxic elements enter the food chain and food web and cause the bioaccumulation of metals (Loska and Wiechula 2003). World Health Organization (WHO) has carried out several studies to prove the significance of toxic element pollution and its effect on human health.

Metallic or metalloid elements with a relatively high-density range of 3.5 to 7 g/cm<sup>3</sup>, toxic at low levels, are termed heavy metals. Numerous elements exist that qualify this criterion, namely, copper (Cu), nickel (Ni), mercury (Hg), lead (Pb), zinc (Zn), arsenic (As), chromium (Cr), cadmium (Cd), thallium (Tl) (Duffus, 2002). Metals are an essential nutrient in the biota at low levels, while high levels may cause toxic effects. They enter the human body through modes of air, water, and food. As informed earlier, toxic elements originate from both natural

and anthropogenic sources. Perceptibly, anthropogenic sources release far more toxic elements than natural sources.

hydrogen 1 H 1.0079																	helium 2 He 4.0026			
lithium 3 Li 6.941	beryllium 4 Be 9.0122											boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180			
sodium 11 Na 22.990	magnesium 12 Mg 24.305											aluminum 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948			
potassium 19 K 39.098	calcium 20 Ca 40.078	scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.64	arsenic 33 As 74.922	selecnium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.798			
rubidium 37 Rb 85.468	strontium 38 Sr 87.62	yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.75	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29			
caesium 55 Cs 132.91	barium 56 Ba 137.33											thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]			
francium 87 Fr [223]	radium 88 Ra [226]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [277]	meitnerium 109 Mt [268]	darmstadtium 110 Ds [271]	roentgenium 111 Rg [272]											
lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.05	lutetium 71 Lu 174.97						
actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]	lawrencium 103 Lr [262]						

Figure 1-1 Periodic table with toxic elements (shaded)

Metals such as sodium (Na), potassium (K), magnesium (Mg), and calcium (Ca) are major metallic nutrients whereas, vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), and molybdenum (Mo) are minor metallic nutrients. Some non-nutrient metals such as arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), antimony (Sb) are highly toxic. These metals are found widely in the earth's crust and are non-biodegradable. Health concern surges due to surplus of these metals in the environment and due to metals present at various oxidation states. Water quality standards in various countries also prescribe limits for the presence of all the metals toxic to human health (Weiner, E.R. 2013).

## 1.2 SOURCES OF TOXIC ELEMENTS IN ENVIRONMENT

Industrial and metallurgical activities comprise mining, plating, surface finishing, and milling discharge numerous toxic elements in the environment. The concentration of such metals has increased in the waters and sediments of rivers, lakes, and ponds. Soils polluted from toxic elements also pose a hazard due to their subsequent entry into food grains and vegetables.

Hence, a real potent threat exists because of toxicity, non-biodegradability, and biomagnification of such metals (Bahadir et al., 2007; Perez-Marín et al., 2008; Reddad et al., 2003).

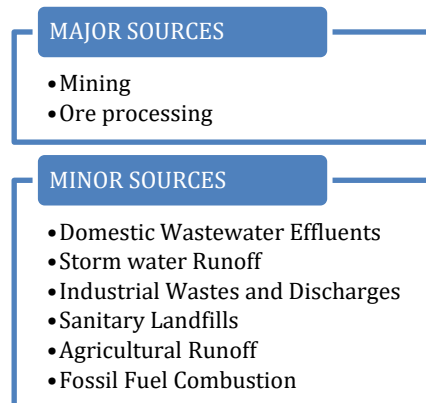


Figure 1-2 Major and minor sources of toxic elements

### 1.2.1 METAL POLLUTION FROM MINING AND PROCESSING ORES

Metallurgical operations such as excavation, extraction, and processing of metallic ores causes detrimental impact over the environment, including habitat loss, loss of cultivable land, and property. It corresponds to pollution of air, water, and soil through the emission of metallic dust and fumes, acid mine drainage. Cadmium (Cd), lead (Pb), selenium (Se), arsenic (As), and their oxides are grave concerns for air pollution. Surface and opencast mining generate multiple times more wastes as compared to underground mining. Deep mining operations may also cause caving of land earthquakes. Annually, a considerable number of casualties occur due to subsidence and caving in of mines. They also cause deep holes on land surface causing roads and buildings to fall into it. The issue aggravates as demand for mined minerals are increasing days by days, hence mines need to go further deeper into the crust to extract as much material as possible. Interaction of moisture, atmospheric gases and sulphur compounds causes formation of acid mine drainage. It is a strong acidic drainage that may increase dissolution of metals and cause further toxic elements issues when precipitation occurs. Both active and abandoned mines release such discharges which are historically associated to groundwater pollution issues. Severity of such emission is unimaginable as subsurface flows cannot be seen or observed directly. Metals such as copper (Cu), nickel (Ni), cobalt (Co), iron (Fe), zinc (Zn) and manganese (Mn) cause severe water quality issues. Moreover, metals such

as arsenic, lead, and silver also discharges into drainage basins and enter the aquatic ecosystems.



*Figure 1-3 Open Cast Mining*

### 1.2.2 OTHER SOURCES OF METAL POLLUTION

*Domestic Wastewater Effluents* - Domestic discharges emit a large amount of trace metals through corrosion of metallic pipes and containers made up of iron, copper, zinc and lead, cadmium from joinery. Numerous household products exist that contain heavy metal such as detergents which releases boron (B), zinc (Zn), copper (Cu), chromium (Cr), manganese (Mn), iron (Fe) and arsenic (As) in large quantities. Treatment at a wastewater treatment plant typically reduces only 50% of metallic concentrations from water leaving behind a huge metallic residue in the effluent stream. Moreover, sludges from such treatment have copious amounts of metals. Hence, discharges of domestic and industrial wastewaters and sludges are major anthropogenic sources of toxic elements. *Storm water Runoff* - Since stormwater runoff is acidic nature, it dissolves metals from the rocks and metallic surfaces it comes in contact with. Urban landscape consists of a lot of such features. A lot of toxic elements are released from features such as roads, construction, traffic and factors such as town planning, traffic, land-use pattern, climatic regimes affect the presence of metals in urban areas. *Industrial Wastes and Discharges* - Industrial clusters, in general, has far more concentration of metals than that prescribed in permissible limits. Metals in effluents, fumes, and solid are found in plenty here. Hence, an imminent need exists to treat metallic discharges before its discharge in water bodies. Concentration of metallic discharge varies from industry to industry due to the raw material, processes used and products and by-products being produced. *Sanitary Landfills* - Solid waste

disposal at landfills causes leaching of a huge volume of pollutants in ground water. Engineered landfills have significantly reduced the release of such metals in the environment. Yet, leachates at sanitary-landfills are observed to contain around 5 ppm copper, 50 ppm zinc, 0.3 ppm lead and around 60 ppm mercury. *Agricultural Runoff* - Together with fertilizers a variety of agricultural chemicals such as pesticides, insecticides, herbicides, fungicides, weedicides, and sewage farming effluent increase concentration of metals in agricultural areas. These metals later get dissolved in precipitation and flow along with stormwater discharge. *Fossil Fuel Burning* - Combustion of fossil fuel in vehicular and industrial consumption releases a huge amount of airborne metal contamination.

Table 1-1 Major sources of toxic elements in environment

Sr. No.	Element	Sources
1.	<i>Arsenic (As)</i>	chemical wastes, mining and metal smelting, pesticides, fungicides, herbicides.
2.	<i>Cadmium (Cd)</i>	Cd–Ni batteries, nuclear (fission) plants, lead, zinc and copper refining, welding, electroplating, manufacture of fertilizer, pesticide.
3.	<i>Chromium (Cr)</i>	cement and asbestos manufacture, metallurgical operation and chemical manufacturers, industries using chromate compounds.
4.	<i>Copper (Cu)</i>	timber burning, acid mine discharge, smelting operations, fertilizer manufacture, fly ash utilization, municipal and industrial waste disposal also release airborne copper.
5.	<i>Iron (Fe)</i>	manufacture of wrought and cast iron, steel and steel alloys, machining works, construction operations, and transport and logistics.
6.	<i>Lead (Pb)</i>	lead based pesticides, mining and smelting operations, coal combustion, emission from coal combustion, petroleum and oil burning, automobile,
7.	<i>Mercury (Hg)</i>	extraction, refinery, mining of mercury, pesticides, medical and engineering instruments.
8.	<i>Nickel (Ni)</i>	coal and oil combustion, plating using Ni salts, metallurgical use of nickel as catalyst, Ni batteries
9.	<i>Zinc (Zn)</i>	galvanizing units, brass, plating, refineries, plumbing

### 1.3 EFFECT OF TOXIC ELEMENTS ON ENVIRONMENT

Toxic elements pollute the environment on an unprecedented scale. It creates undesirable effects on water, soil and air as well. It is furthermore an important concern as concentration of toxic elements goes on accumulating in the environment. Most of the heavy metals are toxic and produce its effects on a variety of plants and animals. Metallic elements having density more than 5 gm/cc are generally considered as toxic element. Yet multiple definitions of heavy metals are found in many literatures. International Union of Pure and Applied Chemistry (IUPAC) states that the term heavy metal is a misnomer and commonly mislead and cause

confusion. In general, heavy metals are found in earth's crust and are mostly essential to life forms to maintain their health. Many elements such as iron, copper, zinc and selenium are trace metals essential to human body. Although, they may create undesirable effects if found in excess magnitude. Many other elements such as cadmium, lead, and mercury cause serious direct negative impact to metabolism of living organisms even at low concentrations. Metals are normally persistent in nature and exist in various forms and mostly enters food chain and ecology of a location. Numerous anthropogenic activities cause these metals to enter the environment namely, mining, extraction, smelting, etc., as listed above. Mostly, toxic element processing industries release a lot of heavy metal such as copper, cadmium, lead, nickel, zinc and chromium. Tissues of living organism readily absorb heavy metals as they are easily soluble in water. Hence, natural water environment is highly susceptible to its toxic effects. The degree of toxicity is increases due to uncontrolled dispersion and diffusion of toxic elements in surface and ground water. Presence of toxic elements in trace quantities or below detectable limits also prove to be a threat due to its resistance to degradation and persistence in natural conditions. Its concentration increases manifold as metals tend to bioaccumulate in the biotic life. Its concentration may increase to such a level to show visible effects of toxic element pollution. Silver (Ag), arsenic (As), gold (Au), bismuth (Bi), cadmium (Cd), cerium (Ce), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), gallium (Ga), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), platinum (Pt), antimony (Sb), tin (Sn), tellurium (Te), thallium (Tl), uranium (Ur), vanadium (Va) and zinc (Zn) are the metals defined as toxic elements of all the toxic metals found. Out of the above toxic elements most damage is caused by Pb, Cd, Hg and As. Excess quantities of these causes acute toxicity whereas long-term exposure may cause chronic toxicity. It may lead to mental and CNS disorders, blood and circulation system disorders, lung damage, kidney and liver malfunction.

Neurological degenerative diseases such as Alzheimer's and Parkinson's diseases, muscular atrophy and dystrophy and sclerosis are the result of long -term exposure to toxic elements. Exposure to heavy metals may also cause allergies and repeated exposure to some may lead to cancer. Heavy metals may enter human body through egestion of water, food, air polluted with toxic elements and even absorption through skin. Industrial and manufacturing operations release a large quantity of toxic elements. Some of such units are very close to residential settlement. Instead of the severe nature of threat from toxic elements, the quantity



of toxic elements goes on increasing, globally. Hence, treatment and disposal of metallic wastes and reduce the toxicological effects of toxic element is very important.

#### 1.4 WATER QUALITY STANDARDS

Water available on earth is limited so are its sources. Water resources are days by days being exposed to pollutants which further reduces the quantity of usable water. Pollutants and contaminants render the water unhealthy any type of consumption by plants and animals. Moreover, large quantity of salts and bases are present in water which causes soil pollution and threat to soil fertility. Apart from agriculture, this water cannot be used in industry as numerous expensive processes for its purification will be required. It disturbs the aquatic ecosystem by affecting turbidity, temperature, conductivity, and many other parameters in the fresh and marine water ecosystems. Hence, use of water for any type of consumption requires a minimum quality standard to ensure that concentration of pollutants is well below the permissible limits. This becomes necessary as water in use shall not pose any threat to the user and environment in general as well. To maintain such quality standard for different consumption types, water quality standards are formulated. These criteria can be made customised or specific according to the purpose. These measures are based on experimental and imperial data about health and environment and assessment of economics of treatment.

Table 1-2 *Drinking Water Standards for Trace & Toxic metals (BIS-10500-2012)*

Sr. No.	Toxic metal	Requirement (Acceptable Limit)		Permissible Limit in the Absence of Alternative Source	
		(mg/L)	(µg/L)	(mg/L)	(µg/L)
1.	Arsenic as As	0.01	10	0.05	50
2.	Cadmium as Cd	0.003	3	No relaxation	
3.	Total Chromium as Cr	0.05	50	No relaxation	
4.	Copper as Cu	0.05	50	1.5	1500
5.	Iron as Fe	0.3	300	No relaxation	
6.	Lead as Pb	0.01	10	No relaxation	
7.	Mercury as Hg	0.001	1	No relaxation	
8.	Nickel as Ni	0.02	20	No relaxation	
9.	Zinc as Zn	5	5000	15	15000

For potable consumption water should be well within standard as direct consumption by humans is in consideration. Domestic supply of water is considered as the most important use of water, also the National Water Policy places it under first priority to provide potable water. Bureau of Indian Standards (BIS) in consultation with many organisations such as Indian Council of Medical Research (ICMR) have formulated water quality standards. They are mostly in consonance with the international standards laid by World Health Organisation (WHO). Table 1-2 shows drinking water standards for trace and toxic metals according to BIS code 10500-2012.

### 1.5 OBJECTIVE

Since the effect of pollution caused by toxic elements is widespread. This project report tries to explore methods to treat heavy metal pollution in water. The objectives of the project are as below:

1. To study phytoremediation process for water pollution control and treatment of wastewater.
2. To study removal of heavy metals and biochemical oxygen demand from wastewater using phytoremediation.
3. To study phytoremediation potential for treatment of kitchen wastewater.

## *Literature Review*

Phytoremediation is a sub-domain of bioremediation where, *phyto* in Greek means 'plant'; and *remedy* comes from Latin, meaning 'restoring balance'. The phytoremediation methodology uses live green plants, having capability to remove hazardous contaminants from water, air and soil. This very safely contain the toxicity and reduce the contaminants in water. In simple words, phytoremediation is defined as removal of environmental pollutants using live plants. It is a very cost-effective plant-based approach to detoxify various compounds. Moreover, it preserves top soil and also maintain the fertility of soil. All types of pollutants in air, water and soil can be removed by phytoremediation. Naturally, toxic elements have lower degradability than organic pollutants. Hence, toxic elements shall be degraded using phytoremediation. In phytoremediation projects, pollutants such as pesticides, explosives, oil, metals and their derivatives have been alleviated. Pigweed, pennycress, mustard. Hemp and alpine, etc are proven high capacity bio-accumulator of pollutants in their biomass Physiology of plants also plays important role in phytoremediation as not all plants can hyperaccumulate contaminants. In the remediation of contaminants there are several mechanisms involved for uptake of metals in the plant biomass from polluted waters for their treatment and render them non-toxic. The different mechanisms involved in phytoremediation are shown in Figure 2-1.

### 2.1.1 PHYTO-EXTRACTION

Phytoextraction, also called as phyto-accumulation or phyto-sequestration, is the ability of plant to extract contaminant from water. It is basically the ability of the plant or algae for removal of pollutants in water. In this process substances from the soil or water are taken up by roots and are concentrated above the ground in the plant biomass. Plants like *Populus* and *Salix* can be used for Phytoextraction. The organisms that take up high number of contaminants are called Hyperaccumulators e.g., *Avena* sp. and *Brassica* sp. This process is

very popular around the world and is used for toxic element removal or other inorganics. A chelating agent conditions the soil to increase solubility of metals for easy plant uptake.

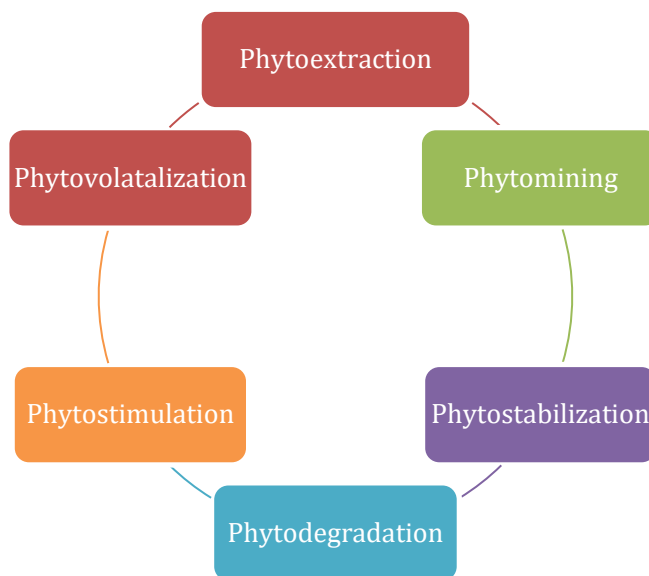


Figure 2-1 Mechanisms involved in phytoremediation

### 2.1.2 PHYTO-MINING

Recovery of metals can be conveniently done using phyto-mining. In this technique, metals are extracted or mined. A study by Hider and Kong, 2010 evaluates the efficiency of phytosiderophores, a high affinity iron-chelating compound, for removal of iron. It undertakes movement of metals throughout the cell membranes (Hider and Kong, 2010) in form of metal complexes in the root zone. After harvesting it is grown and the absorbed metal pollutants stored in the plant biomass are disposed of safely. This process can be repeated several times for the contaminants concentration reduction till it comes to acceptable levels. For example; Arsenic can be accumulated by sunflower (*Helianthus annuus*); Cadmium, Zinc and Copper by willow (*Salix Viminalis*), Alpine pennycress (*Thlaspi caerulescens*). Similarly, chromium is toxic to many plants but Tomato (*Solanum lycopersicum*) helps in its accumulation; lead can be mined using dogbane, mustard (*Brassica juncea*), , poplar, hemp, ragweed (*Ambrosia artemisiifolia*), or. Mercury and selenium can be accumulated by transgenic plants containing genes of bacterial enzymes.

### 2.1.3 PHYTO-STABILIZATION

The contaminants in phyto-stabilization in the soil and ground water are captured through adsorption and/or accumulation by plant roots. It may also be precipitated in the root zone to immobilize (Tangahu et al., 2011). The main focus is on the long-term containment and stabilization of pollutant by binding the pollutants to sediments hence making them less bio-absorptive. This results in reduced exposure and pollutants become less available. It helps in converting toxic element pollutant into less toxic form with the help of chemical reaction by a substance excreted from plants. Migration of metals are prevented through this process.

### 2.1.4 PHYTO-DEGRADATION

It is a process in which roots secrete enzyme that degrade the organic pollutants into soil or within the body of plant. It is also called as Phyto-transformation. With the help of transpiration these molecules are released by plants. The plant enzymes such as oxygenase and nitro-reductases catalyse and expedite the degradation process (Tangahu et al., 2011). Internal and external metabolic processes degrade the organic contaminants, in which Enzymatic process and oxidation during photosynthesis are involved. Plants absorbs the pollutants in the external process and hydrolyse them into simpler components, whereas internal metabolic process uses pollutants as metabolites. Figure 2-2 shows the processes of phytodegradation.

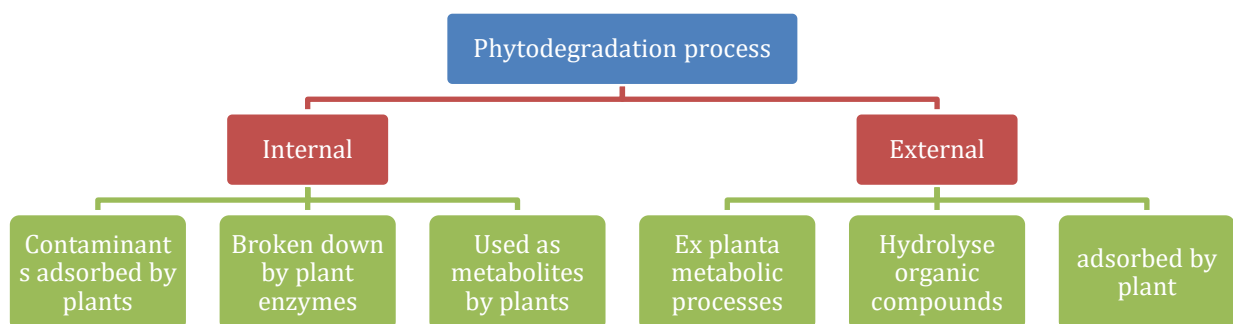


Figure 2-2 Phytodegradation process

## Methodology



The project is worked in two parts:

- i. *Case Study* - involving study on phytoremediation potential of twelve wild plant species for removal of toxic elements.
- ii. *Experimental Study* - by using kitchen wastewater generated from post-cooking washing of utensils as feed to plants for phytoremediation. It included testing of water quality parameters for water at inlet and excess drainage outlet of the pot.

### 3.1 CASE STUDY

The case study pertains to the research conducted by Antoniadis et al., 2021 assessing the phytoremediation potential of twelve wild plants species (as listed below) for removal of toxic elements in contaminated soil.

Table 3-1 *List of plants under consideration*

<i>Sr. No.</i>	<i>Species</i>	<i>Common Name</i>	<i>Image</i>
1.	<i>Alopecurus pratensis</i>	meadow foxtail	
2.	<i>Elytrigia repens</i>	quackgrass, couchgrass, wheatgrass, devilgrass	

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3. *Poa angustifolia* narrow-leaved meadow grass



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4. *Holcus lanatus* velvet grass, Yorkshire fog



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5. *Arrhenatherum elatius* false oat-grass



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6. *Bromus inermis* smooth brome



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7. *Artemisia vulgaris* mugwort, common wormwood



8.	<i>Urtica dioica</i>	common nettle, stinging nettle	
9.	<i>Achillea millefolium</i>	common yarrow, western yarrow, yarrow, milfoil	
10.	<i>Galium mollugo</i>	hedge bedstraw, false baby's breath	
11.	<i>Stellaria holostea</i>	addersmeat, greater, stitchwort	
12.	<i>Silene vulgaris</i>	bladder champion, cowbell, maiden's tears, rattleweed	

### 3.1.1 MATERIAL AND METHOD

Study is located in a Mediterranean climate in Berlin, Germany at the confluence of Saale and Elbe river confluence. Ambient temperature at this location is around 8.7 °C and annual rainfall of 47.3 cm. This area is characterized by frequent flooding depending on melting of snow and intense precipitation. The study included sampling of soil in the nearby areas to access soil properties such as total carbon, total nitrogen by dry combustion and thermal



conductivity detection; organic and inorganic carbon, total phosphorus, and total potassium by XRF spectrometry; particle size distribution by wet sieving and sedimentation using pipette sampling; and pH. Metallic concentration of copper, chromium, nickel, zinc, cadmium, lead, and arsenic.

Table 3-2 *Properties of soil mix*

<i>Properties</i>	<i>Unit</i>	<i>Value (<math>\pm</math>standard deviation)</i>
pH		5.8
Sand	%	33
Silt	%	39
Clay	%	28
Organic	%	6.1
EC	cmolc kg <sup>-1</sup>	28.4
Fe	%	2.25
Mn	%	0.07
FeO	%	1.63
MnO	%	0.09
P	mg kg <sup>-1</sup>	4015.5 ( $\pm$ 131.1)
K	mg kg <sup>-1</sup>	4125.8 ( $\pm$ 265.6)
As	mg kg <sup>-1</sup>	120.8 ( $\pm$ 4.0)
Cd	mg kg <sup>-1</sup>	9 ( $\pm$ 0.4)
Cr	mg kg <sup>-1</sup>	145.3 ( $\pm$ 5.4)
Cu	mg kg <sup>-1</sup>	171 ( $\pm$ 3.4)
Ni	mg kg <sup>-1</sup>	60.7 ( $\pm$ 1.7)
Pb	mg kg <sup>-1</sup>	176 ( $\pm$ 4.1)
Zn	mg kg <sup>-1</sup>	880.1 ( $\pm$ 14.8)

### 3.1.2 EXPERIMENTAL DESIGN

Pot experiments were conducted in a cold-house (glass-house) without heating and with mobile roof. Kick-Brauckman pots with 10 kg soil from contaminated sites were used. A fixed proportion of fertilizer such as calcium hydrogen phosphate, ammonium sulphate, potassium sulphate, magnesium sulphate and ferric chloride was put in to support the growth of plants. 12 plant species as listed in Table 3-1 were used.

### 3.1.3 SAMPLE PREPARATION

For analysis plants were thoroughly cleaned with dil. HNO<sub>3</sub> and rinsed with double distilled water and dried in oven at 60 °C until no loss of weight was recorded. Plants were weighed and ground to fine powder in a non-metallic mill and stored in clean dried plastic containers.

## 3.2 EXPERIMENTAL STUDY


### 3.2.1 MATERIAL AND METHOD

Study is located at Delhi in a overlapped climate between monsoon-influenced humid subtropical (Köppen climate classification Cwa) and semi-arid (Köppen climate classification BSh), with high variation between summer and winter temperatures and precipitation. With River Yamuna passing through its eastern side. Ambient temperature at this location is around 8.7 °C and annual rainfall of 61.7 cm. The study included of sampling and testing of excess water drained from two plant pots (one filled with only soil and other with hibiscus planted in it). For observation the pots were plugging from the bottom after watering to let the plants absorb water and uptake various components in water for two days. Tests for determining various water quality parameters such as pH, electrical conductivity, BOD, COD, phosphate by using the respective standard methods for each parameter was conducted. pH and electrical conductivity and total dissolved solids were measured using a multiparameter analyser; BOD by Winkler's method, COD by gravimetric method and phosphate using UV-Vis Spectrophotometry.

### 3.2.2 EXPERIMENTAL DESIGN

Pot experiment was conducted in the in a semi-shaded yet open to air area under the roof, without heating or artificial lighting. Plastic pot with 3 kg normal garden soil was used in both the pots. A fixed proportion of fertilizer such as NPK in a ratio of 19:9:9 was put in to support the growth of plant. The plant was kept in semi-shaded area with no ingress of rainfall water; 500 ml of kitchen wastewater was fed to the plant and the non-planted pot every alternate days.

Table 3-3 Plant used for experimental study

<i>Sr. No.</i>	<i>Species</i>	<i>Common Name</i>	<i>Image</i>
1.	<i>Hibiscus rosa-senensis</i>	china rose, hibiscus	

### 3.2.3 SAMPLE COLLECTION

For sampling potable water and fertilizer (as stated above) was applied to the plant for several days to maintain its growth. Water was then allowed to dry out partly and then the kitchen wastewater was applied in a regimen of 500 ml every alternate days. Raw feed water was considered as Sample 1. Sample 2 was collected as overflow of excess water from the bottom of the pot containing only soil plugged with a rubber cork for 2 days after application of kitchen wastewater, which represents the filtration capacity of the soil. Sample 3 was collected from the pot with the study plant after 2 days of keeping the bottom of the pot plugged with a rubber cork after application of kitchen wastewater.

## Result and Discussion

### 4.1 CASE STUDY

#### 4.1.1 ARSENIC

Arsenic comes from various sources such as fungicides, pesticides and herbicides, metal smelters, by-products of mining activities, chemical wastes etc. Arsenic is a toxic chemical which affects a variety of lifeforms. Arsenic present in groundwater have been found to be poisonous. Arsenic may get ingested, inhaled or get absorbed through skin. Ingested arsenic causes trouble to the gastrointestinal track.

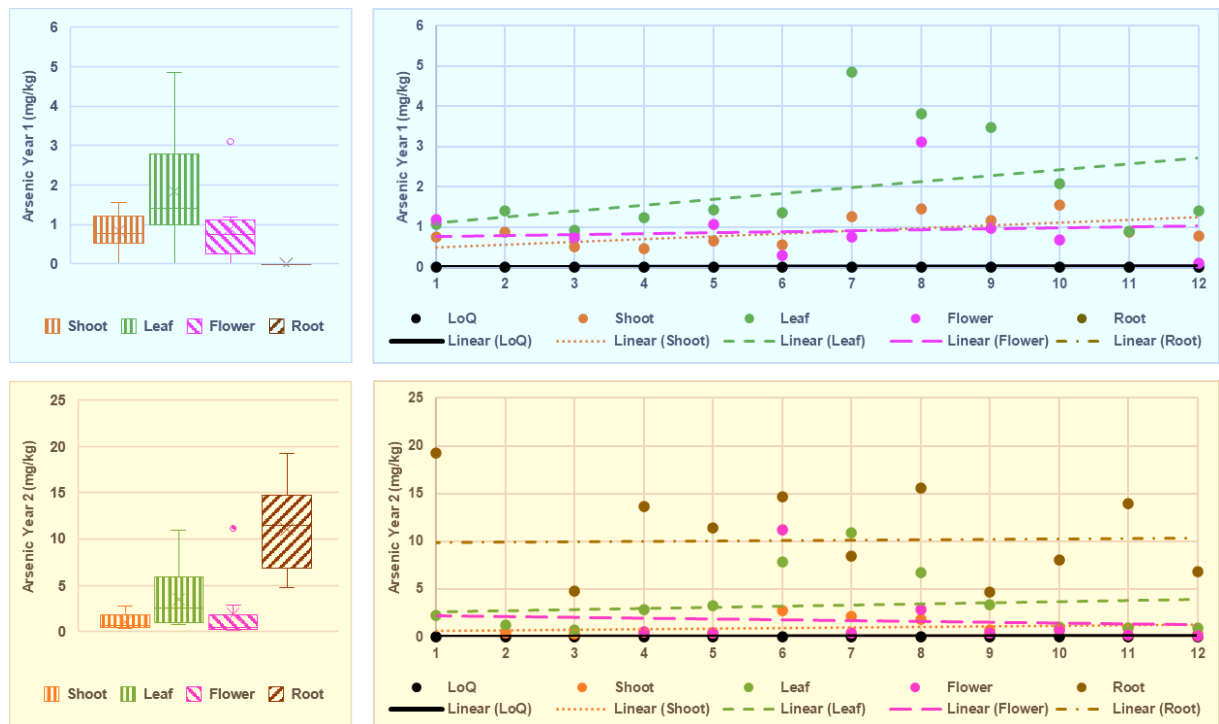


Figure 4-1 Concentration of Arsenic in root, shoot, leaf and flower in 2 years of growth of 12 species of plants

If inhaled, it reaches the bloodstream through the lungs. Late manifestations of consumption of arsenic contaminated water are in form of arsenical skin lesions, conjunctivitis, hyperkeratosis, hyperpigmentation, cardiovascular diseases, issues in peripheral vascular and nervous system, gangrene, skin cancer, leucomelosis, non-pitting swelling, hepatomegaly and

splenomegaly. WHO has prescribed a limit of 10 ppb for arsenic in water. Hence, a stringent watch is required to check the concentration of arsenic in the water environment. Plants mostly treat or remove elements such as arsenic by storing them in their biomass. Hence, chemical uptake of various chemicals is studied to determine the phytoremediation potential of different species of plants. As shown in Figure 4-1, after 1 year of growth of all species of plants under consideration, all components seem to have up-taken and stores arsenic in their biomass i.e., in the shoot, leaf and flowers but very less amount is present in the roots. Due to the photosynthetic activity, leaves has the most concentration of up-taken element. Also, the roots till now are acting as a transportation channel for various fluids and not storing arsenic. Hence, least amount of arsenic is present in roots. In the first year of growth the maximum concentration of arsenic is present in the leaves i.e., of 5 mg/kg. Species such as *artemisia vulgaris*, *urtica dioica*, *achillea millefolium* show maximum accumulation of arsenic in the leaves. *Urtica dioica* also shows arsenic retention in flowers. Yet after 2<sup>nd</sup> year of growth, it is evident that roots now store arsenic in it. Hence, show the maximum concentration of arsenic i.e., up to 20 mg/kg, more so due to the reason that roots are the nearest component to the polluted soil. Arsenic has increased up to 11mg/kg in leaves after 2 years of growth. Increase in shoot and flower is not significant. *Alopecurus pratensis*, *bromus inermis*, *urtica dioica* show maximum retention of arsenic in roots.

#### 4.1.2 CADMIUM

Cadmium is a highly toxic element generated by Cadmium producing industries, electroplating, welding; by-products from refining of Pb, Zn and Cu, fertilizer industry, pesticide manufacturers, cadmium–nickel batteries, nuclear fission plants. Cadmium causes severe chronic health effects whereas acute effects are quite mild. It mostly is ingested and is absorbed by humans and animals through the gastrointestinal track. Cadmium acumulates and gets deposited in bones, liver and kidneys. It is a risk factor for cardiovascular diseases as it accumulates in soft tissues. It reduces bone mineral density and cause osteoporosis, skeletal damage and fractures. Acute exposure may cause salivation, breathing difficulty, nausea, vomiting, pain, anemia, kidney failure and diarrhea. Inhalation may cause throat dryness, headache, chest pain, coughing, bronchial trouble. The US EPA has limited a maximum contaminant level up to 0.005 mg/L of cadmium in drinking water. In phytoremediation, plants convert the subject elements to biomass. Hence, chemical uptake of various chemicals

is studied to determine the phytoremediation potential of different species of plants. As shown in Figure 4-2, after 1 year of growth of all species of plants under consideration, all components seem to have up-taken and stored cadmium in their biomass i.e., in the shoot, leaf and flowers but very less amount is present in the roots. Similar to arsenic, cadmium is also found to have maximum concentration in leaves. And the roots acting are not storing any cadmium in the first year, it is just acting as a channel for transmission of various plant fluids. Hence, least amount of cadmium is present in roots. In the first year of growth the maximum concentration of cadmium is present in the leaves i.e., of approx. 57 mg/kg. Species such as artemisia vulgaris, stellaria holostea, and silene vulgaris show maximum uptake of cadmium in the leaves. After 2 years of growth, being in close contact with the polluted soil, roots now actively store cadmium and show a maximum concentration of up to 118 mg/kg. Uptake of cadmium has not increased significantly in the leaves, shoot and flower after 2 years of growth. Galium mollugo, alopecurus pratensis, and holcus lanatus show maximum retention of cadmium in roots.

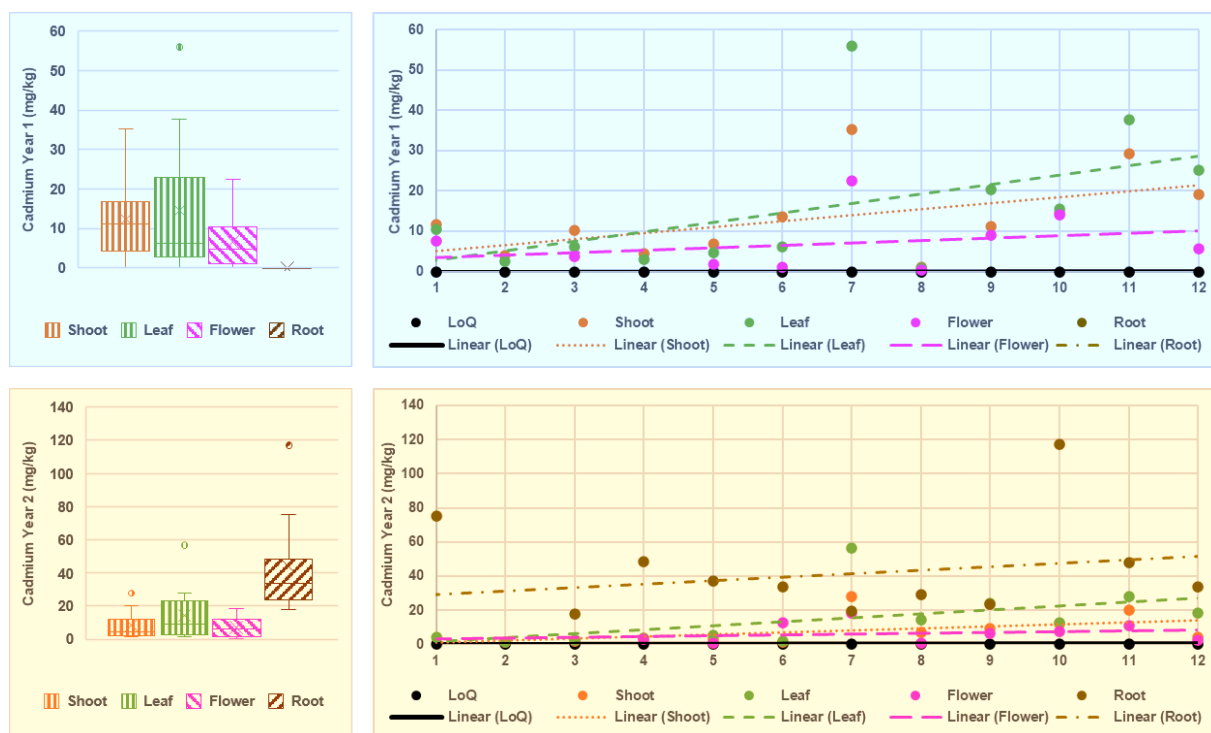


Figure 4-2 Concentration of Cadmium in root, shoot, leaf and flower in 2 years of growth of 12 species of plants

#### 4.1.3 CHROMIUM

Chromium is mostly present in its trivalent or hexavalent form. Cr[III] is most commonly naturally occurring state in soil, whereas Cr[VI] is mostly industrial and domestic in origin.

Apart from rocks, chromium is released from metallurgical and chemical industries, processes using chromate compounds, cement and asbestos units. Tobacco smokers are most susceptible to exposure to chromium, If inhaled chromium causes nose irritations and nosebleeds. It also causes allergic reaction to skin, if present in leather apparels and products.

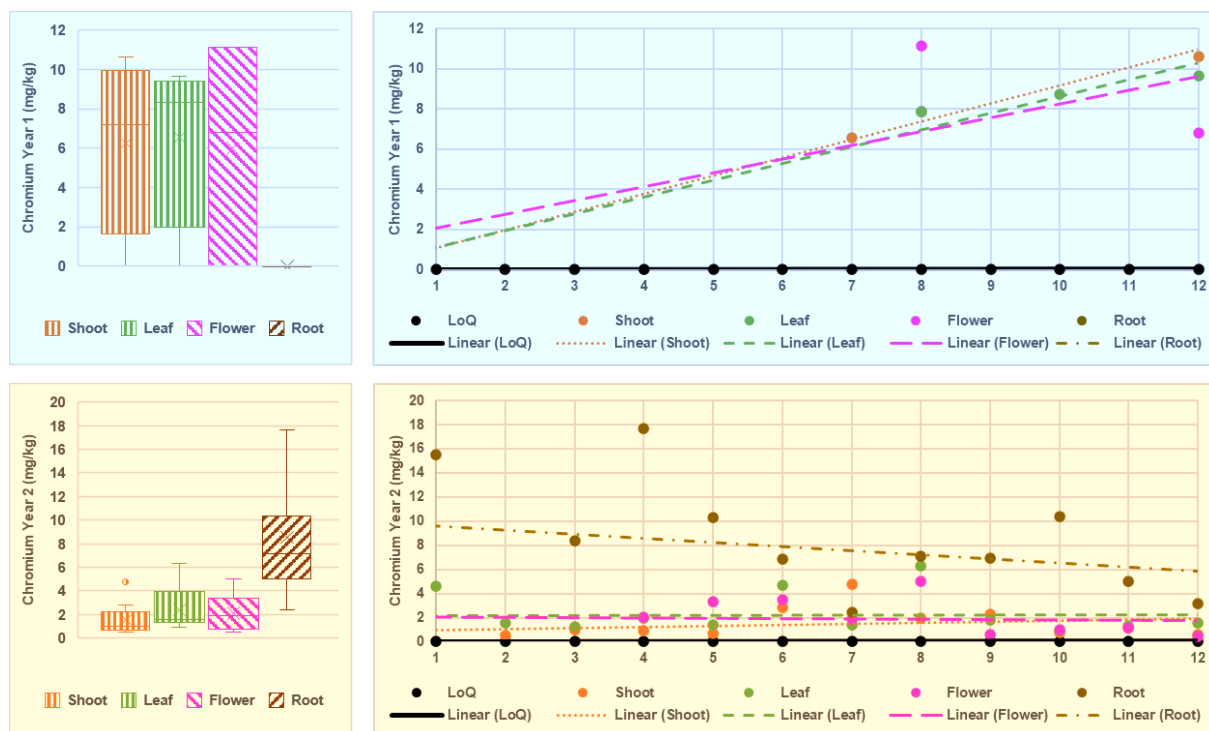


Figure 4-3 Concentration of Chromium in root, shoot, leaf and flower in 2 years of growth of 12 species of plants

Chromium causes skin rashes, upset stomachs and ulcers, respiratory problems, weakened immune systems, kidney and liver damage, alteration of genetic material, lung cancer and even death. Adverse health effects are observed due to exposure to hexavalent form; whereas low toxicity is observed with trivalent form. Inhalation of chromium causes ulcers and perforation of mucous membranes of nasal septum, irritation in pharynx and larynx, asthmatic bronchitis, bronchospasms and edema. Hexavalent chromium is toxic to both plants and animals. The WHO has prescribed a limit of 0.05 mg/l in water. Plants absorb and convert toxic element into its biomass. Hence, uptake of chromium must be studied to determine the potential of phytoremediation by different species of plants. As shown in Figure 4-3, all 12 plant species in their first year of growth shows uptake of chromium in shoot, leaves and flowers. It is worth observing that highest amount of chromium reaches flowers of *urtica dioica* and *artemisia vulgaris*. Chromium is present in biomass of shoot, leaf and flowers but very less amount is present in the roots. Similar to arsenic and cadmium, chromium is also found to have high concentration in leaves; and roots are not storing any chromium during the first year and is

acting as a transportation channel for fluids. Hence, least amount of cadmium is present in roots. In the first year of growth the maximum concentration of chromium is present in the flower i.e., of approx. 11.3 mg/kg. Species such as *urtica dioica* and *artemisia vulgaris* show maximum uptake of chromium in the flowers; whereas *urtica dioica*, *galium mollugo*, and *silene vulgaris* shows high accumulation in leaves. After the 2nd year, roots are now actively involved in storing chromium and show a maximum concentration of up to 18 mg/kg. Whereas, the uptake of chromium has decreased significantly in the leaves, shoot and flower. *Holcus lanatus*, *alopecurus pratensis*, *galium mollugo*, and *arrhenatherum elatius* show maximum retention of chromium in roots.

#### 4.1.4 COPPER

Copper is found in three valence states i.e., Cu(0), Cu(I), and Cu(II). It is mostly found in ores, Hence, iron and steel industry, fertilizer industry, burning of wood, discharge of mine tailings, disposal of fly ash, disposal of municipal and industrial wastes are the sources of copper. Naturally, copper is found as cuprite and malachite. Copper is essential in low concentration to living organisms yet produce toxic effects if present in large magnitude. As an essential metal it helps for proper growth, cardiovascular health, lung elasticity, neuroendocrine functions and metabolism. It also protects against free radical damage to proteins, lipids and nucleic acids, cell and organs. Hence, deficiency of copper may create detrimental effects on health. Yet excess quantities of copper in long term causes irritation to nose, mouth, eyes causing headaches, stomach-aches, dizziness, vomiting, and diarrhea. High intake of copper may cause liver and kidney damage and even death. Industrial exposure to copper fumes results in metal fume fever with atrophic changes in nasal mucous membrane. Chronic exposure results in Wilson's disease, characterized by hepatic cirrhosis, brain damage, demyelination, renal disease and copper deposition in cornea. Uptake of copper must be studied to determine the phytoremediation potential of different species of plants. As shown in Figure 4-3, all 12 plant species in their first year of growth shows uptake of copper in shoot, leaves and flowers. It is worth observing that highest amount of copper is found in leaves. Copper is present in the shoot, leaf and flowers of the plant whereas it is absent in the roots. Similar to arsenic, cadmium, and chromium, copper is also found to have high concentration in leaves; and roots are not storing any copper during the first year and is acting as a transportation channel for fluids. Hence, least amount of copper is present in roots.



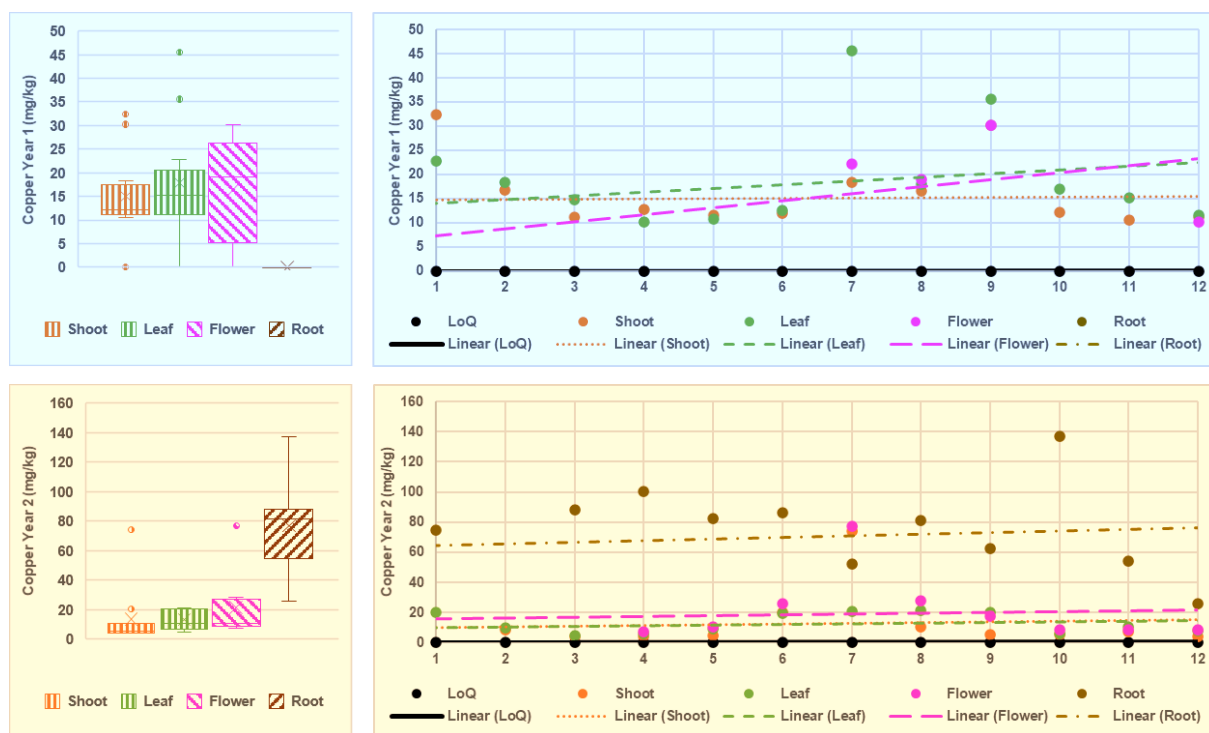


Figure 4-4 Concentration of Copper in root, shoot, leaf and flower in 2 years of growth of 12 species of plants

In the first year of growth the maximum concentration of copper is present in the leaves is approx. 45 mg/kg. Species such as *artemisia vulgaris* and *achillea millefolium* show maximum uptake of copper in the leaves; whereas *alopecurus pratensis* shows high accumulation in the shoot. After 2 years of growth, roots are now actively involved in storing copper and show a maximum concentration of up to 140 mg/kg, whereas the uptake of copper remains unchanged in the leaves, shoot and flower. All the species show high concentration of copper with *galium mollugo*, *holcus lanatus*, and *poa angustifolia* show maximum retention of copper in roots.

#### 4.1.5 NICKEL

Nickel is one of the most abundantly found element in earth's crust. It is a natural component of soil and water. Mostly nickel is released from metallurgical industries using nickel, combustion of fuels containing nickel additives, burning of coal and oil, electroplating units using nickel salts, incineration of nickel containing substances. Naturally, nickel is found in its ores nickelite, millerite and pentlandite. Similar to copper, nickel is also essential in low concentration to living organisms yet produces toxic effects if present in large magnitude. Humans may get exposed to nickel through inhalation, drinking water, by food or by smoking cigarettes. Nickel fumes are respiratory irritants and causes pneumonitis. Dermatitis i.e nickel

itch is caused by skin exposure. Nickel tetracarbonyl ( $\text{Ni}(\text{CO})_4$ ) gas is the most toxic Ni compounds and it is the first to cause deaths in refineries.

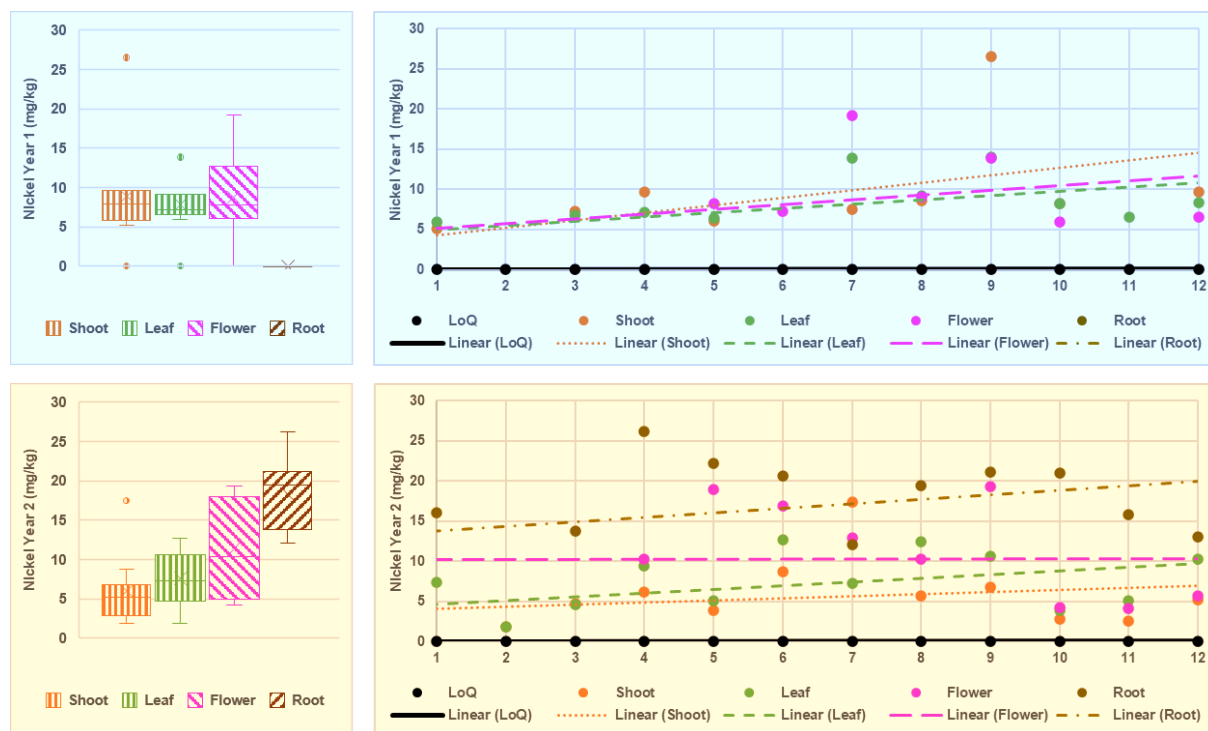


Figure 4-5 Concentration of Nickel in root, shoot, leaf and flower in 2 years of growth of 12 species of plants

The immediate symptoms includes headaches, nausea, weakness, dizziness, vomiting, and epigastric pain. High level occupational exposure has been associated with renal problems, vertigo and dyspnoea. Nickel binds to the biomass of plants and animals, hence its uptake must be studied. As shown in Figure 4-5, all 12 plant species in their first year of growth shows uptake of nickel in shoot and flowers and moderately in leaves. Highest accumulation of nickel is observed in plant shoot. Similar to copper, nickel is also present in the shoot, leaf and flowers of the plant whereas it is absent in the roots. Nickel is also found to have high concentration in leaves; and roots are not actively storing nickel during the first year. In the first year of growth the maximum concentration of nickel is present in the leaves is approx. 27 mg/kg. Species such as achillea millefolium, artemisia vulgaris, and holcus lanatus show maximum uptake of nickel in the shoot; these species also show high accumulation in the leaves and flowers. After 2 years of growth, roots are now actively involved in storing nickel and show a maximum concentration of up to 27 mg/kg, whereas the uptake of nickel also increase in the leaves, shoot and flower. All the species show high concentration of nickel with holcus lanatus, arrhenatherum elatius, achillea millefolium, and galium mollugo show maximum retention of nickel in roots.

#### 4.1.6 LEAD

Lead is the most common heavy metallic element generated by automobile emissions, lead smelters, burning of coal and oil, lead arsenate pesticides, smoking, mining and plumbing. It is mainly used for manufacture of lead-acid batteries, solder and alloys. Lead is not required nutritionally by human yet it is found in all human tissues and organs. It is called systemic poison, once absorbed into the circulation it will distribute throughout the body, where it may affect organs and tissues.

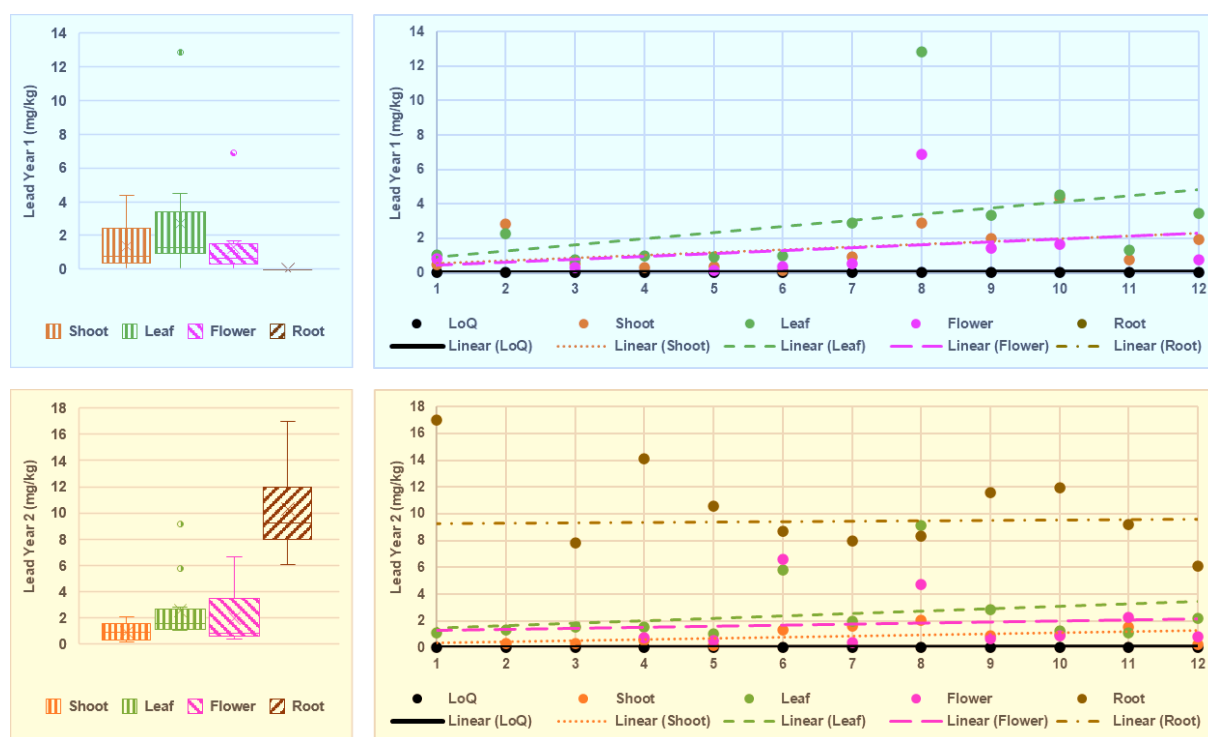


Figure 4-6 Concentration of Lead in root, shoot, leaf and flower in 2 years of growth of 12 species of plants

It causes lead poisoning leading to anaemia, renal tubular dysfunction. Secondary effects include gastrointestinal tract, nausea, anorexia, cramps and constipation. Muscle aches, joint pain, lung damage, asthma, bronchitis, pneumonia are also observed in persons exposed to lead. From point of view of phytoremediation, plants absorb lead and bind to its biomass. Hence, uptake of lead needs to be studied. Phytoremediation potential of different species of plants to absorb lead shall be carried out. As shown in Figure 4-6, after 1 year of growth of all species of plants under consideration, all components seem to have up-taken and stored lead in their biomass i.e., in the shoot, leaf and flowers but very less amount is present in the roots. Similar to previously discussed elements, lead is also found to have maximum concentration in leaves and the roots are not storing any lead. Hence, least amount of lead is present in roots.

In the first year of growth the maximum concentration of lead is present in the leaves i.e., of approx. 12.8 mg/kg. Species such as *urtica dioica*, *galium mollugo*, *achillea millefolium*, and *artemisia vulgaris* show maximum uptake of lead in the leaves. After 2 years of growth, roots now store lead and show a maximum concentration of up to 17 mg/kg. Uptake of lead has been observed to decrease in the leaves, shoot and flower after 2 years of growth. *Alopecurus pratensis*, *holcus lanatus*, *galium mollugo*, and *achillea millefolium* show maximum retention of lead in roots.

#### 4.1.7 ZINC

Zinc is mostly generated from anthropogenic sources such as zinc refineries, galvanizing processes, brass manufacture, metal plating, and plumbing. The major source of zinc in water results from erosion. Zinc is released in air from igneous emission and forest fires. Naturally, zinc is found as sphalerite, smithsonite, hemimorphite, and franklinite. cuprite and malachite. Zinc is essential in low concentration to living organisms yet may become toxic if excessive amount of zinc salts are ingested. Excess amounts of zinc causes nausea, vomiting, fever, stomach cramps, diarrhea, lethargy, dizziness and lack of muscular coordination. Nutritional deficiency of zinc is related to retarded growth, immaturity and anemia. As an essential metal it helps for proper growth, physiological and metabolic processes. Hence, deficiency of zinc may create detrimental effects on health. High intake of zinc may cause acute renal failure.

Uptake of zinc must be studied to determine the phytoremediation potential of different species of plants. As shown in Figure 4-7, all 12 plant species in their first year of growth shows uptake of zinc in shoot, leaves and flowers. It is worth observing that highest amount of zinc is found in leaves. Zinc is present in the shoot, leaf and flowers of the plant whereas it is absent in the roots. Similar to previously discussed elements, zinc is also found to have highest concentration built-up in leaves; and roots are not storing zinc during the first year and is acting as a transportation channel for fluids. Hence, least amount of zinc is present in roots. In the first year of growth the maximum concentration of zinc is present in the leaves is approx. 1200 mg/kg. Species such as *artemisia vulgaris*, *stellaria holostea*, and *silene vulgaris* show maximum uptake of zinc in the leaves; whereas *artemisia vulgaris* also shows high accumulation in the shoot. After 2 years of growth, roots are now actively involved in storing zinc and show a maximum concentration of 1300 mg/kg, whereas the uptake of zinc increase slightly in the leaves and flower. On the contrary, concentration of zinc in shoot has fallen. All

the species show high concentration of zinc with alopecurus pratensis, galium mollugo, and arrhenatherum elatius show maximum retention of zinc in roots. artemisia vulgaris, stellaria holostea still show highest built-up of zinc in leaves.

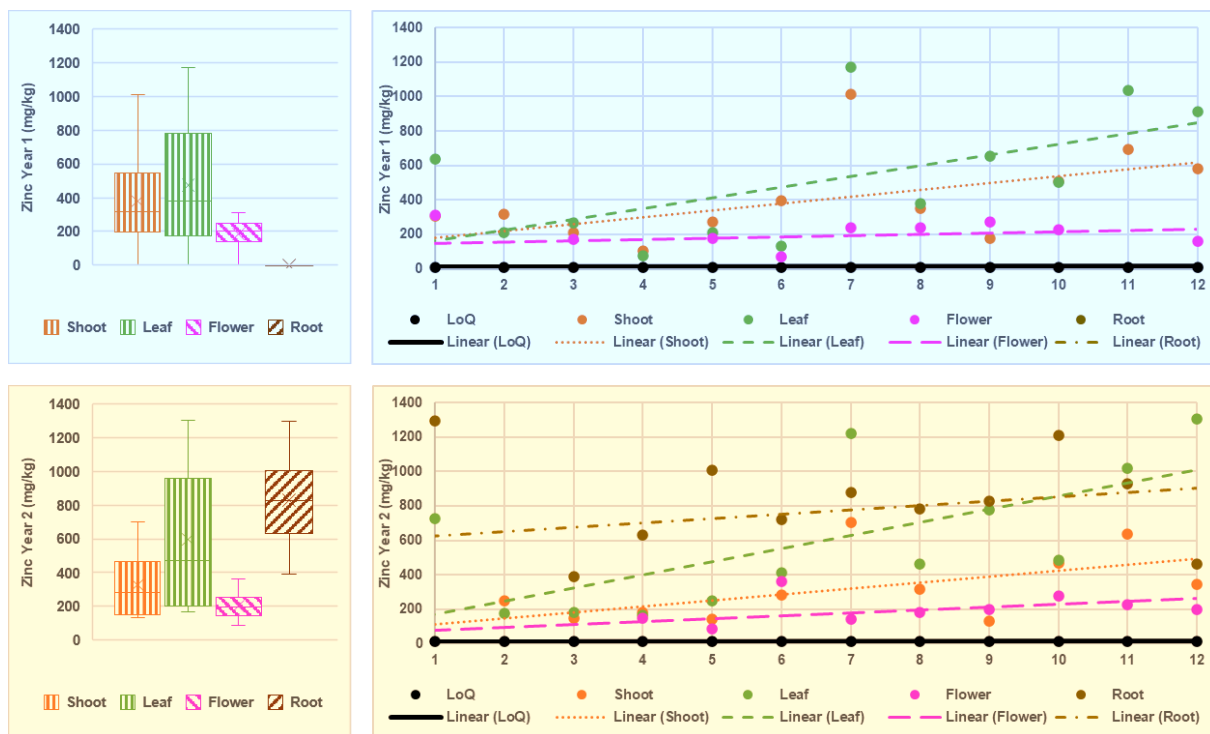


Figure 4-7 Concentration of Zinc in root, shoot, leaf and flower in 2 years of growth of 12 species of plants

Table 4-1 Maximum concentrations of toxic elements in top three species of plants

Sr. No.	Element	Head	1 <sup>st</sup> year				2 <sup>nd</sup> year			
			Root	Shoot	Leaf	Flower	Root	Shoot	Leaf	Flower
1	As	Max. Conc. (mg/kg)	0	1.56	4.84	3.11	19.2	2.79	10.93	11.16
		Species	-	Galium mollugo, Urtica dioica, Artemisia vulgaris	Artemisia vulgaris, Urtica dioica, Achillea millefolium	Urtica dioica, pratensis, Arrhenatherum elatius	Alopecurus pratensis, Urtica dioica, Bromus inermis	Bromus inermis, Artemisia vulgaris, Urtica dioica	Artemisia vulgaris, Bromus inermis, Urtica dioica	Bromus inermis, Urtica dioica, Galium mollugo
2	Cd	Max. Conc. (mg/kg)	0	35.21	56.01	22.49	117	27.82	56.72	18.7
		Species	-	Artemisia vulgaris, Stellaria holostea, Silene vulgaris	Artemisia vulgaris, Stellaria holostea, Silene vulgaris	Artemisia vulgaris, Galium mollugo, Achillea millefolium	Galium mollugo, Alopecurus pratensis, Holcus lanatus	Artemisia vulgaris, Stellaria holostea, Galium mollugo	Artemisia vulgaris, Stellaria holostea, Achillea millefolium	Artemisia vulgaris, Bromus inermis, Stellaria holostea
3	Cr	Max. Conc. (mg/kg)	0	10.63	9.63	11.13	17.68	4.75	6.33	5.04
		Species	-	Silene vulgaris, Urtica dioica, Artemisia vulgaris	Silene vulgaris, Galium mollugo, Urtica dioica	Urtica dioica, Silene vulgaris, Galium mollugo	Holcus lanatus, Alopecurus pratensis, Galium mollugo	Artemisia vulgaris, Bromus inermis, Achillea millefolium	Urtica dioica, Bromus inermis, Alopecurus pratensis	Urtica dioica, Bromus inermis, Arrhenatherum elatius

Sr. No.	Element	Head	1 <sup>st</sup> year				2 <sup>nd</sup> year			
			Root	Shoot	Leaf	Flower	Root	Shoot	Leaf	Flower
4	Cu	Max. Conc. (mg/kg)	0	32.36	45.53	30.27	137.25	74.18	21.17	77
		Species	-	Alopecurus pratensis, Achillea millefolium, Artemisia vulgaris	Artemisia vulgaris, Achillea millefolium, Alopecurus pratensis	Achillea millefolium, Artemisia vulgaris, Urtica dioica	Galium mollugo, Holcus lanatus, Poa angustifolia	Artemisia vulgaris, Bromus inermis, Urtica dioica	Urtica dioica, Artemisia vulgaris, Alopecurus pratensis	Artemisia vulgaris, Urtica dioica, Bromus inermis
5	Ni	Max. Conc. (mg/kg)	0	26.52	14.02	19.2	26.18	17.44	12.66	19.3
		Species	-	Achillea millefolium, Silene vulgaris, Holcus lanatus	Achillea millefolium, Artemisia vulgaris, Urtica dioica	Artemisia vulgaris, Achillea millefolium, Urtica dioica	Holcus lanatus, Arrhenatherum elatius, Achillea millefolium	Artemisia vulgaris, Bromus inermis, Achillea millefolium	Bromus inermis, Urtica dioica, Achillea millefolium	Achillea millefolium, Arrhenatherum elatius, Bromus inermis
6	Pb	Max. Conc. (mg/kg)	0	4.38	12.85	6.89	17	2.05	9.15	6.63
		Species	-	Galium mollugo, Urtica dioica, Elytrigia repens	Urtica dioica, Galium mollugo, Silene vulgaris	Urtica dioica, Galium mollugo, Achillea millefolium	Alopecurus pratensis, Holcus lanatus, Galium mollugo	Urtica dioica, Artemisia vulgaris, Stellaria holostea	Urtica dioica, Bromus inermis, Achillea millefolium	Bromus inermis, Urtica dioica, Stellaria holostea

Sr. No.	Element	Head	1 <sup>st</sup> year				2 <sup>nd</sup> year			
			Root	Shoot	Leaf	Flower	Root	Shoot	Leaf	Flower
		Max. Conc. (mg/kg)	0	1014	1169	311.8	1296	702.7	1304	362.7
7	Zn	Species -		Artemisia vulgaris, Stellaria holostea, Silene vulgaris	Artemisia vulgaris, Stellaria holostea, Silene vulgaris	Alopecurus pratensis, Achillea millefolium, Urtica dioica	Alopecurus pratensis, Galium mollugo, Arrhenatherum elatius	Artemisia vulgaris, Stellaria holostea, Galium mollugo	Silene vulgaris, Artemisia vulgaris, Stellaria holostea	Bromus inermis, Galium mollugo, Stellaria holostea

Table 4-2 Maximum concentrations of toxic elements in top species of plants

Sr. No.	Element	Head	1 <sup>st</sup> year				2 <sup>nd</sup> year			
			Root	Shoot	Leaf	Flower	Root	Shoot	Leaf	Flower
1	As	Max. Conc. (mg/kg)	0	1.56	4.84	3.11	19.2	2.79	10.93	11.16
		Species	-	Galium mollugo	Artemisia vulgaris	Urtica dioica	Alopecurus pratensis	Bromus inermis	Artemisia vulgaris	Bromus inermis
2	Cd	Max. Conc. (mg/kg)	0	35.21	56.01	22.49	117	27.82	56.72	18.7
		Species	-	Artemisia vulgaris	Artemisia vulgaris	Artemisia vulgaris	Galium mollugo	Artemisia vulgaris	Artemisia vulgaris	Artemisia vulgaris
3	Cr	Max. Conc. (mg/kg)	0	10.63	9.63	11.13	17.68	4.75	6.33	5.04
		Species	-	Silene vulgaris	Silene vulgaris	Urtica dioica	Holcus lanatus	Artemisia vulgaris	Urtica dioica	Urtica dioica



Sr. No.	Element	Head	1 <sup>st</sup> year				2 <sup>nd</sup> year			
			Root	Shoot	Leaf	Flower	Root	Shoot	Leaf	Flower
4	Cu	Max. Conc. (mg/kg)	0	32.36	45.53	30.27	137.25	74.18	21.17	77
		Species	-	Alopecurus pratensis	Artemisia vulgaris	Achillea millefolium	Galium mollugo	Artemisia vulgaris	Urtica dioica	Artemisia vulgaris
5	Ni	Max. Conc. (mg/kg)	0	26.52	14.02	19.2	26.18	17.44	12.66	19.3
		Species	-	Achillea millefolium	Achillea millefolium	Artemisia vulgaris	Holcus lanatus	Artemisia vulgaris	Bromus inermis	Achillea millefolium
6	Pb	Max. Conc. (mg/kg)	0	4.38	12.85	6.89	17	2.05	9.15	6.63
		Species	-	Galium mollugo	Urtica dioica	Urtica dioica	Alopecurus pratensis	Urtica dioica	Urtica dioica	Bromus inermis
7	Zn	Max. Conc. (mg/kg)	0	1014	1169	311.8	1296	702.7	1304	362.7
		Species	-	Artemisia vulgaris	Artemisia vulgaris	Alopecurus pratensis	Alopecurus pratensis	Artemisia vulgaris	Silene vulgaris	Bromus inermis

Above table reveals that out of 56 instances, artemisia vulgaris (30.35 % occurrences) is the plant species that absorbs and accumulate most of toxic elements followed by urtica dioica (16.07 %), alopecurus pratensis (8.93%), bromus inermis (8.93%). Overall ranking based on toxic element up take is as follows:

Table 4-3 Overall ranking of species of plants suitable for phytoremediation

Rank	Species	% occurrences
1	Artemisia vulgaris	30.35
2	Urtica dioica	16.07
3	Alopecurus pratensis	8.93
4	Bromus inermis	8.93
5	Galium mollugo	5.36
6	Achillea millefolium	5.36
7	Silene vulgaris	3.57
8	Holcus lanatus	3.57

#### 4.1.8 CORRELATION ANALYSIS

Correlation table reveals that at root level Cu-Cd, Zn-Cd and Pb-Cr pairs show strong positive correlation. Zn-Cd pair appears to have strong positive correlation in the shoot. In general, Zn-Cd show strong correlation in all components i.e., root, shoot, leaf and flower.

Table 4-4 Correlation table for various toxic elements in shoot, root, leaf and flower

Shoot	As	Cd	Cr	Cu	Ni	Pb	Zn
As	1						
Cd	0.22	1					
Cr	0.32	0.46	1				
Cu	0.56	0.4	0.33	1			
Ni	0.38	0.26	0.59	0.63	1		
Pb	0.54	0.1	0.68	0.21	0.34	1	
Zn	0.34	0.89	0.53	0.31	0.03	0.25	1

Root	As	Cd	Cr	Cu	Ni	Pb	Zn
As	1						
Cd	0.23	1					
Cr	0.39	0.46	1				
Cu	-0.08	0.69	0.5	1			
Ni	0.14	0.24	0.57	0.51	1		
Pb	0.41	0.58	0.84	0.25	0.38	1	
Zn	0.38	0.72	0.18	0.11	0	0.56	1

Leaf	As	Cd	Cr	Cu	Ni	Pb	Zn
As	1						
Cd	0.43	1					
Cr	0.02	-0.09	1				
Cu	0.42	0.54	0.42	1			
Ni	0.53	0.29	0.5	0.73	1		
Pb	0.42	-0.08	0.65	0.25	0.5	1	
Zn	0.36	0.9	0.08	0.53	0.27	0.01	1

Flower	As	Cd	Cr	Cu	Ni	Pb	Zn
As	1						
Cd	0.08	1					
Cr	0.21	-0.48	1				
Cu	0.08	0.5	-0.06	1			
Ni	0.27	0.23	-0.16	0.23	1		
Pb	0.77	-0.11	0.61	-0.01	0.01	1	
Zn	0.59	0.39	0.03	-0.06	0.05	0.49	1

## 4.2 EXPERIMENTAL STUDY

### 4.2.1 CHARACTERISTICS OF KITCHEN WASTE

Table 4-5 presents the descriptive statistics of the characteristics of kitchen waste found in various literatures.

Table 4-5 Typical Characteristics of Kitchen Waste (Singh & Reghu, 2015, Gurd et. al, 2019)

Parameter	Mean	Standard Error	Median	Standard Deviation	Sample Variance	Minimum	Maximum
BOD (mg/l)	473.21	84.34	470	315.59	99597.41	58.00	1193.00
COD (mg/l)	1070.63	182.36	980	604.84	365830.85	292.00	2305.00
Total Phosphate (mg/l)	4.36	0.28	4.60	0.49	0.24	3.80	4.70
Na+ (mg/l)	364.24	7.90	358.20	17.66	312.01	348.40	394.20
Ca+ (mg/l)	450.40	35.57	468.00	79.54	6326.80	320.00	534.00
Mg+ (mg/l)	458.40	43.07	430.00	96.30	9274.30	389.00	625.00
K+ (mg/l)	34.72	1.17	33.20	2.61	6.81	32.60	38.50
TDS (mg/l)	1455.20	51.25	1450.00	114.61	13134.70	1281.00	1582.00
Electrical Conductivity ( $\mu S/cm$ )	3.15	0.01	3.15	0.02	-	3.12	3.18
SAR	17.15	0.45	16.66	1.00	0.99	16.26	18.59
Na%	27.85	0.56	27.38	1.25	1.56	26.74	29.49

### 4.2.2 PH

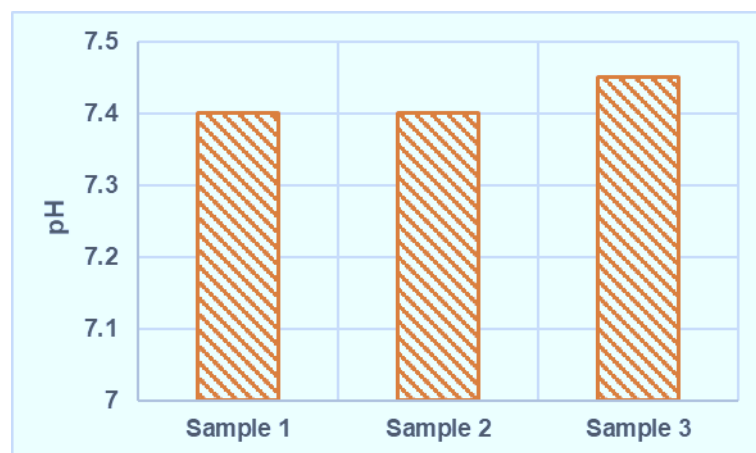


Figure 4-8 Trend of pH for various samples

pH of wastewater generally reduces with time as wastewater degrades and forms acids. Figure 4-8 presents the trend of pH in water at various stages was not significantly varying. pH of kitchen wastewater initially was about 7.4. pH of second sample was 7.4. Whereas, pH of the third sample collected after 2 days of keeping the bottom of the pot plugged with a rubber cork after application of kitchen wastewater was 7.45.

#### 4.2.3 ELECTRICAL CONDUCTIVITY

Electrical conductivity of wastewater changes as the wastewater degrades and is up-taken by the plant. Figure 4-9 presents the trend of EC in water at various stages of phytoremediation. EC of kitchen wastewater initially was about 495  $\mu\text{S}/\text{cm}$ . EC of the second sample was 512  $\mu\text{S}/\text{cm}$ . Whereas, EC of the third sample collected after 2 days of keeping the bottom of the pot plugged with a rubber cork after application of kitchen wastewater was 476  $\mu\text{S}/\text{cm}$ .

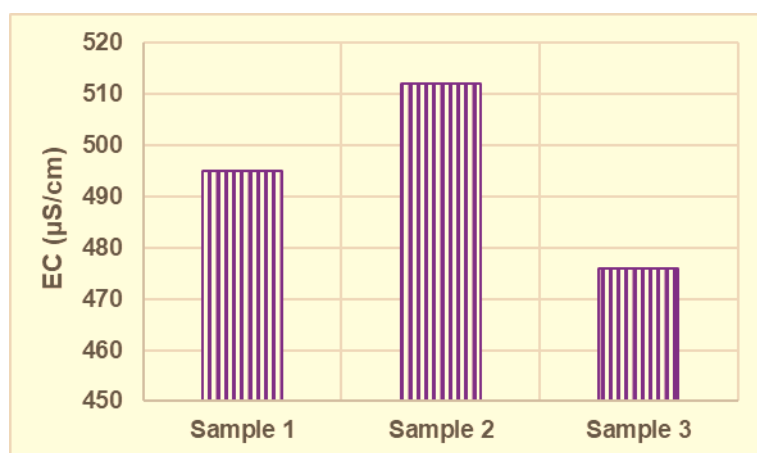


Figure 4-9 Trend of electrical conductivity (EC) for various samples

#### 4.2.4 TOTAL DISSOLVED SOLIDS

Dissolved solids in wastewater are present as the exchanges between wastewater and soil turbidity. Figure 4-10 presents the trend of TDS in water at various stages of phytoremediation. TDS of kitchen wastewater initially was about 261 mg/l. TDS of the second sample was 280 mg/l. Whereas, TDS of the third sample collected after 2 days of keeping the bottom of the pot plugged with a rubber cork after application of kitchen wastewater was 248 mg/l.

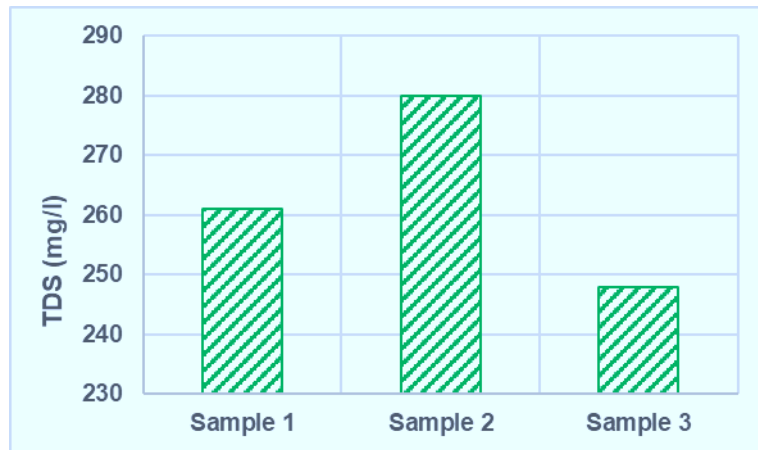


Figure 4-10 Trend of total dissolved solids (TDS) for various samples

#### 4.2.5 BIOCHEMICAL OXYGEN DEMAND

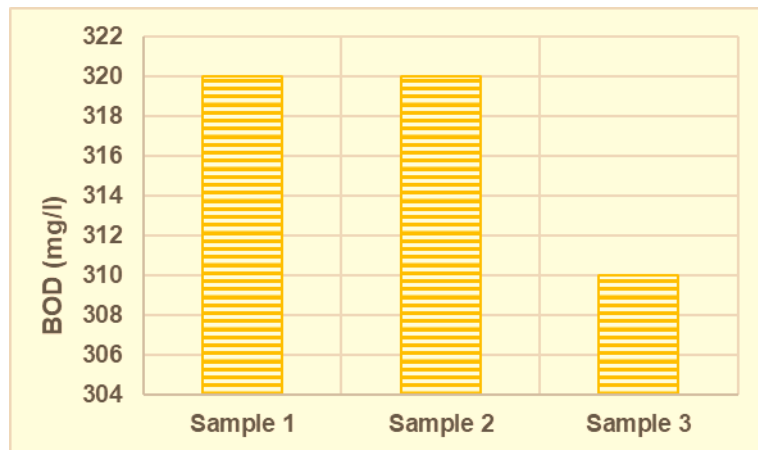


Figure 4-11 Trend of biochemical oxygen demand (BOD) for various samples

Biochemical oxygen demand of wastewater is the most important characteristic for phytoremediation, as the most uptake of plant are the organic constituents. Figure 4-11 presents the trend of BOD of water at various stages of phytoremediation. BOD of kitchen wastewater initially was about 320 mg/l. BOD of the second sample was 320 mg/l. Whereas, BOD of the third sample collected after 2 days of keeping the bottom of the pot plugged with a rubber cork after application of kitchen wastewater was 310 mg/l.

#### 4.2.6 CHEMICAL OXYGEN DEMAND

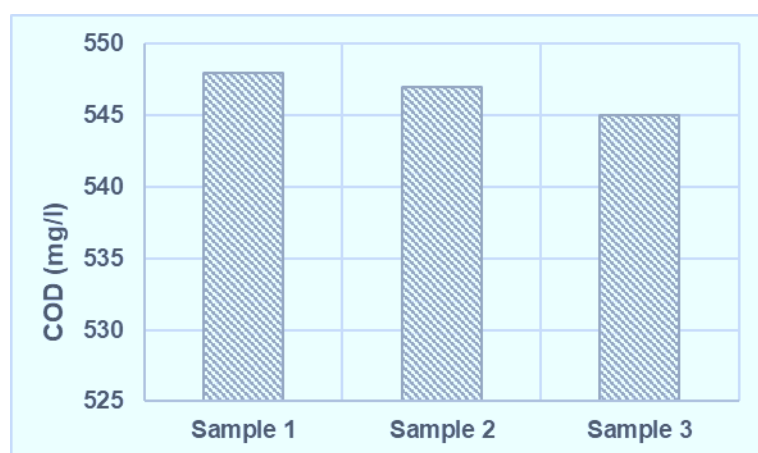


Figure 4-12 Trend of chemical oxygen demand (COD) for various samples

Chemical oxygen demand of wastewater is the factor which may be least affected by phytoremediation as it represents the non-organic component. Figure 4-12 presents the trend of COD of water at various stages of phytoremediation. There is almost no significant change in the trend of COD. COD of kitchen wastewater initially was about 548 mg/l. COD of the second sample was 547 mg/l. Whereas, COD of the third sample collected after 2 days of keeping the bottom of the pot plugged with a rubber cork after application of kitchen wastewater was 545 mg/l.

#### 4.2.7 TOTAL PHOSPHATE

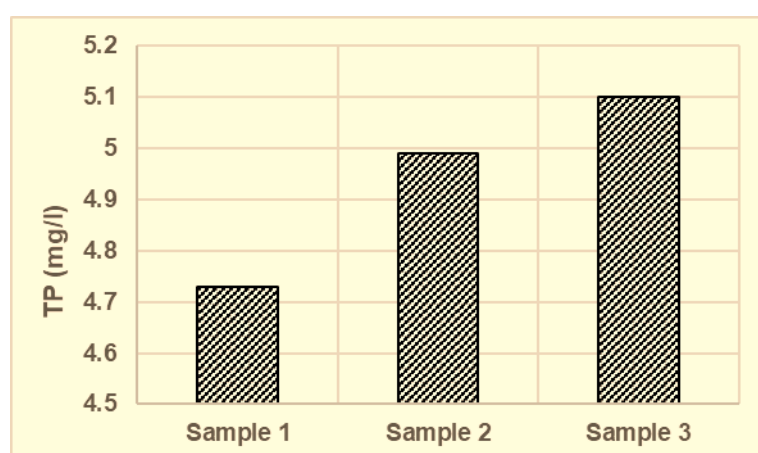


Figure 4-13 Trend of total phosphate (TP) for various samples

Total phosphate is present due to presence of detergents in the kitchen waste and also due to the nutrient dosage in form of fertilizers. It may affect the overall process of phytoremediation

as it supports growth of the plant. Figure 4-13 presents the trend of TP of water at various stages of phytoremediation. TP is found to get dissolved into the wastewater and rise up after interaction with soil. TP of kitchen wastewater initially was about 4.73 mg/l. TP of the second sample was 4.99 mg/l. Whereas, TP of the third sample collected after 2 days of keeping the bottom of the pot plugged with a rubber cork after application of kitchen wastewater was 5.1 mg/l.

#### 4.2.8 CORRELATION ANALYSIS

Table 4-6 Correlation table for various water quality parameters

	pH	TDS	EC	BOD	COD	TP
pH	1					
TDS	-0.81	1				
EC	-0.88	0.99	1			
BOD	-1	0.81	0.88	1		
COD	-0.94	0.57	0.68	0.94	1	
TP	0.73	-0.18	-0.32	-0.73	-0.91	1

Correlation table reveals that TDS-EC, BOD-COD and EC-BOD pairs show strong positive correlation; whereas, pH-BOD, pH-COD, COD-Phosphate pairs appears to have strong negative correlation in the water samples.

## *Conclusion*

The study concludes to prove the use of live plants for removal of environmental pollutants. Phytoremediation bears down to the capacity of plants to absorb, accumulate and store elements from water and soil into their biomass. Physiology of plants plays important role in phytoremediation as not all plants can hyperaccumulate contaminants. In the remediation of contaminants there are several mechanisms involved for uptake of metals from polluted waters for treatment and render them non-toxic. The report studies 13 species of plants and assess their phytoremediation potential to remove BOD from kitchen wastewater in the experimental study and toxic elements such as arsenic, cadmium, chromium, copper, nickel, lead and zinc from contaminated soil in the case study. It was found that plants remove elements by absorbing and binding various elements organically in their biomass. Hence, phytoremediation potential of different species of plants shall be assessed for absorbing different elements. The experimental study rather being of a short duration concludes that there is scope for plants to absorb organic materials and stabilise kitchen wastewater.

In the case study, during the first year of growth, all the species of plants have absorbed and stored toxic elements in their biomass specially in their shoot, leaves and flowers but very less amount was found to accumulate in the roots. Also, due to the photosynthetic activity, leaves contain the most concentration of absorbed element. On the contrary, after the second year of growth, it is evident that roots now actively store toxic elements in it. And maximum concentration of toxic elements later is found in roots. Whereas, concentration of toxic element does not seem to increase significantly in other parts of the plant. Plant species such as *artemisia vulgaris*, *urtica dioica*, *achillea millefolium* show maximum accumulation of arsenic in the leaves. *Urtica dioica* also shows arsenic retention in flowers. Arsenic has increased in leaves after two years of growth whereas, the increase in shoot and flower is not significant. *Alopecurus pratensis*, *bromus inermis*, *urtica dioica* show maximum retention of arsenic in roots. Species such as *artemisia vulgaris*, *stellaria holostea*, and *silene vulgaris* show



maximum uptake of cadmium in the leaves. Uptake of cadmium has not increased significantly in the leaves, shoot and flower after two years of growth. *Galium mollugo*, *alopecurus pratensis*, and *holcus lanatus* show maximum retention of cadmium in roots. Species such as *urtica dioica* and *artemisia vulgaris* show maximum uptake of chromium in the flowers; whereas *urtica dioica*, *galium mollugo*, and *silene vulgaris* shows high accumulation in leaves. Whereas, the uptake of chromium has decreased significantly in the leaves, shoot and flower. *Holcus lanatus*, *alopecurus pratensis*, *galium mollugo*, and *arrhenatherum elatius* show maximum retention of chromium in roots.

Species such as *artemisia vulgaris* and *achillea millefolium* show maximum uptake of copper in the leaves; whereas *alopecurus pratensis* shows high accumulation in the shoot. Whereas the uptake of copper remains unchanged in the leaves, shoot and flower. All the species show high concentration of copper with *galium mollugo*, *holcus lanatus*, and *poa angustifolia* show maximum retention of copper in roots. Species such as *achillea millefolium*, *artemisia vulgaris*, and *holcus lanatus* show maximum uptake of nickel in the shoot; these species also show high accumulation in the leaves and flowers. Whereas the uptake of nickel also increase in the leaves, shoot and flower. All the species show high concentration of nickel with *holcus lanatus*, *arrhenatherum elatius*, *achillea millefolium*, and *galium mollugo* show maximum retention of nickel in roots. Species such as *urtica dioica*, *galium mollugo*, *achillea millefolium*, and *artemisia vulgaris* show maximum uptake of lead in the leaves. Uptake of lead has been observed to decrease in the leaves, shoot and flower after second year of growth. *Alopecurus pratensis*, *holcus lanatus*, *galium mollugo*, and *achillea millefolium* show maximum retention of lead in roots. Species such as *artemisia vulgaris*, *stellaria holostea*, and *silene vulgaris* show maximum uptake of zinc in the leaves; whereas *artemisia vulgaris* also shows high accumulation in the shoot., whereas the uptake of zinc increase slightly in the leaves and flower. On the contrary, concentration of zinc in shoot has fallen. All the species show high concentration of zinc with *alopecurus pratensis*, *galium mollugo*, and *arrhenatherum elatius* show maximum retention of zinc in roots. *artemisia vulgaris*, *stellaria holostea* still show highest built-up of zinc in leaves. Concentration of elements pairs such as Cu-Cd, Zn-Cd and Pb-Cr pairs show strong positive correlation in roots. Zn-Cd pair appears to have strong positive correlation in the shoot. In general, Zn-Cd show strong correlation in all components i.e., root, shoot, leaf and flower. Numerous elements in environment tends to be toxic, hence release of such pollutants shall be consciously disposed taking adequate measures.

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## *Annexure I: Raw Data*

*Table A-1 Experimental Study Data*

Species		pH	TDS, mg/l	EC, mg/l	BOD, mg/l	COD, mg/l	TP, mg/l
Hibiscus rosa-sinensis	Sample 1	7.4	261	495	320	548	4.73
	Sample 2	7.4	280	512	320	547	4.99
	Sample 3	7.45	248	476	310	545	5.1

*Table A-2 Case Study Data (Antoniadis et al., 2021)*

<i>Species</i>		2004							2005						
		As,	Cd,	Cr,	Cu,	Ni,	Pb,	Zn,	As,	Cd,	Cr,	Cu,	Ni,	Pb,	Zn,
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	LoQ	0.0208	0.0052	0.0156	0.0094	0.0271	0.0104	11.5	0.0208	0.0052	0.0156	0.0094	0.0271	0.0104	11.5
<i>Alopecurus pratensis</i>	Shoot	0.77	11.65		32.36	5.15	0.51	309							
		0.52	1.54		4.73		0.37	194.1							
	Leaf	1.07	10.5		22.81	5.96	1.03	640	2.22	4.36	4.63	20.51	7.36	1.09	725



Species		2004						2005							
		As,	Cd,	Cr,	Cu,	Ni,	Pb,	Zn,	As,	Cd,	Cr,	Cu,	Ni,	Pb,	Zn,
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	LoQ	0.0208	0.0052	0.0156	0.0094	0.0271	0.0104	11.5	0.0208	0.0052	0.0156	0.0094	0.0271	0.0104	11.5
		0.24	3.67		3.14	0.63	0.46	274.5	1.11	2.11	9.47	34.57	7.05	0.63	176.7
	Flower	1.2	7.52				0.83	311.8							
		0.16	4.32				0.65	139.3							
	Root								19.2	75.08	15.5	74.5	16.05	17	1296
									3.25	40.92	9.41	15.15	3.55	9.74	217.4
<i>Elytrigia repens</i>	Shoot	0.87	4.01		16.77		2.85	319.1	0.42	1.32	0.54	8.88	1.82	0.35	248.7
		0.57	0.84		1.99		4.54	72.24	0.07	0.25	0.16	2.61	0.51	0.06	74.51
	Leaf	1.41	2.58		18.33		2.3	209.7	1.19	1.23	1.55	10.2	1.88	1.34	177
		0.48	0.93		2.22		1.1	96.68	0.37	0.77	0.22	2.03	0.63	0.91	7.48
	Flower														
	Root														
<i>Poa angustifolia</i>	Shoot	0.51	10.26		11.19	7.32	0.55	211.1	0.29	2.1	0.97	4.34	4.7	0.32	150.6
		0.21	5.63		0.51	1.22	0.39	29.83	0.13	1.03	0.29	0.61	0.43	0.15	49.57
	Leaf	0.92	6.27		14.74	6.79	0.74	269.5	0.75	2.46	1.23	4.89	4.64	1.55	184.6
		0.22	1.74		3.39	1.45	0.29	50.78	0.25	0.87	0.21	0.76	1.31	0.56	47.54
	Flower	0.73	3.69				0.33	170.3							
	Root								4.79	17.9	8.35	88.25	13.83	7.86	390.2
									1.42	6.09	1.7	3.95	0.36	5.85	19.55

Species		2004							2005						
		As,	Cd,	Cr,	Cu,	Ni,	Pb,	Zn,	As,	Cd,	Cr,	Cu,	Ni,	Pb,	Zn,
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	LoQ	0.0208	0.0052	0.0156	0.0094	0.0271	0.0104	11.5	0.0208	0.0052	0.0156	0.0094	0.0271	0.0104	11.5
<i>Holcus lanatus</i>	Shoot	0.47	4.4		12.84	9.65	0.32	102.5	0.54	3.57	0.89	3.93	6.24	0.55	181.3
		0.12	2.2		2.71	1.14	0.18	33.81	0.05	0.95	0.19	0.37	0.88	0.32	64.75
	Leaf	1.23	3.05		10.14	7.14	0.96	74.6	2.87	3.53	1.97	5.88	9.5	1.55	165
		0.28	1.11		1.08	1.24	0.48	11.37	1.77	1.11	1.05	1.33	2.05	1.04	25.77
	Flower								0.48	3.28	2.01	7.2	10.3	0.73	146.7
Root								13.64	48.3	17.68	100.25	26.18	14.09	633.5	
								5.01	11.67	7.05	3.59	2.96	11.45	76.99	
<i>Arrhenatherum elatius</i>	Shoot	0.66	6.84		11.47	6.05	0.36	273.1	0.43	3.36	0.7	4.88	3.95	0.17	144.3
		0.22	1.77		1.58	0.77	0.16	172.2	0.02	1.78	0.36	0.93	1.76	0.1	20.02
	Leaf	1.43	4.61		10.81	6.5	0.92	211.5	3.28	5.17	1.39	9.31	5.11	1.03	248
		0.76	1.79		1.7		0.53	72.17	2.47	1.25	0.47	0.84	1.91	0.43	54.95
	Flower	1.07	1.77			8.23	0.17	178.1	0.4	0.55	3.3	10.4	19	0.51	85.6
Root	0.75	0.8			2.98	0.07	54.22								
								11.43	37.2	10.3	82.25	22.18	10.58	1007	
								2.35	3.8	1.84	4.99	0.86	1.33	108.8	
<i>Bromus inermis</i>	Shoot	0.56	13.7		11.87		0.15	395.3	2.79	1.5	2.83	20.45	8.7	1.3	281.4
		0.21	0.14				0.03	224.4	1.84	0.58	4.6	32.22	7.01	0.86	64.7
	Leaf	1.37	6.15		12.56		0.98	135.2	7.8	1.73	4.7	19.74	12.66	5.78	411.4
		0.36	0.51				1.33	72.48	4.47	1.03	2.56	3.68	3	3.4	145

<i>Species</i>	2004							2005							
	As, mg/kg	Cd, mg/kg	Cr, mg/kg	Cu, mg/kg	Ni, mg/kg	Pb, mg/kg	Zn, mg/kg	As, mg/kg	Cd, mg/kg	Cr, mg/kg	Cu, mg/kg	Ni, mg/kg	Pb, mg/kg	Zn, mg/kg	
	LoQ	0.0208	0.0052	0.0156	0.0094	0.0271	0.0104	11.5	0.0208	0.0052	0.0156	0.0094	0.0271	0.0104	11.5
	Flower	0.31	1.14			7.27	0.38	71.5	11.16	12.56	3.48	25.87	16.93	6.63	362.7
									10.52	20.12	3.14	5.01	11.51	6.04	340.1
	Root								14.7	33.55	6.85	86	20.65	8.72	720.5
									2.97	11.24	2.62	19.8	5.3	3.93	202.9
<i>Artemisia vulgaris</i>	Shoot	1.27	35.21	6.55	18.36	7.53	0.95	1014	2.19	27.82	4.75	74.18	17.44	1.63	702.7
		0.59	17.64		17.45	8.71	1.18	693.2	2.33	10	3.69	52.49	11.2	2.26	189.6
	Leaf	4.84	56.01		45.53	13.86	2.89	1169	10.93	56.72	1.38	20.72	7.3	1.98	1221
		2.43	19.17		15.25	8.24	1.34	470.9	2.34	54.63	1.69	27.91	6.56	0.55	902
	Flower	0.76	22.49		22.24	19.2	0.56	237.1	0.44	18.7	1.92	77	12.9	0.39	142.5
		0.44	6.59		2.98	2.65	0.37	102.8							
	Root								8.49	19.55	2.42	52.25	12.09	8	877.3
									5.8	7.77	2.09	27.43	5.22	6.12	173.3
<i>Urtica dioica</i>	Shoot	1.45	1.11	7.85	16.46	8.59	2.89	349	1.8	7.08	1.98	10.72	5.74	2.05	319.2
		1.37	0.67	1.5	5.02	1.88	2.93	239.6	0.88	14.55	1.17	3.15	1.43	1.34	47.98
	Leaf	3.81	0.84	7.85	18.01	9.16	12.85	380.9	6.7	14.7	6.33	21.17	12.43	9.15	464.8
		2.14	0.37	1.61	3.82	2.13	4.45	111.1	4.31	25.18	2.89	4.76	2.09	10.71	68.89
	Flower	3.11	0.45	11.13	19.03	9.1	6.89	238.1	2.88	0.69	5.04	28.2	10.23	4.75	184.4
		4.81	0.59	7.21	5.25	2.68	11.37	139.2	2.54	0.23	4.06	1.71	0.83	4.52	11.11
	Root								15.6	29.13	7.13	81.38	19.43	8.34	781
									3.86	7.16	2.34	21.9	4.45	2.71	145.6

Species		2004							2005						
		As, mg/kg	Cd, mg/kg	Cr, mg/kg	Cu, mg/kg	Ni, mg/kg	Pb, mg/kg	Zn, mg/kg	As, mg/kg	Cd, mg/kg	Cr, mg/kg	Cu, mg/kg	Ni, mg/kg	Pb, mg/kg	Zn, mg/kg
		LoQ	0.0208	0.0052	0.0156	0.0094	0.0271	0.0104	11.5	0.0208	0.0052	0.0156	0.0094	0.0271	0.0104
<i>Achillea millefolium</i>	Shoot	1.16	11.26		30.27	26.52	2.01	179	0.7	9.1	2.26	5.47	6.8	0.87	130.2
		1.28	5.41			14.04	2.19	209.2	0.09	1.39	2.01	1.06	2.15	0.45	22.84
	Leaf	3.48	20.46		35.6	14.02	3.36	655.6	3.34	24.34	1.83	20.19	10.7	2.82	778.9
		1.26	5.98		6.4	8.15	2.59	242.6	1.04	6.15	0.54	4.52	1.82	1.35	158.6
	Flower	0.98	9.15		30.27	13.85	1.44	270.8	0.37	6.3	0.58	17.9	19.3	0.68	196.9
		1.39	6.59			2.58	1.84	181.7							
	Root								4.7	23.83	6.93	62.75	21.15	11.58	828.5
									0.75	4.31	1.68	8.5	2.02	0.95	158.6
<i>Galium mollugo</i>	Shoot	1.56	14.53		12.2	8.21	4.38	506.5	0.72	12.29	0.75	5.41	2.88	0.96	466.2
		1.06	6.01				1.07	285	0.17	2.48	0.17	0.97	0.87	0.35	110.2
	Leaf	2.09	15.48	8.76	16.97	8.24	4.5	500.7	0.99	12.93	0.89	5.84	3.89	1.23	482.8
		1.29	5.71	1.43	3.55	1.49	4.7	211.3	0.42	2.01	0.34	1	1.16	0.66	104.1
	Flower	0.68	13.98			5.97	1.68	226.8	0.69	7.82	0.99	8.65	4.29	0.92	279.5
		0.43	1.79					127.7	0.34	4.86	0.41	2	0.94	0.44	108.9
	Root								8.08	117	10.38	137.25	20.95	11.95	1208
									3.9	8.12	2.49	18.46	1.68	8	96.7
<i>Stellaria holostea</i>	Shoot	0.89	29.29		10.6		0.76	693.1	0.94	20.13	1.14	7.35	2.54	1.55	637
		0.61	12.91		1.29		0.24	137.9	0.46	5.95	0.93	0.9	0.64	2.15	62.09
	Leaf	0.9	37.7		15.22	6.55	1.3	1035	0.94	27.92	1.31	10.74	5.08	1.12	1017
		0.54	20.69		4.05	1.15	0.53	393.1	0.35	13.93	0.46	3.27	1.14	1.2	208.7

<i>Species</i>	2004							2005							
	As, mg/kg	Cd, mg/kg	Cr, mg/kg	Cu, mg/kg	Ni, mg/kg	Pb, mg/kg	Zn, mg/kg	As, mg/kg	Cd, mg/kg	Cr, mg/kg	Cu, mg/kg	Ni, mg/kg	Pb, mg/kg	Zn, mg/kg	
	LoQ	0.0208	0.0052	0.0156	0.0094	0.0271	0.0104	11.5	0.0208	0.0052	0.0156	0.0094	0.0271	0.0104	11.5
	Flower							0.2	11.3	1.15	8.5	4.2	2.26	225.7	
	Root							13.9	48	5.05	54.5	15.85	9.23	930	
								0.43	3.11	0.35	0.71	0.64	4.14	62.23	
<i>Silene vulgaris</i>	Shoot	0.78	19.14	10.63	11.2	9.66	1.92	584.3	0.34	4.29	0.62	4.35	5.18	0.26	342.5
		1.72	10.54		3.55	2.79	2.98	507.7	0.03	2.84	0.18	0.79	0.59	0.06	39.69
	Leaf	1.41	25.23	9.63	11.46	8.33	3.44	911.6	0.93	18.63	1.55	8.23	10.33	2.21	1304
		1.25	6.95		1.48	2.7	2	342.8	0.42	3.55	0.63	0.62	1.47	1.08	186
	Flower	0.1	5.62	6.81	10.18	6.53	0.75	162.3	0.09	2.58	0.48	8.5	5.68	0.86	202
		0.06	3.52		1.57	1.15	0.25	44.7	0.01	1.03	0.13	0.88	0.22	1.19	16.21
	Root							6.82	33.49	3.17	25.98	13.05	6.07	463	
								0.87	22.52	0.55	4.54	1.17	3	57.9	

# *Vitae*

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