Materials International
Open-Access Journal (ISSN: 2668-5728)

Review
Volume 7, Issue 4, 2025, 38
https://doi.org/10.33263/Materials74.038

Appraisal of Accumulation of Heavy Metals (Ni, Cu, Cd, Zn, and Pb) in Plants by Phytoremediation Mechanism: Sustainable Green Environment

Nur Adam Imam [1], Shruti Nagar [1], Jitin Rahul [1,*]

[1] Department of Environmental Sciences, Sharda School of Engineering and Science, Sharda University, Greater Noida-201210, Uttar Pradesh, India
* Correspondence: jitin.nature@gmail.com;

Received: 12.04.2025; Accepted: 5.08.2025; Published: 10.12.2025

Abstract: The main cause of soil contamination comes from wastes produced by mining, chemical, metal processing, and other related sectors. Essential and non-essential heavy metals are an inherent part of the environment. A rise in geologic and anthropogenic activities has led to an increase in soils that are polluted with heavy metals. The majority of environmental pollutants include Ni, Cu, Cd, Zn, and Pb, especially in regions with significant anthropogenic pressure. Owing to the detrimental impacts on food security, economic benefits, and crop growth resulting from phytotoxicity, as well as on the environmental health of soil micro-organisms, heavy metal aggregation is a significant consideration for agricultural productivity and production in affected soils. Phytoremediation is a very good technique to mitigate heavy metal contamination in the soil. In this article, we critically evaluated how these heavy metals affect plants and their reproduction, development, and growth processes, due to their biological and geological fixation in water and soil pollution. The analysis revealed that heavy metal presence plays a role in both growth and photosynthetic pigments. Hyperaccumulator plant species (*Sansevieria trifasciata*, *Zea mays*, *Asparagus racemosus*, and *Asparagus racemosus*) are used in the phytoremediation process, which is a systematic way to remediate soil or land that has been contaminated with heavy metals, to remove the harmful effects of the heavy metal that is transported on the basis of accumulation in the soil. This appraisal underscores the significance of phytoremediation as a viable strategy for sustainable environmental management and restoration of polluted sites.

Keywords: environment; heavy metals; plants; soil pollution; toxicity.

1. Introduction

Toxicity in heavy metals is known as an excess of needed accumulation. In some cases, it is the unlinked form that is naturally present on the surface of the earth and becomes concentrated during human-caused activities. When a metalloid or HM is highlighted for its potential to cause toxicity, specifically in environmental settings, it is considered toxic. Perceiving, diet, and manual use are all avenues through which heavy metals can enter the human tissues, plants, and animals. They can also bind to and impair the function of essential cellular components. Because of their toxicity, heavy metals have historically been significant environmental pollutants for nutritional, ecological, evolutionary, and environmental factors

[1]. These include heavy metals Ni, Cd, Fe, Pb, Co, Zn, Cr, Ag, and As. These heavy metals and metalloids have an atomic weight higher than 4 g/cm^3 or even more. The term "environment" means the total vicinity of a condition occurring within multiple organisms or a collection of some organisms, specifically the mix of physical factors that plays a vital role in the organisms' survival, development, and growth. They are generally found scattered among formations of the rock. Heavy metals were introduced into the earth's biosphere by human activities, with the greatest availability in soil and marine ecosystems and a comparatively small proportion in the atmosphere as aerosols and water vapors. Since most heavy metals play essential roles in plant reproduction, growth, and development, their toxicity levels in plants vary with plant genus, family, or species, soil composition, soil pH, specific metal concentration, and chemical form. Certain heavy metals, including Zn and Cu, either operate as cofactors or enzyme activators. It displays metallic features such as malleability, ductility, ligand selectivity, cation stability, and conductivity, and is distinguished by a high relative atomic weight and comparatively high density [2]. Although organisms need only trace amounts of heavy metals such as manganese, cobalt, tin, nickel, and zinc, these elements can become toxic at higher levels.

1.1. Overview of heavy metal toxicity.

Heavy metals like Ni, Cu, Zn, Pb, and Cd, (are metalloid but normally termed to be as an HMs) these are very harmful and poisonous to both humans, plants, microbes and animals, because they pollute the environment and its surroundings (air, soil and hydrological parts), which will be deadly, toxic or harmful, and will have a great effect on all living components Figure 1. As a result, they are considered to be the 'main threats' because they do not have any benefits for organisms. Selected plant species roots (Normal) are the central point of contact for heavy metals in the environmental and ecological food energy flow, where they are absorbed in the autotrophic stage and subsequently consumed by secondary consumer reproduction. However, in marine systems, where floral bodies are exposed on the water surface to these ions and particles are left on the foliar surfaces of the leaf, heavy metals (HM's) are directly injected into leaf parts. This essay reviews the nature, characteristics, and effects of soil contamination with heavy metals on plant growth [3-5].

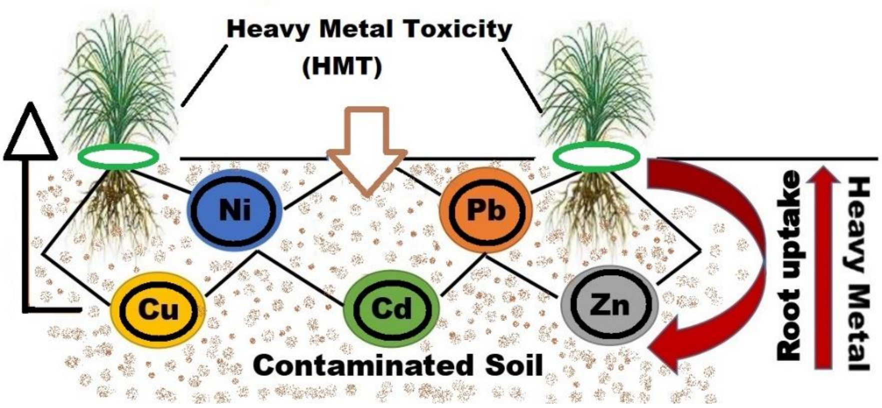

Figure 1. Heavy metal toxicity (HMT) in the contaminated soil.

1.2. Phytoremediation mechanisms.

Heavy metal contamination is increasingly becoming a major environmental concern, especially in urban and industrial areas where industrial discharges and vehicle emissions occur regularly. The accumulation of roadside metals such as lead, zinc, nickel, and cadmium is mainly driven by tire wear, brake lining wear, fuel combustion, and atmospheric deposition (Figure 2).

Phytodegradation is a subset of phytoremediation that uses plants and the microbes in the rhizosphere to break down or transform toxic pollutants, such as certain metal complexes bound to organic matter, into less harmful forms. Heavy metals benefit indirectly from phytodegradation, despite the fact that it has historically been more effective for organic pollutants.

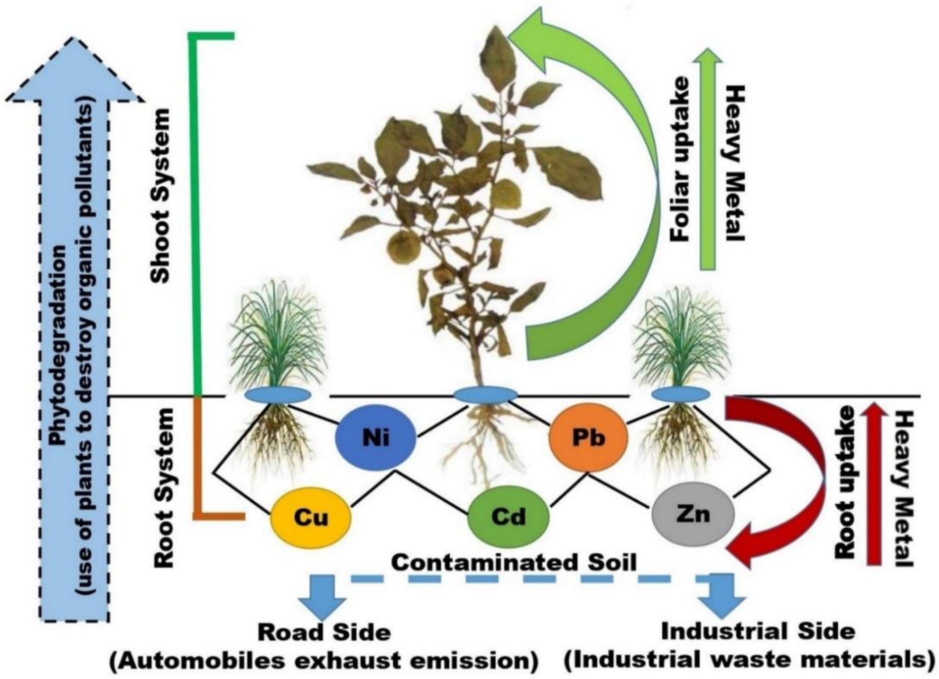

Figure 2. Overview of the heavy metals (HMs) accumulation along the roadside and around the industrial side by phytodegradation.

2. Physiological and Biochemical Effects in Plants

Heavy metals are known to contain a multiple vital aspect in the life of plants: they are major important components in carrying out plant anabolism, catabolism, and metabolism, but the level of accumulation in much concentrations in the soil increases the uptake in plants and can lead to harm or toxicity to the different parts and levels of the selected plants (grass, herb, shrub and tree) [6-8]. By determining and understanding the chemical composition of different plants, one can establish the features for identifying the capacity of plant families and species, their ultimate use as sensitive bioindicators, and their role as bio-monitors for soil contamination states with HVMs. In addition, most plants can be utilized as an agent or component of material [9-14]. Heavy metal aggregation in some selected plant species results from a constant interaction among the plant root system, shoots, various soil particle sizes, soil texture, and natural minerals via interactive adsorption. A certain activity happens for the reason of the sharing of organic acids and hydrogen ions (H^+), which are produced by any type of roots for metal ($^+$) in soil. The degree of metal ($^+$) absorbed from the rigid stage by plants or vegetation species can differ, from hundreds to thousands of rounds. Its uptake is influenced by various factors, including physicochemical properties, morpho-anatomical, physiological, biochemical, and climatic conditions, across different types of plant parts [15-18]. There are complicated interactions between heavy metals and plants. As plants need nutrients for vital physiological functions, heavy metals require trace amounts of nutrients for healthy, adequate growth [16]. Essential functions can be disrupted by inadequate or toxic quantities, which can result in ill health or death. The type of metal, its concentration, bioavailability, and the species all affect how much toxicity or deficiency a plant can withstand to survive. Both maximum (Max) and minimum (Min) levels of (HMs) heavy metal concentrations in roadside and industrial side soil uptake can have an adverse effect on agricultural crop development and proper growth because these metals interfere with plant metabolism, inhibiting respiration and photosynthesis as well as causing organelle degeneration and even plant death Figure 3.

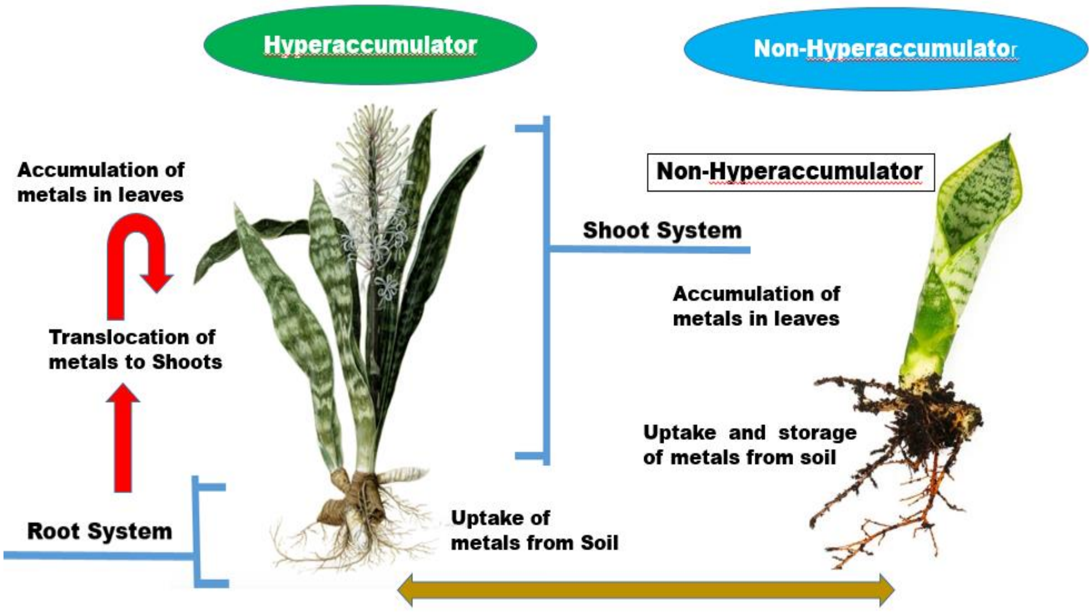

Figure 3. Hyper accumulation and non-hyper accumulation efficiency of Heavy metals through the shoot system and root system of snake plant (*Sansevieria trifasciata*).

2.1. Cadmium (Cd).

Heavy metal cadmium (Cd), which is very uncommon, naturally occurs in mixtures with other metals. Due to its prevalence in soil and car gasoline, cadmium is usually found in roadside dust. As a result, road dust can expose people to Cd through breathing. The intake of Cd compounds following inhalation might depend significantly on the particle ranges and their solubility. A metal called cadmium can be extremely hazardous to people. Long-term Cd exposure can have negative effects on a number of organs, such as the kidneys and urinary tract, as the main target. According to ATSDR- agency for toxic substances and diseases registry, 2012. Toxicology outline of Cd metal Table 1. The following outcomes were made along the Islamabad Expressway on the different levels of cadmium in the samples of roadside dust.

Table 1. Cadmium (Cd) concentration in the soil and bioaccumulation factors (BAF) in *Zea mays* L. (Maize)

S. No.	Sampling Locations	Cadmium (mg kg^{-1})	Bioaccumulation factor (BAF)	References
1.	Industrial pollution (IP)	0.119-0.199	0.081-0.135	[19]
		0.09-0.29	0.17-0.56	[20]
		0.11-3.11	0.00076-0.0049	[21]
		1.58-3.87	0.0019-0.002	[22]
		0.14-0.24	0.1-0.25	[23]
2.	Mining and smelting (MS)	69.0-2300.0	0.005-0.59	[24]
		5.8-74.0	0.01-0.54	[25]
3.	Dumpsites (DS)	1.40-2.59	0.15-0.44	[26]
		21.9-138	0.03-0.058	[27]
4.	Municipal water irrigated (MWI)	3.8-4.1	0.05-0.28	[28]
		0.1-0.27	0.47-0.71	[29]
5.	Battery waste dumpsite (BWD)	163.96-258.38	0.176-0.197	[30]

2.2. Zinc (Zn).

Micronutrient zinc (Zn) is crucial for bodily processes. Zinc is a component of enzymes and also activates a variety of enzymatic processes [31]. Numerous aspects of plant life are significantly influenced by zinc, including nitrogen metabolism, nitrogen uptake, photosynthesis, chlorophyll, protein quality, carbon metabolism, resilience to biotic and abiotic stressors, and defense against additional oxidative damage. In agricultural growth deficiency in Zn is reported frequently Zn deficient in all plants experience stress physiologically brought on by altered metabolic processes and dysfunctional enzymes, stunted growth, inter-venal chlorosis in pre mature leaves, necrotic tips, and has great issues with photosynthetic processes are all indications of a deficit Zn poisoning causes plants to experience physiological stress brought on by altered metabolic processes and dysfunctional enzymes Table 2.

Table 2. Zinc (Zn) concentration in the soil and bioaccumulation factors (BAF) in *Zea mays*.

S. No.	Sampling locations	Zinc (mg kg^{-1})	Bioaccumulation factor (BAF)	References
1.	Industrial pollution (IP)	70.58-85.15	0.203-0.245	[19]
		27.21-30.78	0.23-0.99	[32]
2.	Mining and smelting (MS)	260.0-5500.0	0.03-0.25	[25]
		99.68-99.86	0.678-0.789	[33]
3.	Dumpsites (DS)	156.78-243.81	0.047-0.40	[26]
		63.0-80.2	0.07-0.40	[27]
4.	Municipal water irrigated (MWI)	8.47-12.13	0.1-0.26	[34]
		16.0-162.5	0.44-0.88	[35]
		146.1-238.9	0.18-0.34	[28]

2.3. Lead (Pb).

A silvery-grey or slightly blue metal with an atomic mass of 207.19, and an atomic number of 82, and has a specific gravity of 11.34, lead (Pb) at atmospheric pressure has a boiling point of 1740°C and a melting temperature of 327.5°C. With atomic weights of 208, 206, 207, and 204, it has four naturally present isotopes (in inverse order of relative excess). Its valence shell has four electrons, which is considerably, lead does not necessarily have an oxidation state of +2 as opposed to +4 because only about two out of the four electrons have the capacity to be rapidly ionized. Mostly, the inorganic salt content of lead2+, with the exception of chlorate, nitrate, and chloride, has limited solvability in water World Health Organization) [36, 37]. Lead toxicity or poisoning, collected or retrieved from Lead (Pb), is among the most widespread and consistently shared trace metals today. It can be present in many different forms in natural origins throughout the world. The (Pb) lead comes in various ways from industrial sources, automobile exhaust, fumes, and dust, which can pollute soil and plants within the affected vicinity. Pb^{2+} has been discovered to be acutely harmful to humans in maximum concentrations. Since Pb^{2+} cannot be degraded, once soil or land has been poisoned or when toxic elements are present, it continues to be a source of Pb^{2+} exposure for a considerable number of years Table 3. Heavy metal occupying soil or contamination harms biological systems and doesn't degrade through biodegradation.

Table 3. Lead (Pb) concentration in the soil and bioaccumulation factors (BAF) in *Zea mays* L. (Maize).

S. No.	Sampling locations	Lead (mg kg^{-1})	Bioaccumulation factor (BAF)	References
1.	Industrial pollution (IP)	34.42-42.27	0.0008-0.001	[19]
		12.73-32.40	0.49-1.08	[32]
		21.7-34.0	0.01-0.013	[20]
		33.62-122.1	0.007-0.009	[22]
2.	Mining and smelting (MS)	7.4-55.0	0.083-0.909	[24]
		60.0-570.0	0.002-0.119	[25]
3.	Dumpsites (DS)	6.36-7.76	0.06-0.32	[26]

S. No.	Sampling locations	Lead (mg kg^{-1})	Bioaccumulation factor (BAF)	References
4.	Municipal water irrigated (MWI)	34.76-39.75	0.00075-0.0086	[38]
		10.89-12.39	0.11-0.19	[34]
5.	Battery waste dumpsite (BWD)	3265.8-1273.8	0.0096-0.0105	[30]

2.4. Nickel (Ni).

The earth's crust, nickel, is naturally mixed with other elements. Every soil contains it. It is widely observed as the sulfate or oxides of the environment when related to oxygen or Sulphur. Additionally, power stations that burn coal, oil, and trash incinerators release nickel into the environment. People are usually exposed to Ni by coming into contact with it at their workplaces and, in some cases, even people living around them are at risk to their health, according to the Occupational Safety and Health Administration (OSHA).

2.5. Copper (Cu).

One of the most common heavy metal pollutants in the environment, copper comes from both natural and manufactured sources [39]. Although copper is essential for the best possible growth and development of plants, it can also be hazardous [40]. Due to the careless use of pesticides, fungicides, industrial effluents, and wastewater irrigation, copper (Cu) pollution in agricultural soils is a significant obstacle to sustainable agro-food production, especially in developing nations. Numerous essential enzymes involved in numerous vital biological processes contain copper (Cu). It is a part of plastocyanin, a Cu protein that serves as the photosystem's main electron donor. By boosting the production of ROS, copper excess puts plants under oxidative stress [41].

Table 4. Copper (Cu) concentration in the soil and bioaccumulation factors (BAF) in *Zea mays* L. (Maize).

S. No.	Sampling Locations	Copper (mg kg^{-1})	Bioaccumulation factor (BAF)	References
1.	Industrial pollution (IP)	19.21-22.63	0.056-0.066	[19]
		2.25-33.97	0.011-0.99	[32]
2.	Mining and smelting (MS)	9.3-260.0	0.015-0.16	[25]
		99.91-99.94	99.91-99.94	[33]
3.	Dumpsites (DS)	20.17-21.41	0.1-0.47	[26]
		7.0-18.0	0.44-0.68	[27]
4.	Municipal water irrigated (MWI)	51.9-64.3	0.06-0.12	[28]

3. Bioaccumulation Factor (BAF).

Meanwhile, the bioaccumulation factor (BAF) is also used to calculate metal transfer from soil to various plant parts. He et al. [42] used the following equation to measure BAF:

$$BAF = \frac{C_C}{C_S} \quad (1)$$

Where Cc represents the element contents (in dry matter) in the plants, and Cs shows the element concentration in the corresponding soils. Meanwhile, [43] evaluated the BAF of vegetables as follows:

$$BAF = \frac{C_{plant}}{C_{Soil}} \quad (2)$$

C_{plant} shows the accumulation of heavy metals in the edible part of vegetables, and C_{soil} denotes the amount of heavy metals in soil. The BAF formula used [44] is as follows:

$$BAF = \frac{C_{grain}}{C_{Soil}} \quad (3)$$

Where C_{grain} is the amount of metal determined in the grain of the crop, and C_{soil} is the respective metal content in the soil.

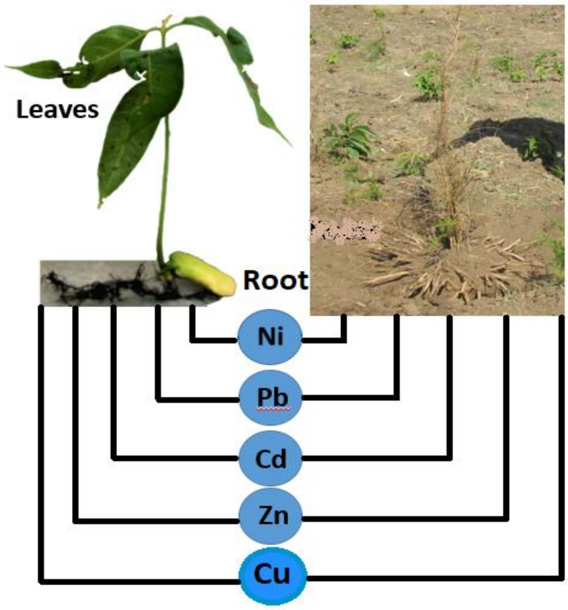

Figure 4. Phytoremediation by young plant (*Mangifera indica L.*) sapling and dry climber plant species (*Asparagus racemosus Willd.*).

4. Heavy Metals Permissible Status

Consequently, heavy metal concentrations or heavy metal amounts in soil and agricultural soil depend on soil texture, soil characteristics, and the soil composition application rate of contamination by chemical fertilizers/inorganic fertilizers, weedicides, pesticides, herbicides, sewage sludge, and industrial/domestic wastewater Figure 4. Table showing the standard of heavy metals limits, permissible level of heavy metals in soil or agricultural soil, and normal heavy metals ranges in plant species.

Table 5. World Health Organization (WHO)/Food and Agriculture Organization (FAO) permissible limit levels of toxic metals in agricultural soil [36, 37].

S. No.	Toxic elements	WHO maximum standard limits (ppm)	FAO/WHO maximum permissible limit values (mg/kg)	Heavy metals range in plant species (mg/kg)		
				Permissible value	Normal value	Toxic value
1	Nickel (Ni)	80	67.9	10	0.02-50	25
2	Copper (Cu)	30	73.3	10	2.5	30
3	Cadmium (Cd)	3	0.2	0.02	<2.4	3-30
4	Zinc (Zn)	300	99.4	0.60	20-100	500
5	Lead (Pb)	100	0.3	2	0.50-30	

5. Natural Sources of Heavy Metals (HMs).

Among the natural sources of heavy metals, igneous and sedimentary rocks are considered the most common. The concentration ranges (ppm) of heavy metals in the igneous and sedimentary rocks are listed in Table 6. It has been found that elements present in one rock type occur in varying proportions, and the proportions of different elements vary from one rock type to another [45].

Table 6. Natural sources of heavy metals range/concentrations (ppm) of (Ni, Cu, Cd, Zn, and Pb) in the rocks [46].

Heavy metals	Granite igneous	Black shales	Basaltic igneous	Sandstone	Shales and clay
Nickel (Ni)	18.0	6.4	45-410	0.2	20-250
Copper (Cu)	5-14	34-1500	48-240	2-41	18-180
Cadmium (Cd)	0.003-0.18	20.3-8.4	0.006-0.6	-	0.0-11
Zinc (Zn)	6-30	7-150	2-18	<1-31	16-50
Lead (Pb)	4-30	20-200	30-160	-	18-120

Heavy metal concentration can be determined according to the type of rocks and the surrounding ecosystem conditions [47]. In addition, soil formation is also considered one of the main reasons for heavy metals accumulation besides river sediments Figure 5.

The main sources of heavy metal pollutants are manmade sources (Anthropogenic) and natural sources.

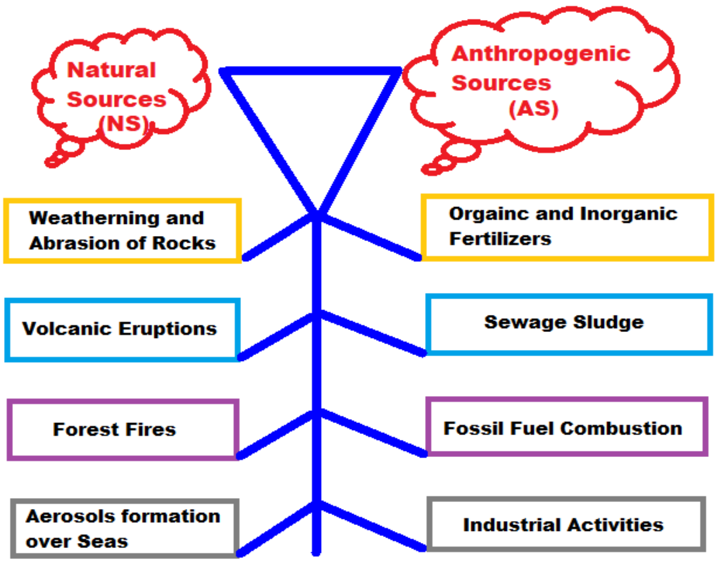

Figure 5. Natural and anthropogenic sources (Human activity) of heavy metals.

6. Global and Regional Accumulation Studies

Table 7 shows the variations of certain metals like Cu, Zn, Pb, Ni, and Cd in each Asian nation. Zn concentrations in Asian nations range from 13.3 to 3840 mg per kilogram, while Pb concentrations are between 11.1 and 1331 mg per kilogram. Ni concentrations ranged from 4.2 to 88 mg kg in different locations throughout Asia. The range of Cu concentrations reported for Asia is from 11.3 to 350 mg kg. The results for the Asian Cd content differ widely, from 1.17 to 5.0 mg kg[1] (Table 7). According to Asian countries' data, the Indian city Kolkata produces more Pd, the Pakistani city Islamabad produces more Cd, and the Chinese city Beijing produces more Ni and Zn into the environment.

Table 7. Asian countries (India, Pakistan, and China) differentiation of the heavy metals (HMs) Cd, Cu, Pb, Zn, Pb and Ni in roadside areas and industrial side areas.

Asian Countries (Capital)		Heavy Metals				Citation
City	Country	Ni	Pb	Zn	Cd	
Kolkata	India	42	536	159	3.12	[48]
Islamabad	Pakistan	23	104	116	5	[49]
Beijing	China	72	126	167	1.67	[50]

The World and Asian Countries Comparison of Roadside and Industrial areas, heavy metals concentration on plant diversity and soil: The aim of this comparison is to know the various effects of heavy metals (HM's) and their impact on plant species and soil around industrial and roadside areas worldwide to rate which continents suffers a lot, and also to determine which species of plant are good in terms of dust capturing efficiency and heavy metals uptake from the soil Table 8, 9 &10.

Table 8. Country-wise standards of heavy metals (HMs) in the soils (mg/kg) adapted from [51].

S. No.	Name of continent	Name of country	Heavy Metals (mg/kg)				
			Ni	**Cu**	**Cd**	**Zn**	**Pb**
1	Europe	Germany	200	200	5	600	1000
2	Europe	Netherlands	100	190	13	720	530
3	Asia	India	75-150	135-270	3-6	300-600	250-500
4	North America	USA	72	270	0.48	1100	200
5	North America	Canada	100	150	3	500	200
6	Asia	China	40-60	50-200	0.3-0.6	200-300	80
7	Australia	Australia	60	100	3	200	300
8	Africa	Tanzania	100	200	1	150	200
9	Zealandia	New Zealand	NA	$>10^4$	3	NA	160
10	Europe	UK	230	NA	1.8	NA	NA

Table 9. Range of variation and descriptive statistics for the HVMs concentrations in the contaminated land around roads and industrial areas compared with the other countries [52].

Counties	Concentration (μg g^{-1} soil)			
	Cd	**Ni**	**Pb**	**Zn**
London, UK	-	-	294.00	183.00
Bangkok, Thailand	26.00	25.00	48.00	118.00
Hong Kong	-	-	93.40	168.00
Palermo, Italy	-	-	202.0	138.0
Central Jordan	83.93	-	62.17	146.94
Canada	64.00	-	70.00	200.00
Argentina	41.10	2.42*	9.42*	106.00
Changchun, China	66.00	-	35.40	90.00
China	-	-	55.00	209.00
Nigeria	186.20	-	469.20	168.10
Montenegro	28.59	96.59	35.35	92.84

* Sample was extracted with HCl.

Table 10. Asian countries' analogy of HVMs Zn, Ni, Cd, and Pb at industrial/roadside [52].

Asian countries		Heavy metals			
Country	**City**	**Zn**	**Ni**	**Cd**	**Pb**
China	Beijing	167	72	1.67	126
China	Hong Kong	168	-	2.18	93.4
China	Hong Kong	3730	28.6	-	120
China	Shanghai	734.8	82.98	1.23	294.9
Bangladesh	Dhaka	154	26	-	74
India	Calcutta	159	42	3.12	536
Jordan	Amman	162-410	42-88	3.1-11.2	210-1131
Jordan	Karak	13.1	4.2	-	11.4
Korea	Taejon	162-215	-	-	52-60
Pakistan	Islamabad	116	23	5	104
Turkey	Istanbul	437-584	31-33	1.4 -2.3	105-556

6. Conclusion and Future Outlook

In heavy-metal-polluted soils, selected plant species exhibited stunted growth and reduced biomass due to alterations in their biochemical, anatomical, and physiological processes. Therefore, it has been clear from the results of several studies of heavy metals that, whether used wisely or present, they have hazardous effects on many living things after a certain threshold. The ecological balance of our world must thus be maintained by stepping up research to achieve a good understanding of the effects of heavy metal toxicity on plant parts and related regions. The relationship between trees, shrubs, herbs, grasses, and heavy metals has two sides: on the one hand, heavy metals are toxic to plants; on the other, plants have developed defenses against heavy metals, reducing their toxicity in heavy metal pollution. The analysis revealed that heavy metal presence plays a role in both growth and photosynthetic pigments. Hyperaccumulator plant species are used in the phytoremediation process, a systematic way to remediate soil or land contaminated with heavy metals, to remove the harmful effects of the heavy metals transported by soil accumulation. Phytoextraction is a widely accepted form of phytoremediation used to treat heavy metal-affected soil because it ensures the complete removal of pollutants. Phytoremediation may be considered a sustainable and cost-effective technique for mitigating heavy metal contamination in soil. Careful observation and analysis are necessary to assess the overall environmental impact. To identify safe delivery methods and how to combine them with other technologies, such as nanoremediation, more research is required. To produce biodegradable and biocompatible materials, more research is needed in addition to encouraging national policies. Large-scale, reasonably priced production of phytoremediation solutions is necessary for wider adoption.

Author Contributions

Conceptualization, J.R.; software and validation, S.N.; formal analysis and investigation, N.A.I.; review and editing, J.R. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement

NIL.

Informed Consent Statement

No.

Data Availability Statement

No.

Funding

No.

Acknowledgments

The authors would like to express their gratitude to the Vice-Chancellor, Prof. (Dr.) Sibaram Khara, Sharda University, Greater Noida, Uttar Pradesh, India, Dean Sharda School of Basic Science and Research Prof. (Dr.) Shyamal Kumar Banerjee, and Head of the Department of Environmental Science, Prof. (Dr.) Pramod Kumar Singh for their support and permission to submit this paper. Special thanks to Prof. (Dr.) Manish Kumar Jain, Department of Environmental Science and Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad, Jharkhand, India, who guided them to carry out this research work.

Conflicts of Interest

No conflicts of interest.

References

1. Bui, H.-T.; Odsuren, U.; Jeong, M.; Seo, J.-W.; Kim, S.-Y.; Park, B.-J. Evaluation of the air pollution tolerance index of 12 plant species growing in environments with different air pollution levels. *J. People Plants Environ.* **2022**, *25*, 23-31, https://doi.org/10.11628/ksppe.2022.25.1.23.
2. Saxena, G.; Purchase, D.; Mulla, S.I.; Saratale, G.D.; Bharagava, R.N. Phytoremediation of Heavy Metal-Contaminated Sites: Eco-environmental Concerns, Field Studies, Sustainability Issues, and Future Prospects. In Reviews of Environmental Contamination and Toxicology Volume 249, de Voogt, P., Ed.; Springer International Publishing: Cham, **2020**; Volume 249, pp. 71-131, https://doi.org/10.1007/398_2019_24.
3. Rahul, J.; Jain, M.K. An Investigation in to the Impact of Particulate Matter on Vegetation along the National Highway: A Review. *Res. J. Environ. Sci.* **2014**, *8*, 356-372, http://dx.doi.org/10.3923/rjes.2014.356.372.
4. Rahul, J.; Jain, M.K. Effect of Heavy Metals on Some Selected Roadside Plants and Its Morphological Study. *Nat. Environ. Pollut. Technol.* **2016**, *15*, 1133-1142.
5. Rahul, J. Stone Crusher Dust and Its Impact: Accumulation Efficiency of Some Woody Tree Species Around the Stone Crusher Plant (SCP). In Proceedings of the Sustainable Energy-Water-Environment Nexus in Deserts; Heggy, E., Bermudez, V., Vermeersch, M., Eds.; Springer, Cham, **2022**; pp. 621-627, https://doi.org/10.1007/978-3-030-76081-6_78.
6. Beregniak, E.; Beregniak, M.; Myronycheva, O.; Balabak, A.; Belava, V.; Boroday, V.; Nedilska, U.; Hudyma, V.; Kucher, L.; Voitsekhivskyi, V. Ecological Analysis of the Current State of Forest Resources in Forest Steppe of Ukraine. *J. Ecol. Eng.* **2023**, *24*, 87-96, https://doi.org/10.12911/22998993/155951.
7. Tretyak, L.N.; Rebezov, M.B.; Korablev, A.V.; Mikhaylova, T.M.; Voskanyan, E.A. Control by the accuracy of the results of studies for the cadmium content in samples applying the microwave laboratory system PLP-01M. *IOP Conf. Ser.: Mater. Sci. Eng.* **2021**, *1047*, 012183, https://doi.org/10.1088/1757-899x/1047/1/012183.
8. Munir, N.; Jahangeer, M.; Bouyahya, A.; El Omari, N.; Ghchime, R.; Balahbib, A.; Aboulaghras, S.; Mahmood, Z.; Akram, M.; Ali Shah, S.M.; Mikolaychik, I.N.; Derkho, M.; Rebezov, M.; Venkidasamy, B.; Thiruvengadam, M.; Shariati, M.A. Heavy Metal Contamination of Natural Foods Is a Serious Health Issue: A Review. *Sustainability* **2022**, *14*, 161, https://doi.org/10.3390/su14010161.
9. Abuova, A.B.; Rebezov, M.B.; Mukhamedyarova, L.G.; Shakirova, S.S.; Khaimuldinova, A.K.; Yermakhanova, F.R. Results of studies of wheat bread for lead content using the additive method. *IOP Conf. Ser.: Earth Environ. Sci.* **2021**, *677*, 052050, https://doi.org/10.1088/1755-1315/677/5/052050.
10. Zykova, I.; Maksimuk, N.; Rebezov, M.; Kuznetsova, E.; Derkho, M.; Sereda, T.; Kazhibayeva, G.; Somova, Y.; Zaitseva, T. INTERACTION BETWEEN HEAVY METALS AND MICROORGANISMS DURING WASTEWATER TREATMENT BY ACTIVATED SLUDGE. *J. Appl. Eng. Sci.* **2019**, *14*, 2139-2145.
11. Kuramshina, N.; Rebezov, M.; Kuramshin, E.; Tretyak, L.; Topuria, G.; Kulikov, D.; Evtushenko, A.; Harlap, S.; Okuskhanova, E. Heavy metals content in meat and milk of Orenburg region of Russia. *Int. J. Pharm. Res.* **2019**, *11*, 1301-1305.
12. Yermishev, O.V.; Mudrak, O.V. Environmental and comparison analysis of functional health of men of different age groups in radiation contaminated and conditionally pure regions. *Biol. Res. Nat. Manag.* **2019**, *11*, 108–118, http://dx.doi.org/10.31548/bio2019.05.012.
13. Cherkasova, E.I.; Rebezov, M.B.; Shariati, M.A.; Kharybina, M.M.; Muradova, Z.V. Monitoring the stability of the results of studies of chilled river fish for cadmium content using the method of additions. *IOP Conf. Ser.: Earth Environ. Sci.* **2021**, *677*, 052060, https://doi.org/10.1088/1755-1315/677/5/052060.
14. Bondar. V.; Makarenko. N. Impact of winter wheat cultivation technologies on lead accumulation and translocation. *Biol. Res. Nat. Manag.* **2019**, *11*, 41–50, http://dx.doi.org/10.31548/bio2019.01.005.
15. Imeri, R.; Kullaj, E.; Duhani, E.; Millaku, L. Impact of rootstock on heavy metal bioaccumulation in apple plant grown near an industrial source in Obiliq, Kosovo. *Agron. Res.* **2019**, *17*, 100–110, https://doi.org/10.15159/AR.19.012.

16. Mazhayskiy, Y.A.; Guseva, T.M.; Kurchevskiy, S.M.; Vcherashnyaya, V.V. Agrochemical methods for reducing the translocation ability of heavy metals in sod-podzolic soil. *Agron. Res.* **2022**, *20*, 310–317, https://doi.org/10.15159/AR.22.014.
17. Bondar, V.S.; Fursa, A.V.; Gumentyk, M.Y.; Svystunova, I.V. Climate Change: Apocalyptic Prognosis and Reality. *Ukr. J. Ecol.* **2020**, *10*, 273–278.
18. Olkhovych, O.; Taran, N.; Hrechishkina, S.; Voitsekhivska, O.; Panyuta, O.; Voitsekhivskyi, V.; Belava, V. Evaluation of Hyper-Tolerance of Aquatic Plants to Metal Nanoparticles. *J. Ecol. Eng.* **2022**, *23*, 249-259, https://doi.org/10.12911/22998993/150719.
19. Yu, R.; Wang, Y.; Wang, C.; Yu, Y.; Cui, Z.; Liu, J. Health risk assessment of heavy metals in soils and maize (*Zea mays* L.) from Yushu, Northeast China. *Hum. Ecol. Risk Assess., Int. J.* **2017**, *23*, 1493-1504, https://doi.org/10.1080/10807039.2017.1327800.
20. Stanislawska-Glubiak, E.; Korzeniowska, J.; Kocon, A. Effect of peat on the accumulation and translocation of heavy metals by maize grown in contaminated soils. *Environ. Sci. Pollut. Res.* **2015**, *22*, 4706-4714, https://doi.org/10.1007/s11356-014-3706-x.
21. Cai, B.X.; Huang, Y.; Wang, Y.; Li, H.X.; Chai, J.L. An analysis of differences in accumulation of heavy metals in main crops in a tin mining area of Yunnan Province. *Geological Bulletin of China* **2014**, 33(8), 1175-81.
22. Jin, Q.; Zeng, Q.H.; Zhu, B.; Wang, M.L.; Mou, Q.S. Investigation and risk assessment for the content of Pb and Cd in soil and vegetables of Zhoushui Bridge District. *Agriculture Science (China)* **2014**, 42(3), 199-202.
23. Yang, H.; Li, Z.; Lu, L.; Long, J.; Liang, Y. Cross-Species Extrapolation of Prediction Models for Cadmium Transfer from Soil to Corn Grain. *PLOS ONE* **2013**, *8*, e80855, https://doi.org/10.1371/journal.pone.0080855.
24. Bi, X.; Feng, X.; Yang, Y.; Li, X.; Shin, G.P.Y.; Li, F.; Qiu, G.; Li, G.; Liu, T.; Fu, Z. Allocation and source attribution of lead and cadmium in maize (*Zea mays* L.) impacted by smelting emissions. *Environ. Pollut.* **2009**, *157*, 834-839, https://doi.org/10.1016/j.envpol.2008.11.013.
25. Bi, X.; Feng, X.; Yang, Y.; Qiu, G.; Li, G.; Li, F.; Liu, T.; Fu, Z.; Jin, Z. Environmental contamination of heavy metals from zinc smelting areas in Hezhang County, western Guizhou, China. *Environ. Int.* **2006**, *32*, 883-890, https://doi.org/10.1016/j.envint.2006.05.010.
26. Oladejo, N.A.; Anegbe, B.; Adeniyi, O. Accumulation of Heavy Metals in Soil and Maize Plant (Zea mays) in the Vicinity of Two Government Approved Dumpsites in Benin City, Nigeria. *Asian J. Chem. Sci.* **2017**, *3*, 1-9, https://doi.org/10.9734/AJOCS/2017/37635.
27. Awokunmi, E.E.; Adefemi, O.S.; Asaolu, S.S. Tissues Accumulation of Heavy Metals by Maize (Zea maize L.) Cultivated on Soil Collected from Selected Dumpsites in Ekiti State, Nigeria. *Am. Chem. Sci. J.* **2015**, *5*, 156-162, https://doi.org/10.9734/ACSJ/2015/9262.
28. Asgari, K.; Cornelis, W.M. Heavy metal accumulation in soils and grains, and health risks associated with use of treated municipal wastewater in subsurface drip irrigation. *Environ. Monit. Assess.* **2015**, *187*, 410, https://doi.org/10.1007/s10661-015-4565-8.
29. Liu, W.-h.; Zhao, J.-z.; Ouyang, Z.-y.; Söderlund, L.; Liu, G.-h. Impacts of sewage irrigation on heavy metal distribution and contamination in Beijing, China. *Environ. Int.* **2005**, *31*, 805-812, https://doi.org/10.1016/j.envint.2005.05.042.
30. Afolayan, A.O.; Hassan, A.T. Lead, Cadmium and Iron Concentrations in *Zea Mays* Grown Within the Vicinity of Ori-Ile Battery Waste Dumpsite, Olodo, Ibadan, Nigeria. *Am. J. Biosci. Bioeng.* **2017**, *5*, 92-103, https://doi.org/10.11648/j.bio.20170505.11.
31. Mousavi, S.R. Zinc in Crop Production and Interaction with Phosphorus. *Aust. J. Basic Appl. Sci.* **2011**, *5*, 1503-1509.
32. Ibrahim, K.N.; Yet, Z.R.; Som, A.M.; Razali, N.; Rahaizah, N.A.M.; Othman, E.N.; Burok, N.A.; Yunos, Y.M.; Othman, R.; Yahya, T.F.T. Heavy metal concentration (Pb, Cu, Fe, Zn, Ni) in plant parts of *Zea mays* L. cultivated in agricultural area near Alor Gajah, Melaka, Malaysia. *Am. J. Environ. Eng* **2015**, *5*, 8-12.
33. Rattan, R.K.; Datta, S.P.; Chhonkar, P.K.; Suribabu, K.; Singh, A.K. Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. *Agr. Ecosyst. Environ.* **2005**, *109*, 310-322, https://doi.org/10.1016/j.agee.2005.02.025.
34. Lu, Y.; Yao, H.; Shan, D.; Jiang, Y.; Zhang, S.; Yang, J. Heavy Metal Residues in Soil and Accumulation in Maize at Long-Term Wastewater Irrigation Area in Tongliao, China. *J. Chem.* **2015**, *2015*, 628280, https://doi.org/10.1155/2015/628280.

35. Lu, A.; Zhang, S.; Shan, X.-q. Time effect on the fractionation of heavy metals in soils. *Geoderma* **2005**, *125*, 225-234, https://doi.org/10.1016/j.geoderma.2004.08.002.
36. World Health Organization. 6.7. Lead. In Air Quality Guidelines for Europe, 2nd Edition; WHO Regional Publications: **2000**.
37. World Health Organization (WHO) Permissible Limits of Heavy Metals in Soil and Plants. Geneva, Switzerland, **1996**.
38. Nwite, J.N.; Alu, M.O. Effect of different levels of spent engine oil on soil properties, grain yield of maize and its heavy metal uptake in Abakaliki, Southeastern Nigeria. *Journal of Soil Science and Environment Management* **2015**, 5(4), 44-51. DOI 10.5897/JSSEM12.070
39. Xiong, Z.-T.; Wang, H. Copper toxicity and bioaccumulation in Chinese cabbage (*Brassica pekinensis* Rupr.). *Environ. Toxicol. Int. J.* **2005**, *20*, 188–194, https://doi.org/10.1002/tox.20094.
40. Yruela, I. Copper in plants. *Braz. J. Plant Physiol.* **2005**, *17*, 145–156, https://doi.org/10.1590/S1677-04202005000100012.
41. Shabbir, Z.; Sardar, A.; Shabbir, A.; Abbas, G.; Shamshad, S.; Khalid, S.; Natasha; Murtaza, G.; Dumat, C.; Shahid, M. Copper uptake, essentiality, toxicity, detoxification and risk assessment in soil-plant environment. *Chemosphere* **2020**, *259*, 127436, https://doi.org/10.1016/j.chemosphere.2020.127436.
42. He, B.; Wang, W.; Geng, R.; Ding, Z.; Luo, D.; Qiu, J.; Zheng, G.; Fan, Q. Exploring the fate of heavy metals from mining and smelting activities in soil-crop system in Baiyin, NW China. *Ecotoxicol. Environ. Saf.* **2021**, *207*, 111234, https://doi.org/10.1016/j.ecoenv.2020.111234.
43. Zhuang, P.; McBride, M.B.; Xia, H.; Li, N.; Li, Z. Health risk from heavy metals via consumption of food crops in the vicinity of Dabaoshan mine, South China. *Sci. Total Environ.* **2009**, *407*, 1551-1561, https://doi.org/10.1016/j.scitotenv.2008.10.061.
44. Chen, H.; Yuan, X.; Li, T.; Hu, S.; Ji, J.; Wang, C. Characteristics of heavy metal transfer and their influencing factors in different soil–crop systems of the industrialization region, China. *Ecotoxicol. Environ. Saf.* **2016**, *126*, 193-201, https://doi.org/10.1016/j.ecoenv.2015.12.042.
45. Bradl, H.B. Chapter 1 Sources and origins of heavy metals. In Interface Science and Technology, Bradl, H.B., Ed.; Elsevier: **2005**; Volume 6, pp. 1-27, https://doi.org/10.1016/S1573-4285(05)80020-1.
46. Cannon, H.L.; Connally, G.G.; Epstein, J.B.; Parker, J.G.; Thornton, I.; Wixson, G. Rocks: Geological Sources of Most Trace Elements. In: Report to the Workshop at South Seas Plantation Captiva Island, FL, US. *Geochem. Environ.* **1978**, *3*, 17–31.
47. Sharma, R.K.; Agrawal, M. Biological effects of heavy metals: An overview. *J. Environ. Biol.* **2005**, *26*, 301–313.
48. Han, L.; Zhuang, G.; Cheng, S.; Wang, Y.; Li, J. Characteristics of re-suspended road dust and its impact on the atmospheric environment in Beijing. *Atmos. Environ.* **2007**, *41*, 7485-7499, https://doi.org/10.1016/j.atmosenv.2007.05.044.
49. Chatterjee, A.; Banerjee, R.N. Determination of lead and other metals in a residential area of greater Calcutta. *Sci. Total Environ.* **1999**, *227*, 175-185, https://doi.org/10.1016/S0048-9697(99)00026-1.
50. Faiz, Y.; Tufail, M.; Javed, M.T.; Chaudhry, M.M.; Naila, S. Road dust pollution of Cd, Cu, Ni, Pb and Zn along Islamabad Expressway, Pakistan. *Microchem. J.* **2009**, *92*, 186-192, https://doi.org/10.1016/j.microc.2009.03.009.
51. 1. He, Z.; Shentu, J.; Yang, X.; Baligar, V.C.; Zhang, T.; Stoffella, P.J. Heavy Metal Contamination of Soils: Sources, Indicators, and Assessment. *J. Environ. India* **2015**, *9*, 17–18.
52. Yan, X.; Gao, D.; Zhang, F.; Zeng, C.; Xiang, W.; Zhang, M. Relationships between Heavy Metal Concentrations in Roadside Topsoil and Distance to Road Edge Based on Field Observations in the Qinghai-Tibet Plateau, China. *Int. J. Environ. Res. Public Health* 2013, *10*, 762-775, https://doi.org/10.3390/ijerph10030762.

Publisher’s Note & Disclaimer