International Journal of Zoology and Applied Biosciences ISSN: 2455-9571
Volume 10, Issue 6, pp: 253-261, 2025
https://doi.org/10.55126/ijzab.2025.v10.i06.028 http://www.ijzab.com

Review Article

HEAVY METALS AND PESTICIDE EXPOSURE IN AGRICULTURAL PRODUCTS AND ITS ADVERSE EFFECTS ON HUMAN HEALTH: A REVIEW

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Article History: Received 12th September 2025; Accepted 26th October 2025; Published 04th November 2025

ABSTRACT

The health of people and agricultural productivity has been negatively impacted by toxic contamination, which is a major environmental concern. The two most dangerous environmental pollutants for wildlife are heavy metals and insecticides. This review looks at the effects of pesticides (insecticides, herbicides, and fungicides) on the agricultural environment (plant and soil) and human health. The heavy metals that are examined include zinc (Zn), copper (Cu), lead (Pb), and cadmium (Cd). Additionally, a thorough investigation was conducted on the accumulation of heavy metals and pesticide residues in plants and soil. There is evidence of pesticides and heavy metals causing ailments in humans. We discuss about the bioaccumulation, mechanism of action, and routes of transfer of pesticides and heavy metals. In the meanwhile, studies have concentrated on the detrimental effects of heavy metals and pesticides together, as well as their antagonistic and synergistic interactions. Every aspect of this review has been covered by incorporating pertinent prior research. This review's contents greatly advance our knowledge of environmental pollutants and their detrimental impacts.

Keywords: Heavy metal Contamination, Pesticide exposure, Toxic effect, Bioaccumulation, Health effects.

INTRODUCTION

Toxic environmental contamination is increasing as a result of industrialization, urbanization, and agricultural runoff, causing worry among local residents (Abdel Khalek *et al*., 2018; World Health Organization., 2009). Rapid economic growth, especially in industry and agriculture, has increased pollution discharge (Barman *et al*., 2018). Natural and manmade environmental contaminants have an impact on both biotic (animals, plants, and humans) and abiotic (air, water, and soil) systems (Ai, P; Jin *et al*., 2020; Bhunia, 2017). Heavy metals like *Cd, Pb, Cu, and Zn,* which are recognized for their high density and chemical toxicity, represent major ecological and health risks when their MRLs are exceeded (Cordero *et al*., 2019; Fan *et al*., 2018). Industrial activities, mining, and agricultural inputs such as fertilizers, pesticides, and wastewater are also potential sources (Cai *et al*., 2019). The rising risk of heavy metal deposition in agriculture emphasizes the critical need for worldwide environmental attention (Shaw *et al*., 2020).

This pollution raises major concern since it accumulates in the soil and is subsequently absorbed by plants (Liu *et al*., 2016). It is critical to address this contamination, and doing so will necessitate innovative and effective methods to mitigate its detrimental consequences (Kim *et al*., 2017). Although humans and plants need some heavy metals to function biologically, excessive concentrations of these substances can be hazardous. Numerous studies have identified agriculture, mining, agrochemicals, and industrial

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activities as significant contributors of heavy metal contamination (Meng, *et al*., 2020). Xiao *et al*., (2017) discovered that agriculture and industry have a considerable impact on heavy metal levels in agricultural soils, particularly those located near cement and electroplating plants. The soil stores these metals, which are then absorbed by plants via the systems of their roots, along with water, and eventually enter the vascular system (Tong *et al*., 2020).

Because they are extremely poisonous, persistent, and non-biodegradable, heavy metals such as Pb, Cd, Hg, and As cause bioaccumulation in living things and food chains. The gastrointestinal, cardiovascular, neurological, renal, hepatic, and endocrine systems are among the major health hazards associated with these metals. Metal levels in contaminated surface, ground, and tap water are frequently higher than the allowable limits established by the USEPA, EUC, EPA, and WHO (2008). Industrial emissions, mining, pesticides, sewage sludge, e-waste, and wastewater irrigation are some of their sources (Alengebawy *et al*., 2021). Globally, elevated amounts have been documented in a variety of water bodies, and they get worse as cities grow faster and waste management gets poorer. Chronic illnesses can result from the disruption of vital physiological processes caused by metals that have no biological function Wang *et al*., (2020).

Heavy metals and pesticides offer major health hazards because they penetrate and accumulate in the food chain and ecology. These toxins can result in heart failure, osteoporosis, lung cancer, and kidney impairment (Qi *et al*., 2018). Heavy metal poisoning posed a significant health risk in China's cities from 2003 to 2009 (Zhang *et al*., 2019). One of the main ways that pesticides can enter the body is by absorption, which can have a serious impact on the central nervous system and result in comas and seizures (Pietrzykowski, *et al*., 2018). Asthma, cancer, birth deformities, and even death are among the major health concerns associated with pesticide and heavy metal contamination of food, water, or air (Keiblinger *et al*., 2018).

Heavy metal sources

In addition to anthropogenic sources like mining, agriculture, and industrial waste, heavy metals also come from natural sources including sedimentary rocks and volcanic activity. Both geological and human factors can contaminate soil, but even with sophisticated techniques, identifying the source is still difficult (Ali *et al*., 2019). Agrochemicals, precipitation, and airborne particles were among the other causes that Alloway found (Meng *et al*., 2018). Prior research has mostly concentrated on Cd, Pb, Cu, and Zn as important environmental pollutants.

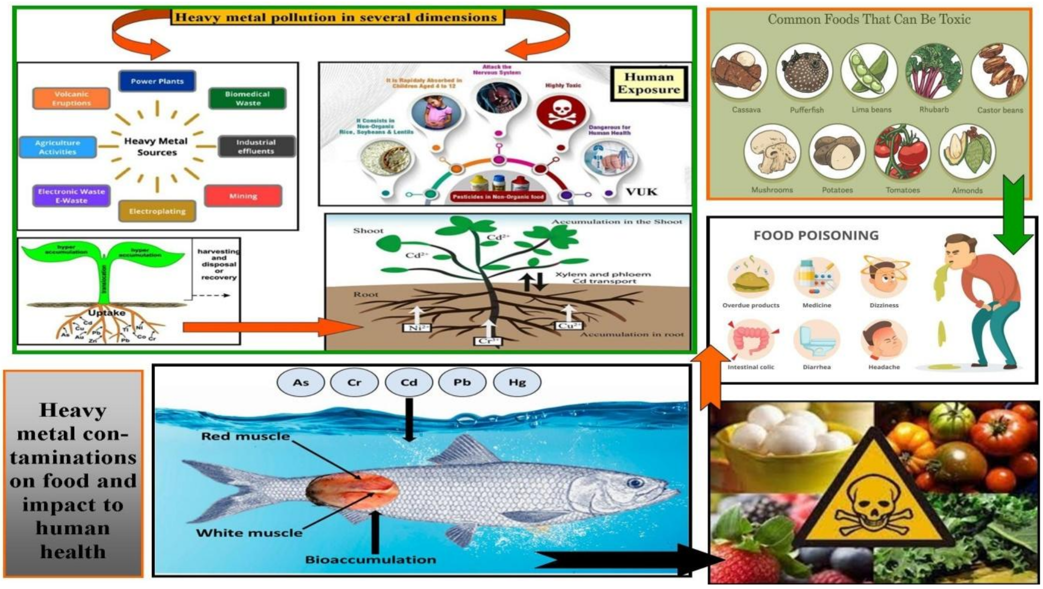

Figure 1. Heavy metal pollution in several dimensions.

Table 1. Range of ppm values for heavy metals in sedimentary and igneous rocks Cannon *et.al.,*1978.

Metals	Basaltic igneous	Granite igneous	Shales & Clays	Black shales	Sand stone
As	0.2-10	0.2-13.8	-	-	0.6-9.7
Cd	0.006-0.6	0.003-0.18	0.0-11	<0.3-8.4	-
Cr	40-600	2-90	30-590	26-1,000	-
Co	24-90	1-15	5-25	7-100	-
Cu	30-160	4-30	18-120	20-200	-

Pb	2-18	6-30	16-50	7-150	-
Mo	09-7	1-6	-	1-300	-
Ni	45-410	2-20	20-250	10-500	-
Zn	48-240	5-140	18-180	34-1,500	2-41

Sources of Heavy Metals in Nature

It is believed that the most common natural sources of heavy metals are sedimentary and igneous rocks (Zhou *et al*., 2019). The ranges of heavy metal concentrations (ppm) in igneous and sedimentary rocks are shown in Table 1. It has been shown that elements in different forms of rock have different quantities from one form to another and from one kind to another (Pietrzykowski *et al*., 2018). The concentration of heavy metals can be ascertained using the kind of rocks present in the area as well as local environmental conditions. Soil formation is considered to be a significant contributor to the accumulation of heavy metals, in addition to river sediments (Zhang *et al*., 2019).

Anthropogenic sources of heavy metals

Anthropogenic heavy metal sources include industries, agriculture, mining, and wastewater. Heavy metal pollution in the ecosystem is caused by various sources, including smelting (Cu, Zn, and As), insecticides, fossil fuel combustion (Hg), and car exhaust (Pb) (Oumenskou *et al*., 2018). Daily human activities including farming, industrial processes, and manufacturing disrupt the biosphere's balance (Lushchak *et al*., 2018).

Agricultural Sources of Heavy Metals

Agro-ecosystems in the vicinity are deteriorated by biotic and abiotic agricultural pollutants, with heavy metals from fertilizers, pesticides, and sewage sludge building up in plants and soil (Alengebawy *et al*., 2021). Common heavy metals such as Cd, Pb, Cu, and Zn are released into the environment as a result of mining, smelting, and manufacture. Additional agricultural practices that contribute to heavy metal accumulation include the use of livestock waste and irrigation with tainted water (Özkara *et al*., 2016). Even if trace levels might be necessary, high concentrations of these metals present major health and environmental hazards that need for efficient mitigation techniques (Wang *et al*., 2019).

Table 2. Metal toxicity aspects and their details.

S. No	Aspects	Details
1	Definition of Heavy Metals	High atomic weight, density **> 5 g/cm³.**
2	Importance of Chemical Properties	More practical due to environmental toxicity when exceeding MRL.
3	Global Attention	Significant attention from think tanks worldwide.
4	Examples of Heavy Metals	Lead (Pb), Copper (Cu), Zinc (Zn), and Cadmium (Cd).
5	Sources of Heavy Metals	Industry, mining, agriculture.
6	Agricultural Sources	Wastewater, pesticides, livestock dung, and fertilization.
7	Environmental Impact	Growing possibility of pollution, particularly in agriculture, which could contaminate plants and soil.
8	Urgency of the Issue	Needs immediate and workable answers to reduce risks.
9	Biological Necessity and Toxicity	For people and plants, it is necessary in modest levels but harmful in large ones.
10	Primary Sources of Pollution	Agrochemicals, mining, industrial, and agriculture.
11	Research Findings (Xiao *et al.*)	The presence of heavy metal pollution in the soil near cement and electroplating companies is largely influenced by agriculture and industry.
12	Mechanism of Plant Contaminations	Plants take heavy metals from the soil through their roots and vascular systems.

Table 3. Pesticides have toxic effects on agricultural soil and plants.

Pesticide Type	Toxic Effects		Reference
	Soil	Plant	
Insecticides	Microbial structural proteins are destroyed, reducing symbiotic characteristics and altering soil chemistry and enzymatic activity.	Reduced grain protein concentration, blocked stomatal conductance, and altered photosynthetic processes.	Vlcek and Pohanka, (2018).
Herbicides	Reduction of soil nutrient availability and inhibition of phosphatase and nitrogenase activity.	Plants become more susceptible to diseases as their physiological and biochemical efficiency is altered.	Tong *et al*., (2020)
Fungicides	Phosphatase, urease, and dehydrogenase	Reduced chlorophyll and carotenoid	Masindi *et*

	activities are disrupted, resulting in suppression of bacterial nitrification.	concentrations, chloroplast death, stomatal closure, and inhibition of electron transport.	*al*., 2018

The Toxic Effect of Heavy Metals on Soil in Agriculture

There are significant dangers to plant and human health from heavy metals as Cd, Pb, Cu, and Zn, which are necessary in tiny levels but poisonous at high doses. Overall fertility is impacted by contamination of agricultural soils because it interferes with microbial activity, deteriorates soil quality, and changes soil structure. Through their roots, plants absorb these metals, which can cause toxicity, nutritional imbalance, and growth suppression Masindi *et al*., (2018). Humans and animals that consume contaminated crops may develop food chain poisoning, which can result in cardiovascular illness, neurological disorders, and kidney damage Vlcek *et al*., (2018).

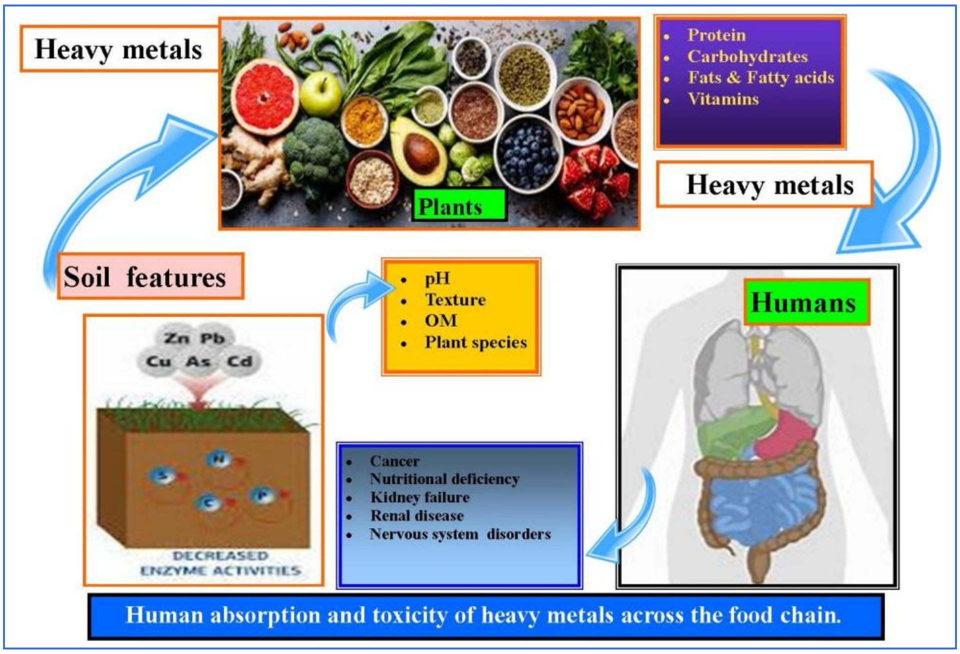

Figure 2. The toxicity and absorption of heavy metals by humans across the food chain.

Heavy metal toxicity in agricultural soil can be mitigated through soil remediation, rigorous limits on heavy metal-containing fertilizers and pesticides, sustainable agricultural methods and public awareness Zhou *et al*., (2019). Phytoremediation, soil washing, and additives can all help lower heavy metal concentrations in contaminated soils. Implementing tight restrictions and monitoring soil and crop quality can help prevent additional pollution. Adopting sustainable farming practices and boosting public knowledge about heavy metal contamination can lead to safer practices and lower health risks (Özkara *et al*., 2016).

Heavy metal toxicity's effects on agricultural soil and plants

Even at low concentrations, heavy metals such as Pb, Cd, Cu, Zn, and Cr can seriously harm soil health, plant growth, and food safety; in many situations, their levels surpass WHO's allowable limits (Kim *et al*., 2017). Concentrations of Cd in soil and Cu in plants are especially dangerous because they interfere with enzyme function, microbial activity, and plant physiology (Oumenskou *et al*., 2018). Oxidative stress, chloroplast damage, and food chain pollution result from these metals' entry into agricultural soils through mining, fertilizers, wastewater irrigation, and industrial discharge (Fernandes *et al*., 2020). Crop breeding, soil amendments, phytoremediation, and sound agricultural practices are all essential mitigation techniques to reduce toxicity and safeguard human and environmental health Tong, *et al*., (2020).

The impact of cadmium toxicity on plants and agricultural soil

In areas like China and the West, cadmium (Cd) buildup in soil due to industrialization and agricultural intensification changes the pH and organic matter of the soil, making it insufficient to meet environmental quality standards (Keiblinger *et al*., 2018). Particularly in saline environments, Cd has a detrimental effect on biomass, respiration, and soil microorganisms. Because Cd is mostly absorbed by plants through their roots, it builds up in edible portions and disrupts physiological processes such nutrition intake, photosynthesis, and mineral transport. Elevated levels of Cd pose major concerns to the environment and food safety because they inhibit seed germination, root growth, and total plant biomass Ali *et al*., (2019).

Lead toxicity's effects on plants and agricultural soil

A very toxic heavy metal, lead (Pb) damages soil fauna such as earthworms and decreases soil microbial diversity, fertility, and enzymatic activity. Pb buildup affects the bioavailability of soil by changing important characteristics as pH, cation exchange capacity, and organic matter Zhou *et al*., (2019). It causes physiological disturbances such as DNA damage, decreased enzyme activity, and stunted growth after being absorbed by plant roots and moving through the xylem. High Pb levels impair protein synthesis, chlorophyll content, seed germination, and overall plant production Łukowski, *et al*., (2018).

Impact of Copper Toxicity on Plants and Agricultural Soil

Copper (Cu) is necessary for plant growth and soil health, but too much of it, usually from copper-based fungicides or farming methods, can be harmful, particularly in acidic soils Lan *et al*., (2020). Because toxic Cu levels denaturize proteins, damage cell membranes, and lower microbial activity and oxidation potential, they disturb microbial communities. Cu mostly accumulates in the root epidermis, where it impacts chlorophyll synthesis, nutrient uptake, and overall plant productivity. The requirement for appropriate Cu management in agriculture is highlighted by the fact that concentrations over 5 mg/kg can hinder growth and yield Lippmann *et al*., (2020).

Effect of Zinc Toxicity on Agricultural Soil and plants

Although necessary for plant growth, excessive amounts of zinc (Zn) can be harmful and disturb soil health by deactivating microorganisms, blocking enzymes, and changing pH and structure. Zinc-based agrochemicals, mining, wastewater irrigation, and industrial operations are the sources of contamination. Reduced photosynthesis and plant production result from zinc poisoning, which also affects root development, chloroplast activity, nutrient intake, and seed germination. To effectively control zinc levels, mitigation techniques include crop rotation, organic amendments, phytoremediation, routine soil monitoring, and the use of hyperaccumulators Masindi *et al*., (2018).

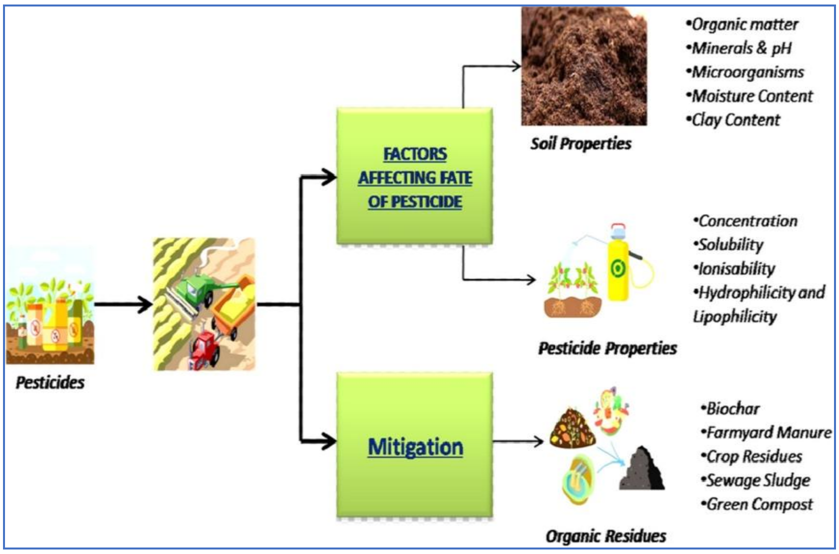

Figure 3. Pesticides activity in soil
Source: Saheem.R., *et.al.*,2022

The Effects of Heavy Metal Toxicity on Human Health

Heavy metals, such as lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), and chromium (Cr), are hazardous elements that can cause major health problems even at low levels. Many factors, including as tainted food and water, occupational exposure, air pollution, and direct contact with contaminated dust or soil, can expose humans to heavy metals. Human health is negatively impacted by heavy metal toxicity in many ways, including both acute and long-term issues. Heavy metals, such as lead and mercury, can cause neurological damage, cardiovascular illness, kidney failure, respiratory problems, and gastrointestinal disorders Qi *et al*., (2018). Lead poisoning can cause developmental delays, cognitive deficiencies, learning disabilities, and behavioral issues in children. Chronic exposure can cause hypertension, atherosclerosis, and other conditions. Chronic exposure might also cause respiratory and gastrointestinal issues.

Table 5. Heavy Metal Toxicity on Human Health.

Metal	Impact of Area	Impact	Reference
Lead (Pb):	Neurological**:**	Cognitive impairment, encephalopathy, peripheral neuropathy.	Alengebawy *et al*., (2021)
	Hematological**:**	Anemia, due to inhibition of hemoglobin synthesis.	Ali *et al*., (2019)
	Reproductive**:**	Reduced fertility, adverse pregnancy outcomes such as miscarriage and preterm birth.	Qi *et al*., (2018)
	Skeletal**:**	Lead can be stored in bones, leading to skeletal abnormalities and delayed growth in children.	Shaw *et al*., (2020)
Mercury (Hg):	Neurological**:**	Tremors, cognitive dysfunction, sensory impairment (vision, hearing).	Yadav *et al*., (2017)
	Renal**:**	Acute kidney injury, chronic renal disease.	Wang *et al*., (2019)
	Reproductive and Developmental**:**	Prenatal exposure can cause developmental defects, cerebral palsy, and other neurodevelopmental disorders.	Kim *et al*., (2017)
Cadmium (Cd):	Renal**:**	Chronic kidney disease, proteinuria.	Alengebawy, *et al*., (2021)
	Skeletal**:**	Osteomalacia, osteoporosis, bone fractures.	Jibril *et al*., (2017)
	Respiratory**:**	Emphysema, lung cancer.	Masindi *et al*., (2018)
Arsenic (As):	Dermatological**:**	Skin lesions, hyperkeratosis, pigmentation changes.	Özkara *et al*., (2016)
	Cardiovascular**:**	Hypertension, cardiovascular disease.	Xiao *et al*., (2017)
	Carcinogenic**:**	Increased risk of cancers (skin, lung, bladder, liver).	Kim *et al*., (2107)
Chromium (Cr):	Respiratory**:**	Asthma, lung cancer, nasal and sinus cancers.	Kumar *et al*., (2020)
	Dermatological**:**	Allergic dermatitis, skin ulcers.	Keiblinger, *et al*., (2018)
	Gastrointestinal**:**	Oral ingestion can cause ulcers, gastrointestinal bleeding.	Fernandes *et al*., (2020)

Heavy metals provide serious health hazards, impacting many organ systems and causing acute and chronic health problems. The long-term impacts include carcinogenicity, immunotoxicity, endocrine disruption, and genetic toxicity. Strict laws, public health measures, medical screening, and environmental cleanup are all used as prevention and mitigation strategies· Strict laws, public health education and the promotion of safe occupational practices can all contribute to reducing environmental contamination and protecting human health Lushchak *et al*., (2018). Effective preventive, regulation, and treatment measures are critical for mitigating the negative consequences of heavy metal exposure.

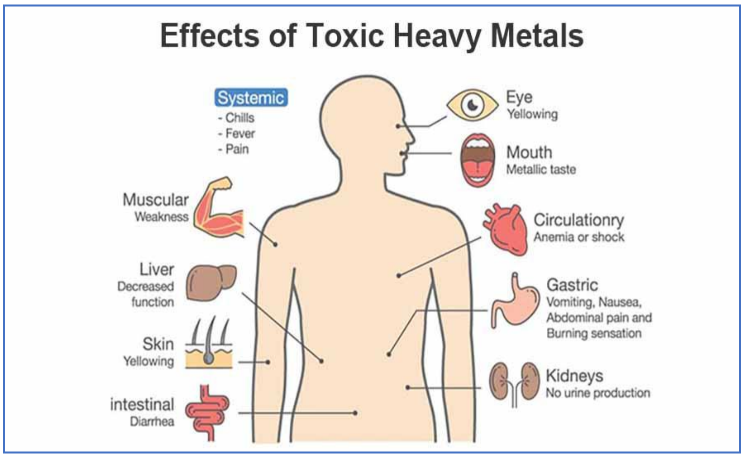

Figure 4. The effects of heavy metal poisoning on human organs.

Effect of Heavy Metals and Pesticides Toxicity on Human Health

Heavy metals, which occur naturally in the environment, are an important toxicant because of their toxic effects, long-term accumulation, and bio-magnification properties. Their existence in ecosystems enhances the likelihood that living species will consume these poisonous components, causing damage to numerous body systems. Humans worldwide are exposed to heavy metals by inhalation or ingestion, with particularly high hazards in industry, illegal disposal sites, and lifestyle subsistence (Kumar *et al*., 2020). The increased usage of metals in production and modern uses has resulted in large environmental hazardous metal emissions, raising serious health issues Shaw *et al*., (2020).

Heavy Metals Toxicity

Heavy metals such as lead, mercury, cadmium, and arsenic are toxic because they remain in the environment and bioaccumulate in living creatures. Lead exposure, primarily from contaminated water, can result in cognitive impairments, hypertension, renal impairment, and reproductive disorders. Mercury exposure, most commonly from tainted fish, can cause neurological impairment. Cadmium exposure from cigarette smoke and contaminated food can lead to kidney impairment, bone demineralization, and an increased risk of cancer. Arsenic exposure can result in skin lesions, cardiovascular problems, and neuropathy (Cai *et al*., 2019)

Pesticides Toxicity on Humans

Pesticides, which include insecticides, herbicides, and fungicides, are commonly used in agriculture to control pests and increase crop yields (Łukowski *et al*., 2018). However, their toxicity to non-target creatures, including people, is a serious problem. Organophosphates: Organophosphates, which are routinely used insecticides, inhibit acetylcholinesterase, causing acetylcholine to accumulate in nerve synapses. This leads to continual nerve impulse transmission, which causes muscular twitching, respiratory difficulty, and, in severe cases, death. Chronic exposure has been associated to neurodevelopmental disorders and cognitive impairment. Organochlorines: Organochlorines, such as DDT, are persistent in the environment and bioaccumulate in food chains. These substances are endocrine disruptors, which have been linked to reproductive difficulties, developmental delays, and an increased risk of cancer, notably breast cancer (Lushchak, *et al*., 2018). Carbamates: Carbamates, like organophosphates, block acetylcholinesterase but are often less durable. Acute exposure causes symptoms such as nausea, vomiting, and respiratory problems, however prolonged exposure is associated to neurotoxicity and immunotoxicity Özkara *et al*., (2016)

Pyrethroids

Pyrethroids, which are commonly employed in domestic and agricultural contexts, are synthetic analogues of natural pyrethrin. Although less harmful to mammals, prolonged exposure can cause neurotoxic consequences such as dizziness, headache, and, in severe cases, seizures (Ra¸tiu, *et al*., 2018)

Combined Exposure and Synergistic Effects

Humans are frequently exposed to various heavy metals and pesticides at the same time, which can have a synergistic impact and increase toxicity. Combined exposure can increase oxidative stress, inflammation, and disruption of cellular activities, raising the risk of chronic diseases like cancer, cardiovascular disease, and neurological disorders (Vlcek, *et al*., 2018).

CONCLUSION

The detrimental consequences of pesticides and heavy metals on plants, soil, and human health are highlighted in this review. Crop productivity, pH, and soil microorganisms are all adversely impacted by heavy metals such as copper, lead, and cadmium. Pesticides harm plant physiology and decrease helpful microbes. Plant diseases like chlorosis and necrosis result from disturbances in the microbial balance and enzyme activity of the soil. Human exposure results in a variety of malignancies as well as neurological, musculoskeletal, and hormonal problems. Toxic combinations and cutting-edge remediation techniques like phytoremediation and bioremediation should be the main topics of future research.

ACKNOWLEDGMENT

The authors express sincere thanks to the head of the Department of Botany, Government Degree College Husnabad for the facilities provided to carry out this research work.

CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

FUNDING

This study received no specific funding from public, commercial, or not-for-profit funding agencies.

AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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