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A Systematic Review of Heavy Metal Contamination and Human Health Risk Assessment in Soils and Vegetables of Jhansi, Bundelkhand Region, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Heavy metal contamination in soil and vegetables poses a serious threat to environmental safety and human health, particularly in regions with intensive agricultural and industrial activities. This review focuses on the extent of heavy metal contamination in the Jhansi district of the Bundelkhand region, analyzing its sources, pathways, accumulation in vegetables, and associated health risks.

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Metals such as lead (Pb), cadmium (Cd), chromium (Cr), and mercury (Hg) have been detected at alarming levels in both soil and edible plants, primarily due to the use of contaminated water for irrigation, application of chemical fertilizers and pesticides, and proximity to traffic and industrial zones. Health risk assessments, including Estimated Daily Intake (EDI) and Target Hazard Quotient (THQ), indicate potential non-Harmful chemicalsic and Harmful chemicalsic risks, especially among vulnerable populations like children and the elderly. The findings highlight an urgent need for continuous monitoring, public awareness, and the implementation of regulatory measures to control the sources of contamination.

Keywords: Heavy metals; chemical fertilizer; pesticides and vegetables.

1. INTRODUCTION

Heavy metals, which are a major environmental problem, have a natural residency in the continental mantle. In general, a heavy metal is nothing but any chemical element which is metallic with a comparatively higher density that is poisonous above a tolerable range, such as mercury (Hg), cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), and so on [National Research Council, 2001, Needleman, 2000, Nordberg et al., 2007). The study of heavy metal contamination in vegetables is crucial due to its significant impact on human health and environmental safety (Kumar, 2020; Sankhla et al., 2016). Vegetables are a vital part of the human diet, providing essential nutrients and minerals. However, when grown in polluted soil or irrigated with contaminated water, they can absorb toxic heavy metals such as lead, cadmium, mercury. These metals are non-biodegradable and tend to accumulate in the body over time, leading to serious health issues (Moghaddam et al., 2022). Exposure to heavy metals through vegetable consumption can cause various harmful effects, including kidney damage, neurological disorders, weakened immune function, and even ailments (Jabeen et al., 2020, Duruibe et al., 2007; Liu et al., 2013). Exposure to heavy metals through the consumption of contaminated vegetables is linked to a range of serious health issues, including kidney damage, neurological disorders, a weakened immune system, and an increased risk of ailments (Gupta et al., 2011). Cadmium (Cd): Numerous studies have shown that chronic cadmium exposure, often through contaminated food crops like vegetables, is a major cause of kidney damage. Cadmium accumulates in the kidneys, particularly in the proximal tubules, leading to impaired reabsorption of essential substances and ultimately kidney dysfunction (Duruibe et al., 2007). Lead (Pb): Chronic lead exposure can also damage the kidneys, leading to lead nephropathy, characterized by interstitial fibrosis and impaired kidney function. Neurological Disorders (Neurotoxicity): Lead (Pb): Lead is a well-established neurotoxin, particularly harmful to the developing brains of children. Exposure through contaminated vegetables can contribute to cognitive deficits, learning disabilities, behavioral problems, and reduced IQ. In adults, chronic lead exposure has been linked to neurological disorders and neurodegenerative diseases (Arya, 2023, Li et al., 2005). Mercury (Hg): While methylmercury from fish is a primary concern, inorganic mercury contamination in vegetables can also pose neurological risks, although often at lower levels. Mercury can damage the central nervous system (Bläsing & Amelung, 2018). Weakened Immune System (Immunotoxicity): Exposure to even at relatively low levels, has been shown to suppress the immune system, making individuals more susceptible to infections (National Research Council, 2001). Cadmium (Cd) and Lead (Pb): Studies have also indicated that exposure to cadmium and lead can impair immune function, affecting both cell-mediated and humoral immunity. Accumulates in the kidneys and can lead to kidney dysfunction, bone damage (Itai-Itai disease), and ailments (Shetty et al., 2025). Cadmium (Cd): Cadmium is classified as a probable with evidence linking occupational and environmental exposure to lung, prostate, and kidney ailmentss. Dietary intake through contaminated vegetables can contribute to overall exposure (IARC, 1993). Chromium (Cr): Hexavalent chromium is a known human Harmful chemicals, primarily through inhalation. However, contamination of soil and water can lead to uptake in vegetables, and ingestion is also a concern (IARC, 1993). It's important to note that the specific health effects and their severity depend on various factors, including the type of heavy metal, the level and duration of exposure, individual susceptibility, and nutritional status. However, the scientific consensus is clear: heavy metal contamination in vegetables poses a significant threat to human health. Therefore,

monitoring and mitigating heavy metal contamination in agricultural environments are crucial for ensuring food safety and protecting public health.

Children are particularly vulnerable, as their developing bodies are more sensitive to toxic substances. Moreover, long-term intake of contaminated vegetables can affect agricultural productivity and biodiversity, threatening food security. This review is important to identify the sources and levels of contamination, raise awareness among consumers and farmers, and promote safe agricultural practices (Gupta, 2021). It also provides essential data for policymakers to implement strict regulations and monitor food safety standards. Ultimately, understanding heavy metal contamination in vegetables helps protect public health, ensure food quality, and maintain a sustainable environment. The data from recent research and surveys to assess the concentration of these metals in commonly consumed vegetables such as spinach, brinjal, and tomatoes (Gupta et al., 2014). Health risk assessments, including Estimated Daily Intake (EDI) and Target Hazard Quotient (THQ), indicate potential non-Harmful chemicalsic and Harmful chemicalsic risks, especially among vulnerable populations like children and the elderly. The findings highlight an urgent need for continuous monitoring, public awareness, and the implementation of regulatory measures to control the sources of contamination. The review underscores the importance of adopting safe agricultural practices and promoting phytoremediation and organic farming to mitigate health risks in the Jhansi region (Gamage et al., 2023). The presence of heavy metals like Cd, Pb, and Ni in vegetables poses significant health risks, particularly non-Harmful chemicalsic effects, when consumed regularly (Yan & Allen, 2021). Children are especially vulnerable due to their higher susceptibility to toxic agents. The studies emphasize the need for continuous monitoring of soil, irrigation water, and vegetables to prevent excessive accumulation of heavy metals in the food chain. Some recommendations like regular monitoring testing of soil and vegetable samples, identifying the source of heavy metals contamination such as industrial emissions, vehicular pollution, and the use of contaminated water for irrigation and public awareness, educating local farmers and consumers about the risks associated with heavy metal contamination and promote safe agricultural practices.

2. OBJECTIVES OF THE REVIEW

The objective of this review is to assess the extent and impact of heavy metal contamination in vegetables, focusing on its sources, pathways, and health implications. Vegetables, being a vital component of the human diet, are often exposed to heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) through contaminated soil, water, and air. Industrial activities, excessive use of fertilizers and pesticides, untreated wastewater irrigation, and urban pollution are major contributors to this contamination. This review aims to highlight how these metals accumulate in vegetables and pose serious health risks to consumers. Prolonged exposure to heavy metals can lead to various health issues such as kidney damage, neurological disorders, developmental delays in children, and increased risk of ailments. The review also emphasizes the vulnerability of low-income and urban populations who may rely on vegetables grown in polluted environments. By summarizing current research findings; the review intends to create awareness among policymakers, farmers, and consumers about the need for strict monitoring, sustainable agricultural practices, and effective regulation. Ultimately, the goal is to promote food safety and public health by reducing heavy metal exposure through contaminated vegetables.

3. GEOGRAPHICAL AND ENVIRONMENTAL OVERVIEW OF JHANSI-BUNDELKHAND REGION

About location and climate , Jhansi is a major city in the Bundelkhand region, which spans parts of southern Uttar Pradesh and northern Madhya Pradesh, lies on the plateau of central India, in the southern part of Uttar Pradesh, Approximately 25.45° N, 78.58° E. the topography characterized by Rocky terrain, Undulating plains, Isolated hillocks, Elevation varies between 150 to 450 meters above sea level. Semi-arid climate (hot and dry) Summers (March to June): Very hot, temperatures can exceed 45°C, Monsoon (July to September): Moderate rainfall, around 800–1000 mm annually, Winters (November to February): Mild and dry, temperature drops to 4–6°C at night. Vegetation and Natural Resources includes predominantly thorny scrub and dry deciduous forests, Key trees: Babul, Neem, Palash, Ber, Soil: Mostly black cotton soil and red loamy soil, but also rocky and infertile in many areas.

Limited forest cover due to deforestation and overgrazing, Minerals found: Granite, limestone, sandstone, and minor deposits of mica and quartz. Agriculture Major crops: Wheat, gram, jowar, bajra, and pulse, Rain-fed agriculture dominates due to poor irrigation, Water scarcity and erratic rainfall are major challenges (Bläsing & Amelung, 2018). Efforts are being made to promote watershed management and rainwater harvesting. Some Environmental Issues like Drought-prone area with frequent water crises, Soil erosion and land degradation due to deforestation and over-farming, Scarcity of perennial rivers; relies on seasonal rivers like the Betwa, Ken, and Dhasan, Climate change has worsened rainfall patterns and crop yield unpredictability. Conservation and Development in progress, Government and NGOs are involved in, Water conservation projects (check dams, tanks), Afforestation efforts, Promotion of sustainable agriculture, Development programs aim to improve rural livelihoods and drought resilience.

4. INDUSTRIAL AND URBAN INFLUENCES

The Jhansi-Bundelkhand region in Uttar Pradesh faces increasing soil pollution due to various industrial and urban influences. One major contributor is the unregulated disposal of industrial waste from small-scale industries such as paint, textile dyeing, and chemical manufacturing. These industries often discharge harmful chemicals directly onto land or into nearby drains without proper treatment, leading to toxic accumulation in the soil. Additionally, urbanization has led to the rapid expansion of residential areas and construction projects. The use of cement, plastic, and non-biodegradable materials in urban development introduces pollutants into the soil. Solid waste dumping, especially in unplanned and open landfills, further worsens the problem, as garbage-including plastics, electronic waste, and heavy metals—leaches harmful substances into the ground. Vehicular emissions and oil leakage from poorly maintained vehicles in urban centers like Jhansi also contaminate the soil with hydrocarbons and heavy metals. Moreover, excessive use of chemical fertilizers and pesticides in peri-urban agriculture around Jhansi adds to soil degradation. These combined industrial and urban pressures reduce soil fertility, harm plant life, and pose risks to human health through contaminated food and water (Järup and Åkesson, 2009). Effective waste management and pollution control are essential to mitigate soil pollution in this region (https://jhansi.nic.in;https://censusindia.gov.in).

5. HEAVY METALS OF CONCERN

The soil in Jhansi, part of the Bundelkhand region, is significantly affected by heavy metal contamination, posing ecological and health risks. Key pollutants include cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr), copper (Cu), zinc (Zn). Among these, Cd is particularly concerning due to its high contamination levels and ecological risk across various soil types (Moghaddam et al., 2022). Anthropogenic activities such as industrial emissions, vehicular traffic, and the use of contaminated irrigation water contribute to the elevated levels of these metals (Tiwari & Singh, 2014). Studies have shown that vegetables like spinach and fenugreek grown in contaminated soils accumulate high levels of Cd, Mn, and Pb, exceeding safe consumption limits and posing non-Harmful chemicalsic health risks.Mining activities, especially granite mining, have further exacerbated the situation by contaminating groundwater with Cd, Fe, and Pb, affecting nearby residential areas . The spatial distribution of these metals indicates hotspots of contamination, necessitating targeted remediation efforts (Singh, 2006). To mitigate these risks, continuous monitoring of soil and water quality is essential. Implementing sustainable agricultural practices and controlling industrial emissions can help reduce heavy metal accumulation in the environment.

Lead (Pb)- The soil in the Jhansi region of Bundelkhand contains elevated levels of lead (Pb), primarily due to industrial activities, vehicular emissions, and use of chemical fertilizers. Lead contamination poses serious risks to agriculture, groundwater, and human health, especially affecting neurological development in children and reducing soil fertility over time (Clarkson et al., 2003, Gupta et al., 2021, Needleman, 2000).

Cadmium (Cd)- Cadmium (Cd) contamination in the soil of Jhansi, Bundelkhand region, is mainly due to industrial waste, use of phosphate fertilizers, and atmospheric deposition. High Cd levels pose risks to crops, animals, and human health, potentially entering the food chain and affecting kidney function, bone health, and overall ecosystem balance.

Contamination in the soil of Jhansi, Bundelkhand, is a significant environmental issue.

Mercury (Hg)- Mercury (Hg) contamination in the soil of Jhansi, Bundelkhand, poses serious health risks to the local population. The region experiences soil pollution from industrial waste, mining, and improper disposal of mercury-containing products. Prolonged exposure to mercury leads to neurological disorders, kidney damage, and other severe health issues. Chromium (Cr)- Chromium (Cr) contamination in the soil of Jhansi, Bundelkhand, is a growing concern, particularly in regions with mining activities. Prolonged exposure to chromium can lead to severe health issues such as skin diseases, respiratory problems, and kidney damage. The soil contamination affects both human health and agricultural productivity (Gupta, 2021, Nordberg et al., 2007, Sharma et al., 2013).

Industrial discharges in the Jhansi-Bundelkhand region have significantly impacted the soil and environment, contributing to several health problems. The release of untreated waste from factories contaminates the soil with toxic chemicals like heavy metals, pesticides, and industrial effluents (Central Pollution Control Board (CPCB), India. (2012). This pollution not only degrades soil quality but also disrupts local agriculture, leading to reduced crop yields. The contaminated soil has been linked to various diseases, such as skin rashes, respiratory issues, and gastrointestinal disorders among the local population. Additionally, exposure to toxic substances in the soil can lead to long-term health problems, affecting the overall well-being of the community (Yaradua et al., 2023).

6. USE OF PESTICIDES AND FERTILIZER

The Application of fertilizers, pesticides, atmospheric deposition, and wastewater irrigation are other factors that are also involved in elevating contents of HMs in roadside agricultural soil (Shetty et al., 2025). In the Jhansi Bundelkhand region, the use of pesticides and fertilizers has significantly impacted the soil quality. While these chemicals help boost crop production, they lead to soil degradation over time. Excessive use of fertilizers causes nutrient imbalance, reducing soil fertility. Pesticides harm beneficial microorganisms and disrupt the natural ecosystem. Additionally, the chemicals contaminate groundwater, affecting both soil health and local water sources. This has led to the spread of various soil-borne diseases, making it harder for crops to thrive and challenging the region's agricultural sustainability. Proper management and organic alternatives are essential to protect soil health.

7. WASTEWATER IRRIGATION

Wastewater irrigation in Jhansi, Bundelkhand, a region prone to diseases due to water scarcity, can be both a solution and a challenge. The reuse of wastewater for agricultural purposes offers a potential way to address water shortages, but it also brings health risks. Contaminants in untreated wastewater, such as heavy metals, pathogens, and chemicals, can harm soil fertility and pose health risks to crops and humans. Proper treatment and monitoring of wastewater are essential to prevent disease transmission and protect the environment (Poggio et al., 2008). Research and sustainable practices are crucial to ensure safe wastewater use in irrigation for this region.

8. ATMOSPHERIC DEPOSITION

Atmospheric deposition refers to the process by which airborne pollutants, such as dust, gases, or particulate matter, are deposited onto the Earth's surface. In regions like Jhansi in Bundelkhand, atmospheric deposition can have a significant impact on soil health. Pollutants from industrial emissions, vehicle exhaust, and agricultural activities can settle on the soil, leading to contamination (National Research Council, 2001, Needleman, 2000). This can alter the soil's nutrient composition, pH levels, and overall fertility, affecting crop growth and ecosystem balance. The deposition of harmful substances like heavy metals and chemicals can also pose risks to both human health and biodiversity in the region.

9. SOIL CONTAMINATION ASSESSMENT

Sampling techniques are essential for studying diseases in regions like Jhansi in Bundelkhand, where access to healthcare can vary and health challenges may differ due to factors such as climate, agriculture, and local lifestyle. In disease research, it's important to choose appropriate sampling methods to ensure that the collected data represents the population accurately (DC, 2001).

9.1 Random Sampling

This method involves selecting individuals randomly from the population in Jhansi, ensuring

every person has an equal chance of being chosen. This technique can help avoid bias and ensure a diverse sample representing different demographics and locations within Bundelkhand.

9.2 Stratified Sampling

In Bundelkhand, where there might be regional differences in disease prevalence, stratified sampling divides the population into subgroups (strata), such as rural and urban areas, or by age and gender. A sample is then drawn from each subgroup, which provides more precise data.

9.3 Cluster Sampling

Given that Bundelkhand consists of numerous villages and towns, cluster sampling may be used. In this method, specific villages or towns are selected randomly, and then all individuals within those selected areas are surveyed. This is cost-effective for large areas with difficult access.

9.4 Systematic Sampling:

This method involves selecting every nth individual from a list of households in Jhansi, ensuring an even distribution across the region. By employing these sampling techniques, researchers can gather representative data on the diseases affecting the region and formulate more effective public health interventions.

10. ANALYTICAL METHODS

Soil analysis is essential for understanding the fertility, texture, and nutrient composition of soils in the Jhansi region of Bundelkhand. The region has a predominantly dry climate, and soil characteristics vary widely due to its unique topography and climatic conditions. In Bundelkhand, the soils are mainly red, yellow, and black, with varying levels of organic matter and mineral content (Bellinger, 2011).

To assess soil health, a few key analytical methods are employed:

pH Testing: The pH of the soil helps in understanding its acidity or alkalinity, which influences nutrient availability. Soils in Bundelkhand can be alkaline, requiring pH management for better crop yield.

Electrical Conductivity (EC): This measures the salinity level of the soil. High salinity can affect plant growth, so it's critical to monitor in water-scarce areas.

Nutrient Analysis: This includes testing for essential nutrients like nitrogen (N), phosphorus (P), potassium (K), and micronutrients. Bundelkhand's soils often lack nitrogen and organic matter, making nutrient management crucial.

Texture Analysis: The relative proportions of sand, silt, and clay in the soil influence water retention and root development. The region's soils are mostly sandy or loamy, which require proper water management. These methods help farmers in Bundelkhand make informed decisions on irrigation, fertilization, and crop selection for optimal productivity.

Levels Detected and Comparison with Standards: Soil contamination assessment in the Jhansi region of Bundelkhand involves the identification and quantification of pollutants to evaluate the health of the soil. Various levels of contamination, often resulting from agricultural activities, industrial discharge, and urbanization, are compared with standard soil quality guidelines to assess their impact (Rahman & Rahman, 2020). Typically, contaminants like heavy metals (lead, cadmium, mercury), pesticides, and other chemical residues are of primary concern. Soil in the Bundelkhand region has been reported to contain elevated levels of some of these pollutants, primarily due to extensive use of chemical fertilizers and pesticides in agriculture. The analysis is done by comparing the detected levels of these contaminants with national and international standards, such as those set by the Indian Ministry of Environment, Forest and Climate Change (MoEFCC) or the World Health Organization (WHO). In some parts of Jhansi, heavy metal concentrations in soil exceed permissible limits, which could lead to long-term environmental and health risks. For example, Regular monitoring and adherence to standards are necessary to mitigate soil degradation and safeguard both the environment and human health in this region.

Vegetable Contamination Analysis: Vegetable contamination in the Jhansi Bundelkhand region has become a growing concern due to various factors affecting the local agricultural practices and food safety. In this region, vegetables such as tomatoes, spinach, and cauliflower often show high levels of pesticide residues, which pose health risks to consumers. The use of chemical fertilizers and pesticides is common among local farmers, but often, these chemicals are applied

improperly or excessively, leading to contamination of the produce. Moreover, water sources in Bundelkhand are often contaminated with pollutants from nearby industries and untreated sewage, which are used for irrigation. This further contributes to the contamination of vegetables. The lack of proper storage facilities and transportation infrastructure also leads to spoilage and microbial contamination, especially in the summer months when temperatures soar. To address these issues, it is essential to promote sustainable farming practices, such as organic farming and the use of bio-pesticides. The government can also play a role by offering training programs for farmers on the safe use of chemicals and better water management techniques. Additionally, public awareness about the importance of washing and cleaning vegetables before consumption is crucial to reducing health risks related to contaminated produce (Sharma et al., 2008).

Commonly Affected Vegetables: In the Jhansi Bundelkhand region, agricultural activities are central to the economy, with vegetables like tomatoes, potatoes, onions, cauliflower, and peas being commonly grown. However, these vegetables are susceptible to contamination due to various factors.

The main causes of contamination include the use of pesticides and chemical fertilizers, improper handling during harvesting, and poor irrigation practices. Pesticides, while essential for pest control, can leave harmful residues on vegetables, posing health risks to consumers. Moreover, the use of untreated water for irrigation often leads to microbial contamination, with pathogens like E. coli or Salmonella entering the food supply. Additionally, environmental factors like water scarcity and soil erosion affect the quality and yield of vegetables. Poor soil health, compounded by inadequate crop rotation, can result in nutrient deficiencies and make crops more vulnerable to diseases and pests. To mitigate these issues, there is a growing emphasis on sustainable agricultural practices such as organic farming, integrated pest management, and improved water management. Increasing awareness about food safety, better monitoring of pesticide use, and strict regulations on water quality are vital for reducing vegetable contamination in the region and ensuring the safety of the local food supply (National Research Council, 2001).

Bioaccumulation Patterns: Bioaccumulation refers to the gradual accumulation of harmful substances, such as pesticides, heavy metals, and other pollutants, in living organisms over time. In the Jhansi Bundelkhand region, the analysis of bioaccumulation patterns in the local ecosystem has raised concerns about the contamination of vegetables consumed by the population. This region, like many other agricultural areas, relies heavily on the use of chemical pesticides and fertilizers to boost crop yields. These chemicals often find their way into the soil, water, and air, eventually being absorbed by plants (Poggio et al., 2008). Vegetables grown in this area, particularly leafy greens, are at risk of absorbing high levels of toxic substances, such as cadmium, and lead, through their roots. These contaminants can then accumulate in the tissues of the plants. Over time, as humans consume these contaminated vegetables, harmful substances accumulate in their bodies, leading to potential health issues, such as ailments, neurological damage, and kidney problems. Efforts to mitigate bioaccumulation in the Bundelkhand region include promoting organic farming practices, reducing the use of harmful pesticides, and conducting regular soil and water testing to monitor contamination levels. Awareness campaigns for local farmers and consumers are also essential to mitigate health risks related to vegetable contamination.

Transfer Factors from Soil to Plant: In the Jhansi Bundelkhand region, the transfer of factors from soil to plants and subsequent vegetable contamination is a significant concern. The region, primarily agricultural, faces challenges related to the use of chemical fertilizers, pesticides, and water pollution, which impact the soil quality and affect the crops grown. Soil contamination can occur due to the accumulation of heavy metals such as lead, cadmium, as well as pesticides that seep into the soil over time. These contaminants are then absorbed by the plants through their root systems (Shetty et al., 2025). Vegetables and crops grown in such soils can accumulate these harmful substances, leading to contamination. For instance, leafy vegetables, such as spinach or coriander, are particularly vulnerable to pesticide residue, while root vegetables can absorb heavy metals (Liang et al., 2019). This poses health risks to consumers, as contaminated vegetables can lead to long-term health issues, including neurological disorders, kidney damage, and even ailments.

Contamination analysis in this region involves testing soil and plant samples for the presence of harmful chemicals. Studies have shown that despite efforts to regulate the use of chemicals, the persistence of pollutants in soil and water continues to be a major challenge. Effective measures, such as organic farming, better waste management practices, and water treatment systems, are crucial to mitigating this issue and ensuring the safety of local produce.

Health Risk Assessment: In the Jhansi Bundelkhand region, health risks related to vegetable contamination are a growing concern due to various factors like poor farming practices, excessive pesticide use, and inadequate storage facilities. Vegetables grown in this area often face contamination from harmful chemicals, heavy metals, and microbial pathogens, which can lead to serious health issues for consumers. The overuse of pesticides and chemical fertilizers, coupled with the region's limited access to modern agricultural techniques, increases the risk of harmful residues in vegetables (Syed et al., 2014). These chemicals can cause long-term health effects, including ailments, hormone disruption, and damage to the liver and kidneys (Gupta, 2001). Additionally, the lack of proper sanitation and storage facilities leads to microbial contamination. Vegetables are often exposed to dirty water sources, leading to the spread of pathogens like E. coli and Salmonella, which can cause foodborne illnesses. To reduce these health risks, it is crucial to promote sustainable farming practices, such as organic farming and the proper use of pesticides. Improving water quality, storage conditions, and raising awareness among farmers about safe agricultural practices are vital steps toward ensuring the safety of vegetables in this region. Public health campaigns and regulatory measures are also necessary to monitor and control contamination levels in food production (Fowler et al., 2007).

Dietary Intake Estimation: In the Bundelkhand region, particularly in Jhansi, the dietary intake and vegetable contamination are crucial concerns for public health. The region primarily depends on agriculture, with local diets heavily relying on cereals, pulses, vegetables, and fruits. However, the nutritional intake in rural areas often falls short of the required daily values, especially in terms of vitamins and minerals. Traditional diets are generally deficient in fresh vegetables, leading to malnutrition, particularly in children and women.

11. CONCLUSION

The present review concludes that heavy metal contamination in soil and vegetables of the Jhansi district, Bundelkhand region, poses a serious environmental and public health concern. The elevated levels of toxic metals such as lead (Pb), cadmium (Cd), mercury (Hg), and chromium (Cr) in soil and edible crops primarily result from industrial effluents, vehicular emissions, excessive use of fertilizers and pesticides, and irrigation with contaminated water. These metals accumulate in vegetables and enter the human food chain, leading to potential non-Harmful chemicalsic and Harmful chemicalsic health risks, particularly affecting children and other vulnerable groups. To mitigate these threats, it is essential to implement regular monitoring of soil and vegetables, promote organic and sustainable farming practices, ensure proper treatment of industrial and domestic wastewater, and raise public awareness regarding safe agricultural and consumption practices. Strengthening regulatory frameworks and encouraging community participation will be key to restoring soil quality, ensuring food safety, and protecting the health of the population in the Bundelkhand region.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author(s) hereby declare that no generative artificial intelligence (AI) technologies, such as large language models (e.g., ChatGPT, Copilot, etc.) or text-to-image generators, were used in the preparation, writing, or editing of this manuscript. All content presented herein is the result of the author(s)' original research and analysis.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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