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Assessment and Analysis of Heavy Metals Present in Vegetables Grown Near Yamuna River Region: A Review

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Abstract

The sacred river Yamuna traverses through Delhi, transporting a multitude of contaminants and heavy metals, which subsequently contaminate the water utilised for irrigation purposes. Vegetables, which are essential for our survival, contain significant amounts of heavy metals such as Arsenic (As), lead (Pb), mercury (Hg) and more. These metals are absorbed by vegetables from the soil due to irrigation with contaminated river water. Furthermore, the use of sewage water and industrial effluents has been highlighted as the main factor contributing to the contamination of heavy metals. It can lead to severe health consequences such as cancer, neurological damage, carcinogenic effects, and organ damage. Moreover, it has detrimental impact on the aquatic organisms that inhabit it, and when ingested by living organisms, it leads to harmful consequences. Cancer is a leading cause of mortality, and its aetiology remains unknown, however it is believed to be influenced by the daily dietary intake of individuals. Heavy metals present in vegetables can potentially contribute to the development of several chronic diseases. Several advanced elemental analysis techniques are employed to acquire accurate and reliable data in the assessment and characterisation of heavy metals present in vegetables grown in soil areas near the Yamuna River.

Keywords: Heavy Metals; Vegetables; Yamuna River; Cancer; Elemental Analysis Techniques

Abbreviations

As: Arsenic; Pb: Lead, Hg: Mercury; WHO: World Health Organisation; BIS: Bureau of Indian Standards; Ni: Nickel; Cr: Chromium; Fe: Iron; Co: Cobalt; Zn: Zinc; Cu: Copper; Cd: Cadmium; F^-: Fluoride; PPM: Parts Per Million; AAS: Atomic Absorption Spectroscopy; XRF: X-Ray Fluorescence; ICP-MS: Inductively Coupled Plasma Mass Spectrometry; ICP-OES: Inductively Coupled Plasma Optical Emission Spectroscopy; ETAAS: Electrothermal Atomic Absorption Spectroscopy; LA-ICP-MS: Laser Ablation Inductively Coupled Plasma Mass Spectrometry.

Introduction

Rivers are vital conduits for civilisations, serving as essential mechanisms for supporting ecosystems, agriculture, and human populations. India possesses an extensive system of rivers, including notable ones such as the Ganges, Yamuna, Brahmaputra, Narmada, Godavari, Krishna, and Kaveri. These rivers are essential for maintaining agriculture, supplying drinking water, preserving biodiversity, and enabling trade and commerce throughout the country. These rivers also sustain diverse ecosystems, providing habitats for a vast variety of plant and animal species. Nevertheless, a significant number of these rivers are facing growing risks from pollution, excessive water extraction, and climate change, which pose a threat to their capacity to sustain their crucial functions [1,2].

The Yamuna River holds significant religious and cultural importance in India. The river is the primary affluent of the Ganga, spanning over 1376 kilometres before merging with the Ganga at Allahabad. The river is revered in Indian mythology and is home to several pilgrimage centres such as Yamunotri, Paonta Sahib, Mathura, Vrindavan, Bateshwar, and Allahabad. The Yamuna River traverses seven Indian states: Uttarakhand, Himachal Pradesh, Uttar Pradesh, Haryana, Delhi, Rajasthan, and Madhya Pradesh. The river has an annual flow rate of approximately 10,000 m3/s. The yearly utilisation of water from the river is approximately 4400 m3/s, with irrigation accounting for 96% of the total demand [3,4].

The river has an extensive catchment area in the National Capital Territory constitutes only 1% of the entire catchment area of the river, although it is responsible for almost 50% of the pollutants present in the Yamuna. The Yamuna River, which has an annual discharge of approximately 10,000 m3 and a utilisation rate of 4,400 m3, provides almost 70% of Delhi's water supply [3].

Additionally, the river functions as a primary source of irrigation for extensive agricultural fields located along its path. The mean concentration of heavy metals was consistently high, frequently beyond the allowable thresholds for surface water drinking standards set by the Bureau of Indian Standards (BIS) and World Health Organisation (WHO). According to the HPI (ranging from 98.2 to 555.1), approximately 85% of the river water was categorised as very polluted. Therefore, it is not advisable to drink this water [3,5].

Vegetables are vital constituents of human diets, offering crucial nutrients and promoting health advantages. Nevertheless, the cultivation of these crops, especially in regions adjacent to polluted water sources, gives rise to apprehensions over the presence of heavy metal pollution resulting from irrigation methods and soil conditions [6,7].

Heavy Metals in Vegetables

The widespread prevalence of heavy metals in the environment, specifically in agricultural soils and crops, has emerged as a major problem. Heavy metals are a category of elements and compounds with a high atomic mass and density at least five times greater than water. arsenic (As), cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr), iron (Fe), cobalt (Co), zinc (Zn), copper (Cu) and mercury (Hg) are very poisonous to living beings, even in low amounts. Their bioaccumulation in the food chain can have significant health consequences for humans and animals. There is a potential risk to human health through consumption of agricultural products grown in fields irrigated with contaminated water [4,8].

The utilisation of sewage water and industrial effluents for irrigation has been identified as the primary cause of heavy metals pollution and buildup in the surface and tissues of fresh vegetables cultivated in West Bengal and other regions. Plants primarily absorb these metals through their roots, where they can attach to soil particles and be transported into the edible parts of the plants [3]. Various types of freshwater vegetation, including algae, mosses, and higher aquatic plants, have been found to be reliable markers of the presence of heavy metals in freshwater ecosystems. It has been concurred that the absorption of metals from food is the primary pathway in the environment [4,5].

Impact on Aquatic Life

The aquatic species in the Yamuna River are adversely affected by the presence of heavy metal pollution in the water and sediments. Heavy metals have the ability to accumulate in the tissues of fish, which can result in toxic consequences that can negatively impact their health and ability to reproduce. The process of bioaccumulation poses a potential threat to humans who consume seafood. This chronic exposure to the toxins can result in serious health problems, such as neurological damage and/or cancer [9,10].

Aquatic animals acquire heavy metal content through two pathways: direct uptake of free ions and simple compounds dissolved in the water through the skin, gills, and alimentary canal, and incorporation of metals accumulated in their food organisms through nutrition [10,11].

Physiological Effects of Heavy Metals on Fish

Bioaccumulation and Toxicity: Due to their position in the aquatic food web, fish are highly susceptible to heavy metal contamination. Accumulation of heavy metals, including cadmium, lead, mercury and chromium in fish tissues can result in toxicity. Heavy metals have the potential to do significant harm to the health of fish, impacting their growth, reproduction, and immune system [12,13].

Heavy metals can induce distinct pathogenic alterations in different organs of fish. The liver, gills, and kidneys are specifically impacted: The liver frequently exhibits indications of harm as a consequence of its function in detoxification. Histopathological examinations have identified cellular deterioration, necrosis, and alterations in enzyme activity in fish that have been exposed to heavy metals [13,14].

Gills play a vital role in respiration and are directly exposed to pollutants present in water. Exposure to heavy metals can cause physical harm, excessive production of mucus, and decreased effectiveness of the respiratory system, ultimately leading to low oxygen levels in the body and higher risks of death [14,15].

Heavy metal toxicity can hinder the proper functioning of the kidneys, resulting in imbalances in bodily fluids and heightened vulnerability to infections [12,14].

Health Hazards to Humans: The accumulation of heavy metals in fish through the process of bioaccumulation presents substantial health hazards to humans, especially for populations that depend on fish as their main source of sustenance. Consuming seafood that is contaminated can result in many health problems, such as:

Neurological Damage: Heavy metals such as mercury are recognised as neurotoxic substances that can induce cognitive deficits and neurological diseases in humans.

Carcinogenic Effects: Certain heavy metals are categorised as carcinogenic, meaning they have the potential to cause cancer when there is extended exposure through consumption in the diet [12,15].

Sediment as a Contaminant Reservoir

The Yamuna River's sediments serve as a repository for heavy metals, allowing them to persist for long durations. Heavy metals that build up in sediment can have a negative impact on the benthic species living in those sediments, causing disruptions in the local food chains. When sediments are disrupted, such as by agricultural activities or riverine alterations, these metals can be released again into the water, causing more pollution in the aquatic environment and impacting fish populations [9,16].

Consequences

The presence of heavy metals in vegetables in the Yamuna River basin has significant implications for human health, agriculture, and the environment. Continuous ingestion of polluted vegetables can result in the accumulation of hazardous metals including lead (Pb), cadmium (Cd), and arsenic (As) in the human body, leading to long-term health problems such as neurological diseases, kidney malfunction, and several types of cancer. Children are especially susceptible to these harmful impacts, as exposure to lead has been associated with cognitive deficits and delays in development [8,16-18].

Adverse Health Risks Associated with Heavy Metal Contamination

Bioaccumulation and Toxicity: The process of accumulating and retaining harmful substances in living organisms, and the detrimental impact on their health and well-being. Heavy metals are not capable of being broken down by natural processes and have the ability to build up in the tissues of humans, resulting in a range of health problems. Ingesting polluted veggies can lead to the failure of multiple organs, harm to the central nervous system, and an elevated chance of developing cancer [16].

Health Risk Assessment: Evaluations of health risks indicate that children are especially susceptible, with hazard indices surpassing acceptable thresholds in multiple areas along the river. This indicates a possibility of negative impacts on health, such as problems with growth and an increased vulnerability to infections, as a result of long-term exposure to food sources that are polluted [19-21].

Environmental Consequences

Impact on soil: The environmental consequences are similarly concerning since the presence of heavy metals in soils can alter the populations of microorganisms in the soil, diminish soil fertility, and hinder plant growth. This poses a threat to agricultural productivity and food security in the region. Furthermore, the existence of high levels of heavy metals in the food chain can cause a series of negative consequences on the overall well-being of the ecosystem, impacting not just people but also animals and other organisms that rely on the polluted plants [16,19].

Sources of Pollution: The pollution of the Yamuna River is caused by both human activities and natural sources, such as the release of industrial waste, the runoff from urban areas, and the use of polluted water for irrigation in agriculture. This diverse contamination enhances the likelihood of heavy metal buildup in the food chain [17].

The presence of heavy metal contamination has adverse impacts on both human health and agricultural sustainability. Persistent cultivation of contaminated crops can result in soil deterioration and diminished agricultural yield over an extended period [17,21,22].

Socio-Economic Implications: Moreover, these contaminants have great importance since farmers residing in polluted regions may encounter diminished agricultural output, rejection of their goods on the market, and subsequent economic setbacks, hence worsening poverty and food insecurity in susceptible communities. The preceding outcomes emphasise the immediate requirement for thorough evaluation, control, and restoration initiatives to alleviate the hazards linked to the presence of heavy metals in agricultural systems located in close proximity to the Yamuna River [23].

Mortality Due to Heavy Metals Contamination

The presence of high levels of heavy metals in the environment constitutes a significant threat to public health, since it can cause various severe and long-lasting health problems that may finally result in death. Heavy metals, including lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg), are very poisonous, even at low levels, and have been associated with higher death rates in populations exposed to them.

Exposure to lead (Pb) is linked to cardiovascular disease, hypertension, and renal damage, all of which can elevate the likelihood of premature mortality. Research has demonstrated that even little levels of lead exposure can raise blood pressure and contribute to heart disease, hence increasing the likelihood of death from cardiovascular problems [24].

Cadmium (Cd) is a very poisonous metal that has the ability to build up in the kidneys and liver, leading to gradual damage to these organs. Prolonged exposure to cadmium is closely linked to a heightened risk of death caused by renal failure and cardiovascular illnesses. Furthermore, there is a correlation between exposure to cadmium and the development of cancer, specifically lung cancer, which has a substantial impact on the death rates of the afflicted populations [25].

Arsenic (As) exposure is a widely proven factor in the development of different types of cancer, such as skin, lung, bladder, and liver cancer. Prolonged exposure to arsenic, typically from tainted drinking water or food, can cause the formation of several types of malignancies, leading to increased death rates. In addition, there is a correlation between arsenic exposure and the development of cardiovascular disease and diabetes, which in turn increases the likelihood of mortality [26].

Mercury (Hg), especially in its organic form called methylmercury, is recognised for its ability to harm the nervous system and is especially hazardous to pregnant women and growing foetuses. Prolonged exposure to mercury can result in neurological diseases, such as cognitive impairment, tremors, and amnesia. These health problems might worsen other disorders, such as cardiovascular disease, which increases the chances of dying prematurely [27].

Statistical Data

Multiple studies have been undertaken to evaluate the presence of heavy metal pollution in vegetables cultivated in the vicinity of the Yamuna River area. These studies offer essential knowledge about the degree of contamination and the factors that affect the absorption of metals by plants. As an example:

Comparative Analysis conducted by Singh et al. in 2010 was based on comparison of the levels of heavy metal concentrations in vegetables cultivated in various places along the Yamuna River. The study unveiled regional disparities in metal pollution, which were driven by the proximity to industrial zones and points of wastewater release [28].

In 2022, Manish Jaiswal et al. carried out a study which utilised a thorough health risk assessment employing fuzzy logic to analyse the levels of contamination of heavy metals such as arsenic, cadmium, chromium, and lead over the whole length of the Yamuna River. The study emphasised notable contamination hazards, particularly in proximity to industrial effluent outlets, which have an impact on the safety of crops irrigated with this water [19].

A study by Alam et al. in 2023 conducted a comprehensive assessment of the concentration of different heavy metals, such as lead (Pb), copper (Cu), cadmium (Cd), mercury (Hg), chromium (Cr), arsenic (As), and fluoride (F^-), in vegetables obtained from three locations: Mayur Vihar, Kalindi Kunj, and in close proximity to a thermal power plant. The study revealed concerning levels of pollution, especially during the monsoon season, with the most elevated values documented as follows: The concentration of lead (Pb) in spinach is 18.05 parts per million (ppm), the concentration of copper (Cu) in ladyfinger is 32.60 ppm, and the concentration of cadmium (Cd) in radish is 2.59 ppm. It is worth mentioning that mercury and arsenic were not detected in any of the samples. The results suggest that heavy metals were present in all of the locations that were tested. This raises concerns about the potential health hazards of consuming these vegetables. The accumulation of these toxic elements in the human body can result in multi-organ failure and other severe health problems [20].

Analysis of Heavy Metal Content in Vegetables and Soil

In a 2023 study by Asim et al. in which researchers examined the occurrence of heavy metals in several vegetables, such as cabbage, fenugreek, tomato, onion, potato, radish, and spinach, cultivated in areas next to the Yamuna River. The study revealed concerning levels of lead (Pb) and cadmium (Cd), with results suggesting that these metals were present in concentrations that beyond the acceptable thresholds established by health authorities. The study highlighted the importance of consistently monitoring both soil and vegetable samples in order to reduce health hazards related to the consumption of heavy metals [3].

A study by Chatterjee and group in 2020, investigating the ability of Eichhornia crassipes (water hyacinth) to accumulate heavy metals in the Yamuna River revealed that this aquatic plant has a substantial capability to accumulate significant amounts of heavy metals from the water. The study emphasised that the contamination of the Yamuna River, mostly caused by urban trash and industrial effluents, is responsible for the elevated concentrations of heavy metals detected in both the water and the crops irrigated with this water. This study highlights the interdependence between water quality and food safety [6].

Some International Case History Involving Heavy Metals and its Corelation to River Water

A study examines the presence of heavy metals in the water of Bone River in Indonesia, mostly caused by artisanal small-scale gold mining activities. The study emphasises the accumulation of different types of heavy metals and examines the consequences for the water quality in the area and the well-being of the community. The results suggest substantial pollution levels that present hazards to both the ecosystem and human well-being [29].

The primary objective of the study in the Old Brahmaputra River in Bangladesh is to monitor and evaluate the presence of heavy metal pollution in the surface water and sediment of the Old Brahmaputra River. This method use statistical approaches to assess regional and temporal fluctuations in water quality, offering valuable insights into the origins and impacts of heavy metals in the river environment [30].

The study in Bangladesh near a Coal Thermal Power Plant assesses the environmental and human health hazards linked to the presence of high levels of heavy metals in water and sediment in close proximity to a coal-fired power station. The document offers comprehensive statistical studies of nine specific elements, namely Cu, Cr, and As. Additionally, it explores the likely origins of these pollutants and their influence on the quality of nearby water sources [31].

Some International Case History Involving Heavy Metals and its Corelation with Vegetables

The study examines the influence of artisanal small-scale gold mining on the presence of heavy metals in the Bone River, Indonesia. The investigation reveals substantial concentrations of mercury (Hg) and other metals, underscoring the hazards to both local water quality and agricultural production. The study presents quantitative data on the levels of metals and examines the potential consequences for both human health and the environment [29].

A study conducted in Bangladesh in Agricultural Soils and Vegetables assessed the concentrations of heavy metals in agricultural soils and their subsequent absorption by vegetables. The study revealed that soils contaminated with metals such as arsenic and cadmium resulted in substantial buildup in crops, particularly leafy greens. This study emphasises the transmission of toxic metals down the food chain and the possible health hazards for populations that depend on these veggies for sustenance [31].

A study conducted in Turkey from contaminated sites examined the accumulation of heavy metals in vegetables cultivated in close proximity to industrial locations. The study documented elevated concentrations of lead, cadmium, and chromium in several vegetables, which were found to be associated with soil pollution resulting from industrial operations. The results emphasise the significance of overseeing and controlling agricultural methods to avert the absorption of heavy metals in food crops [32].

Analytical Techniques

Advanced analytical techniques are crucial for obtaining precise and dependable data in the evaluation and characterisation of heavy metals found in vegetables cultivated in contaminated areas, such as those adjacent to the Yamuna River. These methods allow scientists to identify and measure small amounts of heavy metals, which is crucial for comprehending the degree of pollution and its possible health hazards [33].

Atomic Absorption Spectroscopy (AAS) is frequently employed in such studies to quantify the quantity of particular metals in vegetable samples. Through an analysis of the light absorption by the metal atoms present in the sample, Atomic Absorption Spectroscopy (AAS) offers accurate determinations of metal concentrations. This makes it an invaluable instrument for monitoring the levels of hazardous metals such as lead (Pb) and cadmium (Cd) [4,9,34].

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is a highly effective method commonly used in environmental research. ICP-MS is highly advantageous for concurrently analysing numerous metals at extremely low concentrations, hence offering a thorough assessment of metal pollution in vegetables. This method is particularly beneficial when evaluating the combined exposure to different heavy metals that may exist in the food chain [34-37].

X-ray Fluorescence (XRF) is commonly employed to quickly analyse heavy metal content in soil and vegetable samples. This method enables to quickly identify regions with elevated levels of contamination, facilitating more targeted and comprehensive study using alternative techniques. The non-destructive nature of XRF enables repeated testing and analysis without modifying the sample, making it advantageous for longitudinal investigations [34,38].

Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) is a method employed for the study of the amount of heavy metals in vegetables. ICP-OES enables the concurrent identification of numerous metals by analysing the emitted light from the sample when it is stimulated in a plasma state. This method is extremely efficient in conducting a comprehensive study of metals such as arsenic (As), mercury (Hg), and chromium (Cr), which are prevalent contaminants in agricultural areas near polluted water sources [34,39].

Electrothermal Atomic Absorption Spectroscopy (ETAAS) is a technique that provides improved sensitivity and is commonly employed for analysing metal concentrations that are exceptionally low. This method is very valuable for identifying extremely small amounts of heavy metals in vegetable samples, which is crucial for conducting risk assessment studies [34,40].

Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) is a method employed to analyse the distribution of metals within vegetable tissues with spatial resolution. This can aid in comprehending the process by which various components of the plant acquire metals, which is crucial for determining which portions of the vegetable are more prone to posing a hazard to customers [34].

These methodologies, each with unique advantages, are essential for the thorough evaluation of heavy metal pollution in vegetables. They offer comprehensive and precise information necessary for assessing environmental health hazards and developing plans to reduce the effects of pollution on the food chain.

Discussion

The elevated levels of heavy metals in vegetables cultivated in the vicinity of the Yamuna River region pose a substantial public health risk, mostly due to the extensive pollution in the river and the adjacent agricultural areas. This review emphasises the essential requirement to monitor and analyse the levels of heavy metals in vegetables, as these pollutants can infiltrate the food chain and provide significant health hazards to consumers. It has regularly demonstrated increased concentrations of metals such as Arsenic (As), cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr), Iron (Fe), Nickel (Ni), cobalt (Co) zinc (Zn), copper (Cu) and mercury (Hg) in vegetables that are watered with contaminated water from the Yamuna River. These metals are known for being poisonous and having the ability to induce long-lasting health consequences, such as kidney impairment, neurological diseases, and heightened risk of cancer.

The utilisation of sophisticated analytical methods such as Atomic Absorption Spectroscopy (AAS), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), X-ray Fluorescence (XRF), and other techniques has played a crucial role in identifying and measuring these pollutants at very low concentrations. These techniques offer the necessary sensitivity and precision to evaluate the degree of contamination and detect the individual metals found in different vegetable samples. Furthermore, the utilisation of techniques such as Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) has allowed scientists to get knowledge on the arrangement of metals in vegetable tissues, which enhances the understanding of potential risks and the development of strategies to minimise them.

The results of this study highlight the immediate necessity for continuous monitoring of heavy metal pollution in agricultural regions adjacent to contaminated water sources. Additionally, there is an urgent requirement for efficient intervention measures to decrease the concentrations of toxic metals in the surroundings. These measures include enhancing the capabilities of wastewater treatment facilities, implementing more stringent rules on industrial waste disposal, and advocating for the use of safer farming methods. Public awareness initiatives are crucial for educating farmers and consumers about the hazards of heavy metal pollution and the significance of food safety.

Conclusion

This research highlights the significant problem of heavy metal pollution in vegetables cultivated near the Yamuna River, caused by environmental contamination from industrial, agricultural, and home origins. Advanced analytical techniques have played a crucial role in precisely measuring and evaluating the levels of hazardous metals in these vegetables, uncovering substantial threats to public health. It emphasises the necessity of thorough and ongoing surveillance, along with efficient measures to reduce harm, in order to safeguard public health and guarantee the security of the food chain in impacted areas. To tackle this problem, a comprehensive strategy is needed that encompasses government regulation, scientific investigation, and community awareness. This will help minimise the risk of heavy metal exposure and protect the well-being of consumers.

Conflicts of Interest

The authors declare no conflict of interest

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