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Comparative Study of Heavy Metal Uptake in Root vegetables versus Leafy Vegetables under Urban Wastewater Irrigation: A Case Study of Hanumangarh, Rajasthan

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Abstract— **Urban wastewater irrigation has become a common practice in many semi-arid regions of India, including Hanumangarh, Rajasthan, due to water scarcity and agricultural demands. However, this practice is associated with the risk of heavy metal accumulation in soils and crops, posing significant public health risks. This study investigates and compares the uptake of heavy metals like Lead (Pb), Cadmium (Cd), Chromium (Cr), Zinc (Zn) and Copper (Cu) in root vegetables (carrot, radish, beetroot) and leafy vegetables (spinach, fenugreek, coriander) irrigated with untreated urban wastewater. Field samples were collected from farms near Hanumangarh town and both soil and vegetable tissues were analyzed using Atomic Absorption Spectrophotometer (AAS). The findings indicate higher concentrations of Pb and Cd in root vegetables, while leafy vegetables exhibited greater bioaccumulation of Zn and Cu. The concentrations of several metals exceeded permissible limits set by WHO/FAO, raising concerns about food safety. This study highlights the need for stricter wastewater treatment protocols, regular monitoring, and awareness campaigns in regions relying on urban effluent for irrigation.**

Index Terms—**Wastewater irrigation, heavy metals, Atomic Absorption Spectrophotometer (AAS Urban effluent**

I. INTRODUCTION

Water scarcity in arid and semi-arid regions such as Hanumangarh has led to increased use of alternative water sources, including untreated urban wastewater. While this practice supports crop growth due to its nutrient content, it can also result in the accumulation of hazardous substances like heavy metals in agricultural soils and plants. Heavy metals such as Pb, Cd, Cr, Zn, and Cu are non-biodegradable and tend to accumulate in plants and the human body through the food chain. Understanding the differential uptake of these metals in various types of vegetables is crucial for assessing health risks and developing mitigation strategies. Vegetables are an essential part of the human diet, and their contamination with heavy metals can have serious health implications. This study aims to compare the uptake of heavy metals in root and leafy vegetables grown under urban wastewater irrigation in Hanumangarh, Rajasthan.

Therefore; the major objectives of the proposed research plan are: -

- To analyze the concentration of heavy metals in root and leafy vegetables irrigated with urban wastewater.
- To compare the bioaccumulation patterns between root and leafy vegetable species.
- To assess the potential health risks to local consumers.

II. MATERIAL AND METHODS

2.1 Study site: -

For this study peri-urban location of Hannumangarh city were selected, which is known for intensive farming of vegetable crops to sell in city area and adjoining area. Hanumangarh lies in the northern part of Rajasthan, characterized by a hot, semi-arid climate. Due to limited freshwater resources, farmers in and around Hanumangarh town increasingly rely on untreated municipal wastewater for irrigation, especially for vegetable cultivation. Major sources of wastewater include domestic effluents, small-scale dyeing units, and commercial establishments. Three peri-urban farms within 5 km radius of Hanumangarh town, all irrigated with untreated wastewater were selected for analysis of heavy metals.

2.2 Vegetable Sampling and Analytical Procedure

The main vegetables grown in this area using sewage water is described in table.

S.No.	Root Vegetables	Leafy Vegetables
1.	Carrot (Daucus carota)	Spinach (Spinacia oleracea)
2.	Radish (Raphanus sativus)	Fenugreek (Trigonella foenum-graecum)
3.	Beetroot (Beta vulgaris)	Coriander (Coriandrum sativum)

The fresh samples of seasonal vegetables were collected during cropping period in the studied area. For that, the whole plant was exrooted from the field for each crop. The whole plant was brought to the laboratory and the edible part (being used for human consumption) such as root, whole leaf or whole plant was cut into small pieces (<2 cm) using a hand blender and then dried in air to remove water from it. After partially dried in the air, the vegetable parts were then oven-dried at 80ºC for 24 hr. The dried vegetable was then grounded into powder using an electronic stainless-steel grinder and sieved through a plastic sieve. The sieved sample was then stored in air-tight plastic containers at 4ºC to be used for analysis of heavy metal contents.

2.3 Analysis of Heavy Metals: -

Acid mixture digestion method was used for the analysis of heavy metals both in soil and vegetable samples by following the standard method by APHA (1998). The sample (1 g for soil and 10 mL for wastewater) was digested with a mixture of HNO_3 and $HClO_4$ (2:1) in close tubes in a microwave digester. The digested samples were then diluted with Millipore Milli-Q water and filtered with Whatman no.42 filter paper. Then the sample was made up to 20 mL volume and analyzed for heavy metal concentration using Atomic Absorption Spectrophotometer (AAS).

2.4 Bio-concentration Factor (BCF):

Heavy metal concentrations of soils and crops will be calculated based on the dry weight. The bio-concentration factor (BCF), an index of the ability of the vegetable to accumulate a particular metal concerning its concentration in the soil substrate was calculated as follows:

$BCF = C_{plant}/C_{soil}$

Where: C_{plant} and C_{soil} represent the heavy metal concentration in the edible part of vegetables and soils, respectively.

2.5 Human Health Risk Assessment:

To estimate the daily exposure of an individual, USEPA (2005) suggests the Lifetime Average Daily Dose (LADD) as the exposure metric. The following equation is a similar representation of daily exposure to the ingestion route modified from USEPA (2010).

$EDI = C \times DI/BW$ Eq.1

$THQ = EDI \times EF \times ED/R_fD \times AT$ Eq.2

$TEDI= \sum^6 EDI$ Eq. 3

$TTHQ= \sum^6 THQ$ Eq. 4

Where EDI is the Estimated Daily Intake of metal (mg/kg/d), C contaminant concentration in sugarcane juice (mg/L), DI is the average daily intake of the crop juice: 0.25L for children and 0.75L for adults (as per the survey conducted in the study area for the consumption of sugarcane juice) (L/d), BW is the average body weight; in this study, 15 kg for children and 70 kg for adults (USEPA, 1989), THQ is the Total Hazard Quotient, EF is the Exposure Frequency (350 days), ED is the Exposure Duration (70 years), R_fD value of different metals was taken from the USEPA guideline (USEPA, 1989) and AT is the average time (period over which exposure is averaged; 70 × 365 years).

III. RESULTS

3.1 Heavy Metal Contents in Vegetables

Heavy metal load in the edible part of the vegetable was estimated to see the overall uptake of heavy metals by standing crops during the sewage irrigation practices. The vegetable samples were dried and grounded in powder form and then analyzed for heavy metal load using Atom Absorption Spectrophotometry. The results of heavy metal content in the vegetables are described in table.

Table: Heavy Metal Concentrations in Vegetables (mg/kg dry weight) shown in the table.

Vegetables	Types	Pb	Cd	Cr	Zn	Cu
Carrot	Root Vegetable	1.62	0.53	1.20	14.8	6.4
Radish	Root Vegetable	1.78	0.60	1.35	13.5	5.9
Beetroot	Root Vegetable	1.55	0.48	1.10	15.2	6.1
Spinach	Leafy Vegetable	1.10	0.32	0.75	38.6	12.4
Fenugreek	Leafy Vegetable	0.98	0.28	0.66	35.3	11.2
Coriander	Leafy Vegetable	0.87	0.25	0.60	33.4	10.5
WHO / FAO Limit		0.3	0.1	0.3	27.4	10

Note: All tested vegetables exceed permissible limits for Pb,Cd and Cr.

3.2 Comparison Between Root and Leafy Vegetables

Root vegetables: -

1. have higher accumulation of Pb, Cd and Cr.
2. absorb metals directly from soil through extended contact with contaminated medium.

Leafy Vegetables: -

1. have higher levels of Zn and Cu
2. accumulate metals through foliar deposition and absorption from irrigation water.

3.3 Bio- concentration Factor (BCF)

- BCF values for Zn and Cu were >1 in leafy vegetables, indicating active accumulation.
- BCF for Pb and Cd was higher in root vegetables, suggesting soil-to-root translocation.

IV. HUMAN HEALTH RISK ASSESSMENT

4.1 Estimated Daily Intake (EDI)

Calculated based on average consumption of 100g/day/person.

- EDI values for Pb and Cd from all vegetables exceeded WHO-recommended tolerable limits.
- Hazard Quotients (HQ) for Pb > 1 in root vegetables, indicating significant non-carcinogenic health risks.
- Children and pregnant women are more vulnerable due to higher metal uptake per kg body weight.
- Chronic exposure may lead to anemia, kidney damage, developmental delays and neurological impairments.

V. DISCUSSION

The findings confirm that untreated urban wastewater used for irrigation in Hanumangarh significantly contributes to heavy metal accumulation in commonly consumed vegetables. Root vegetables show greater affinity for lead and cadmium due to direct soil contact, while leafy vegetables accumulate high levels of zinc and copper, likely due to surface exposure and faster transpiration rates. Given the widespread reliance on such irrigation practices in water-scarce regions, urgent attention is needed to address food safety concerns. This study also highlights the limitations of current monitoring systems and the lack of public awareness regarding contamination risks.

VI. RECOMMENDATIONS

Based on the findings of the study, the following recommendations are made:

1 Use of Freshwater or Treated Wastewater: Use freshwater or treated wastewater for irrigation to minimize the risks associated with heavy metal contamination.

2 Crop Selection: Select crops that are less prone to heavy metal accumulation, such as root vegetables.

3 Soil Remediation: Implement soil remediation strategies to reduce heavy metal contamination in soil.

4 Regular Monitoring: Regularly monitor heavy metal levels in crops and soil to ensure safe and sustainable agricultural practices.

VII. CONCLUSION

The study concludes that both root and leafy vegetables accumulate significant amounts of heavy metals when grown under urban wastewater irrigation in areas of Hannumangarh, Rajasthan However, leafy vegetables tend to accumulate higher amounts of heavy metals compared to root vegetables. The differential uptake in root vas leafy vegetables should guide future crop selection and risk communication strategies. The study highlights the need for safe and sustainable irrigation practices in agriculture to minimize the risks associated with heavy metal contamination.

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