e-ISSN No.: 2582-4228

Journal of Indian Association for Environmental Management

Journal homepage: www.http://op.niscair.res.in/index/php/JIAEM/index

Assessment of Heavy Metals and Associated Health Risk with the Consumption of Vegetables Grown in the Flood Plains of River Yamuna in Delhi

Mamta Prakash[1*], Rashmi Misra[2], Priyanka Saxena[1], and S.K.Goyal[1]

[1]CSIR-NEERI, Zonal Laboratory Centre. New Delhi, India;
[2] CSIR-HQ, Anusandhan Bhawan, New Delhi
*Corresponding Author: mamta.prakash@csir.res.in

Submitted: 12 May 2026 Revised: 31 May 2026 Accepted: 05 June 2026

***Abstract*: The present study assesses the levels of heavy metals and their risk on human health through ingestion of commonly grown vegetables in floodplain of Yamuna river stretch of Delhi. The metal content in soils collected from different locations of the floodplain were in the order of Fe > Mn > Cr > Zn > Ni > Cu > Co > Pb > Cd > Hg and were within the permissible limits of *MoEF & CC, 2015* except Cd. Significantly high correlation was found among concentration of metals in soil between Ni-Co, Ni-Mn, Cr-Pb, Cr-Zn, Cu-Zn, Cu-Pb, Cu-Cr and Zn-Pb which could be due to similar anthropogenic sources. The Pollution load index of soils fell under the category of baseline level of pollutants and the Ecological risk index was also found low. The levels of metal intake (Zn, Cu, Ni, Cd and Hg) through vegetables grown in floodplains were found within the permissible limit of *FSSAI 2011*except for Pb, where the concentration exceeded the standard limit. The Health Risk Index (HRI), in vegetables for all metals were found < 1.0 and was found safe except for Spinach and Brinjal, wherein the HRI value of Pb was 1.09 and1.01 respectively which was found slightly higher than 1.0 which indicates matter of concern and requires regular monitoring to ascertain the levels of metals within the safe limits of human consumption.**

Keywords: Metal Contamination, Bioaccumulation factor, Ecological risk index, HRI

I. INTRODUCTION

Heavy metals (HMs) in agricultural soils have become one of the major cause of concern due to their persistent bio-accumulative nature. The sources of these heavy metals are industrial effluents, domestic sewage, vehicular emissions, diesel run generators and pesticides application in agricultural fields. Heavy metal accumulation often leads to soil degradation and consumption of vegetables grown in such soils infiltrate the food chain leading to metal toxicity. (*Singh.S. 2006*). Amount of heavy metals are generally higher in the soil than in the plants grown in them, which indicates that only a small portion of heavy metal is taken up by the plant from soil. However, roots act as barrier in the translocation of heavy metals within the plant parts. Different parameters of soil viz., texture, pH, Organic carbon and cation exchange capacity greatly influence the permeation of metals in the vegetables (*Daulta,R., et al 2023*). Heavy metals uptake and its translocation in different parts of the plant are the main aspects of plant's ability to accumulate and overcome their high concentrations (*Kumar,A. et al 2017*).

Heavy metals have the tendency to affect physiological functioning of a normal human body by depleting some essential nutrients. According to a study, consumption of vegetables contaminated with heavy metals reduces the availability of necessary nutrients resulting in compromised defence mechanism of the body and intrauterine growth restriction (Iyengar & Nair, 2000; Garg et al, 2014). Heavy metal contamination on human health and animals can result in muscular weakness, low psychometric tests score and symptoms of peripheral neuropathy (Hussain et.al 2013). Some heavy metals are mutagenic, carcinogenic and cytotoxic in nature which pose serious threat to urban population that depend on vegetables and foliage crops grown (*Sumit Pal.et.al.2018*). As a result of awareness of risk of these heavy metals various national and international regulatory bodies have laid down standard limits for toxic metals in different food items.

Yamuna River is the lifeline of Delhi which shows high levels of heavy metals, pesticides and herbicides residues. Agricultural farming is being practised by growing of vegetables along the Yamuna floodplains in Delhi and NCT regions. Heavy metals in vegetables and soils have been reported by *sehgal,M. et.al 2012;2014* and *Toxic links 2014*, a city based NGO. Because the vegetables grown in flood plains of Yamuna river are consumed by people living in Delhi, it becomes relevant to study the amount of heavy metals in the vegetables and check their suitability for consumption. Present study is undertaken to assess the levels of heavy metals in the soil and edible portion of plants grown in Yamuna floodplains, there by evaluating the health risk in the target population.

II. Materials and Methods

Study Area

The study area was along the flood plains of Yamuna river stretch in Delhi. Yamuna river in Delhi state, traverse through 22 km, which is 2% of the total Yamuna stretch and accounts for 80% of the pollution load (*Alam,S. et al;2017*). The river is the main source of water for domestic usage, drinking, agricultural purposes, industrial usage, and other anthropogenic activities. A systematic approach of sampling was designed to study the contamination levels in the agricultural fields at different locations along the river stretch. Four locations with agricultural practices were identified along the river in Delhi, starting from the entry point viz., Dashera followed by Usmanpur Khadar, Geeta Colony and Mayur Vihar Phase-1 as shown in **Figure 1 (a & b).**

Sampling of Vegetables

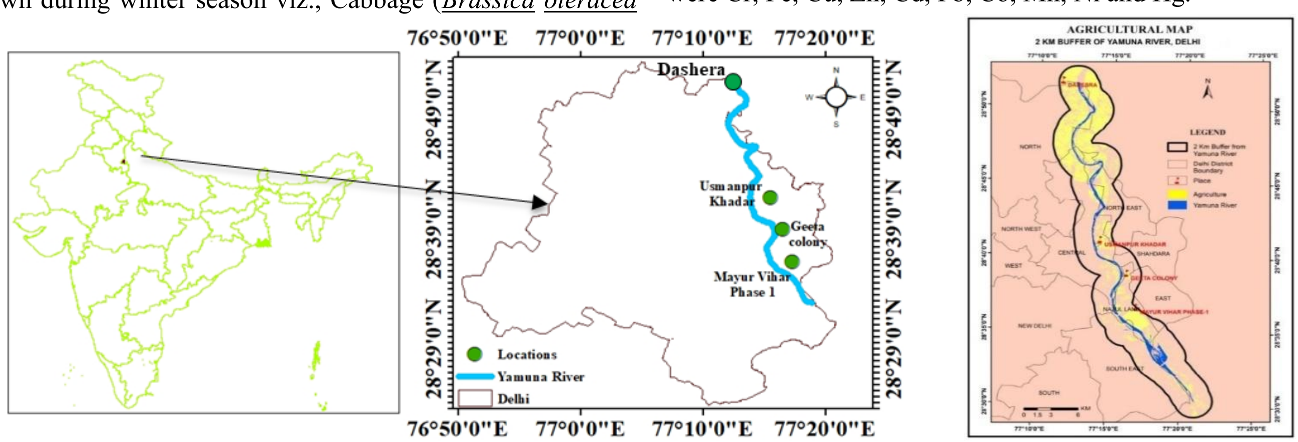
The vegetables were sampled from four locations from floodplains of river Yamuna. Seven vegetables commonly grown during winter season viz., Cabbage (*Brassica oleracea* var. capitata), Radish (*Raphanus sativus*), Coriander (*Coriandrum sativum*), Spinach (*Spinacia oleracea*), Cauliflower (*Brassica oleracea* var. botrytis), Brinjal (*Solanum melongena*) and Fenugreek (*Trigonella foenum-graecum*) were identified for the analysis and assessment of the heavy metal load. Vegetable samples were collected from different points of the agricultural fields from different locations of the Yamuna floodplains. The distance between the river and agricultural fields at different locations varied distinctly viz., Dahsera-1.9km, Usmanpur-0.6km, Geeta Colony-0.1km and Mayur Vihar phase-1-2.3km. The vegetables were cleaned with distilled water to remove foliar contaminants like dust, mud, fertilisers, and pesticides. The edible part of the vegetables were cut into small pieces and were air dried initially and then oven dried at 60°C to remove the moisture completely. The dried samples were ground and used for analysis.

Soil Sampling

The soil sampling was carried out from agricultural fields of respective vegetables sampled at all the four locations with the help of a Khurpi, within 0-30 cm depths from root zone area.3-4 soil samples were collected from each location and were made composite. The soil samples were collected in labelled polythene bags and were air dried. The soil samples were processed by grinding and sieving for further analysis.

Heavy Metal Analysis

Soil and plant samples were digested using microwave digester (CEM, Model: MARS ONE, 240/50) using CEM recommended methods with minimal modification. 0.5 gm of soil sample was digested with 10 ml aqua regia and 0.5 gm of plant sample was digested with 5ml HNO_3+ 2ml H_2O_2. Blank was also digested in both kind of samples. The digested samples were filtered using Whatmann filter paper No. 42 followed by syringe filtration (0.45 microns). Final make-up volume was 50 ml and the samples were refrigerated for heavy metal analysis using ICP-OES (Model: Prodigy High Dispersion ICP, M/S Teledyne Leeman Labs). The metals undertaken in the study were Cr, Fe, Cu, Zn, Cd, Pb, Co, Mn, Ni and Hg.



a) Study area map showing the location of the Yamuna River floodplain in Delhi, India

b) Map showing Agricultural practices in 2Kms Buffer Zone

Figure 1: Map Showing Locations of Vegetables and Soil Samples Collection from Agricultural fields in Yamuna Flood Plains of Delhi

To assess the soil quality of floodplains, contamination due to heavy metals was calculated.

Contamination factor (C_f): Soil contamination due to heavy metals is calculated as

$$C_f = Analytical\ value\ for\ ith\ component\ /Permissible\ limit\ for\ ith\ component$$

C_f values were interpreted as $C_f < 1$= Low contamination; $1 < C_f < 3$= Moderate contamination; $3 < C_f < 6$= Considerable Contamination and $C_f > 6$= Very High contamination. *(Hakanson1980)*

Pollution Load Index (PLI): PLI of the soil was also evaluated to assess the soil/sediment quality.

$$PLI = (C_{f1} \times C_{f2} \times \ldots\ldots C_{fn})^{1/n}$$

Where *n* is *number* of metals and C_f the contamination factor of each metal present in the sediment/soil. PLI ≤ 0 represents perfection or control, PLI value of >0-1 indicates the baseline level of pollutants and PLI>1 indicates progressive deterioration of the site due to elevated metal content (*Pobi,K.K. et al. 2019*).

Ecological Risk Assessment (RI): The risk level with respect to toxicity of metals in the sediment/soil is evaluated by potential ecological risk index (RI) (Hakanson1980). The following equation can be used to calculate the potential ecological risk factor (Er) for individual metal and RI of multi-element

$$RI = \sum_{i=1}^{n} E_r^i = \sum_{i=1}^{n} C_f^i \times T_r^i$$

Where C_f^i is the contamination factor for the element "I" and T_r^i is the toxic response factor for the given element of "I", which accounts for the toxic and the sensitivity requirements. The toxic response factors for Pb, Cd, Cr, Cu, Hg, Ni, Zn and Co were 5, 30, 2, 5, 40, 5, 1 and 5 respectively (*Santos-Francés, F. et al 2017,Pobi,K.K. et al 2019*). Metal (viz., Fe) with Er value < 1 is not considered for the calculations of RI.

Metal Pollution Index (MPI): MPI was calculated as

$$MPI = (Cf\ 1 \times Cf\ 2 \times Cf\ 3 \ldots\ldots\ldots\ldots\ldots\ Cf\ n)\ 1/n$$

Where, Cf_1 is a concentration of metal1 and Cf_n is the concentration of the n^{th} metal in a vegetable sample (*Usero J. et.al 1996*).

Bioaccumulation Factor (BAF): BAF was calculated as

$$BAF = C_{vegetable}/C_{soil}$$

Where $C_{vegetable}$ and C_{soil} are the heavy metal concentration in the edible parts of vegetables and respective soil on dry weight basis. Plants with BAF > 1 are accumulators; with BAF = 1 have no influences and with BAF < 1 are "excluder" (*Radulescu et al., 2013*).

Health Risk Index (HRI): HRI was calculated as the ratio of estimated exposure of analysed vegetables in the study to the oral reference dose given by the following equation:

$$HRI = DIM/\ RfDo.$$

Where the DIM and *RfDo* represents daily intake of metal and reference oral dose respectively. The DIM is calculated by using the following equation:

$$DIM = C_{metal} \times C_{factor} \times D_{food\ intake}/B_{average\ weight}$$

Where C_{metal} is heavy metal concentration in edible part of plant (mg/Kg), C_{factor} is the conversion factor of 0.085 to convert fresh weight to dry weight, $D_{food\ intake}$ is the daily food intake in the form of vegetable and *B average weight* is the average body weight of the consumer i.e. 60 Kgs (Datta etal.2005). The daily intake of vegetables i.e. Cabbage, Radish, Spinach, Cauliflower, Brinjal and Fenugreek was taken as 300gm. However, daily intake of Coriander was taken as 100gms. The oral reference dose for Cr, Fe, Cu, Zn, Cd, Pb, Co, Mn, Ni and Hg reported was 1.5, 7.0×10^{-1},4.0×10^{-2},3.0×10^{-1},1×10^{-3},4×10^{-3},4.3×10^{-2},1.4×10^{-1},$2\times10^{-2}$and 1×10^{-4} respectively (*USEPA 2010-2013, WHO1993, Food & Nutrition board 2004*). If the health risk Index is more than 1, the potential non-cancer effects may be of concern (*USEPA 2010*).Health Index is the summation of Health risk Indices *(USEPA1989).*

III. Result and Discussion

Heavy Metal Concentration in Agricultural Field Soils

Sub surface soil samples (0-30cm) were collected from the agricultural floodplains of the river from four locations viz., Dahesra, Usmanpur khadar, Geeta colony and Mayur Vihar phase-1. Table 1 shows the average concentration of heavy metals in mg/Kg at each location. Metal concentration in soils were in the following order: Fe (21508-24642) > Mn (320-385) > Cr (51-76) > Zn (41-62) > Ni (16-18) > Cu (14.7-28.4) > Co (8.84-9.18) > Pb (4.65-13.53) > Cd (1.89-3.26) > Hg (0.007-0.013) mg/Kg. In reference to Indian standards for agricultural soils MoEF & CC 2015, the mean concentrations of heavy metals in the agricultural field soil were well within the standard limits except Cr and Cd. Concentration of Cr was found to exceed the standard limit at Mayur Vihar only whereas Cd exceeded the standard limit at all four sampling locations. Overall, concentration of heavy metals at Mayur Vihar Phase -1 was at the higher side as compared to other locations. This could be because Mayur Vihar Phase- 1, lies at the downstream of Yamuna as it enters Delhi at Dahesra (upstream). When water flows downstream, it accumulates contaminants from different sources on its way, leading to overall higher concentrations.

Mean values of Contamination factor (C_f) and Pollution load index (PLI) are shown in Table 2. The C_f values of Cd at all the locations and Cr at Mayur vihar location showed moderate contamination. The soils were categorised under baseline level of pollutants on the basis of pollution load index. The potential ecological risk for each metal was also computed Table 3 in which cadmium showed moderate potential risk level while rest metals were at low potential risk level at all locations. However, the Ecological Risk calculated was low at all the locations (*as per classification of Er, RI Hakanson 1980*).

Significant correlations were observed between metal concentrations in soils at different locations as showed in Table 4. Copper with Zinc, Cadmium, Lead and Manganese (Cu-Zn, Cu-Cd, Cu-Pb, Cu-Mn),Chromium with Copper, Zinc, Cadmium, Lead(Cr-Cu, Cr-Zn, Cr-Cd, Cr-Pb),Nickel with Chromium, Copper, Zinc, Lead, Cobalt and Manganese (Ni-Cr, Ni-Cu, Ni-Zn, Ni-Pb, Ni-Co, Ni-Mn) Zinc with Cadmium and Lead(Zn-Cd, Zn-Pb),Cadmium with lead(Cd-Pb) and Cobalt with Iron(Co-Fe). A significant correlation between the metals suggests the possibility of similar anthropogenic source i.e. industrial, municipal wastewaters etc. Statistically significant correlation between Ni-Zn, Ni-Cu, Ni-Mn, Zn-Cu and Cu- Mn has also been reported.(*Sehgal et.al 2012, Sumit Pal et.al 2018).*The source of these metals could be from, steel processing industries, electroplating industries, proximity of highways and main roads, and use of agrochemicals containing heavy metals (*S.Singh 2006).*The treated or untreated industrial wastewaters from different sources, and city sewage waters are discharged in the Yamuna river which introduces these contaminants to the agricultural soils of the floodplains through irrigation or during flood.(*Sehgal et.al 2014*).

TABLE 1
Heavy Metal Concentration (mg/Kg) in rhizospheric Soil

Location	Cr	Fe	Cu	Zn	Cd	Pb	Co	Mn	Ni	Hg
Dahesra	52.25± 6.18	24466± 3361	16.00± 2.71	42.25± 4.86	2.45± 0.30	4.65± 1.18	9.18± 1.03	349.25± 48.84	17.18± 2.00	0.008± 0.003
Usmanpur khadar	51.71± 6.60	24075± 1551	16.71± 3.40	42.71± 5.38	1.94± 0.17	6.53± 1.91	9.04± 0.47	385.57± 12.96	17.66± 1.18	0.009± 0.002
Geeta Colony	51.14± 13.80	24642± 5606	14.71± 6.87	41.43± 10.67	1.89± 0.39	5.10± 3.54	8.84± 1.22	320.00± 62.45	16.26± 3.14	0.007± 0.002
Mayur Vihar -Phase I	76.00± 12.96	21508± 2312	28.43± 5.56	61.71± 10.23	3.26± 0.44	13.53± 4.15	9.09± 0.50	380.29± 24.38	18.00± 1.81	0.013± 0.005
Standard value*	64	-	63	200	1.4	70	40	-	50	6.6

*Standards for Agricultural soils (mg/Kg) MoEF & CC 2015

TABLE 2
Contamination factors (Cf) and Pollution Load Index (PLI) of Heavy Metals in Soil Samples from different Locations of Yamuna Floodplains

Site location	C_f								PLI
	Cr	Cu	Zn	Cd	Pb	Co	Ni	Hg	
Dahesra	0.816	0.254	0.211	1.750	0.066	0.229	0.343	0.0012	0.163
Usmanpur khadar	0.808	0.265	0.214	1.387	0.093	0.226	0.353	0.0014	0.168
Geeta Colony	0.799	0.234	0.207	1.347	0.073	0.221	0.325	0.0011	0.152
Mayur Vihar – Phase I	1.187	0.451	0.308	2.326	0.193	0.227	0.360	0.0019	0.242

TABLE 3
Potential Ecological risk factors (Er) and Ecological Risk Indexes (RI) of Heavy Metals in Soil Samples from different Locations of Yamuna Floodplains

Site location	E_r								RI
	Cr	Cu	Zn	Cd	Pb	Co	Ni	Hg	
Dahesra	1.63	1.27	0.21	52.50	0.33	1.15	1.72	0.049	58.86
Usmanpur khadar	1.62	1.33	0.21	41.63	0.47	1.13	1.77	0.055	48.21
Geeta Colony	1.60	1.17	0.21	40.41	0.36	1.11	1.63	0.043	46.52
Mayur Vihar – Phase I	2.38	2.26	0.31	69.80	0.97	1.14	1.80	0.077	78.71

TABLE 4
Pearson's Correlation Matrix of Heavy Metals for Agricultural Field Soils of Yamuna Floodplains

	Cr	Fe	Cu	Zn	Cd	Pb	Co	Mn	Ni	Hg

Cr	1									
Fe	0.006742	1								
Cu	0.989868	-0.00076	1							
Zn	0.998853	-0.00033	0.991792	1						
Cd	0.713633	-0.06166	0.737004	0.714484	1					
Pb	0.971059	-0.13345	0.977174	0.975017	0.664836	1				
Co	0.510543	0.714561	0.539543	0.50704	0.301746	0.424684	1			
Mn	0.584436	0.333619	0.649968	0.592524	0.392438	0.59674	0.76719	1		
Ni	0.728445	0.521793	0.747577	0.725932	0.355785	0.668835	0.901686	0.851228	1	
Hg	0.432346	-0.13135	0.494787	0.443336	0.583552	0.45015	0.173533	0.440108	0.264304	1

Heavy Metal Concentration in Edible Part of the Vegetables

Healthy and balanced diet requires intake of vegetables for proper nourishment. Vegetables are rich source of minerals and vitamins which is essential for the maintenance of good health. Being an important human dietary constituent, it is necessary to ascertain heavy metal content in order to ensure the vegetable quality. The overall heavy metal concentration in edible part of considered vegetables is presented in Table 5. Based on the analysis of the study, the Iron was maximum and was highest in leafy vegetables as compared to others. The mean concentration of Fe ranged between 45.7 mg/kg(Cabbage) to 917.2mg/kg (Spinach) followed by Zn 11.3 mg/kg (Brinjal) to 34.2 mg/kg(Spinach), Mn 8.75 mg/kg(Radish) to 67.7mg/kg(Spinach), Cr 7.3 mg/kg (Brinjal) to 25.5 mg/kg(Spinach) , Pb 2.55 mg/kg(Cabbage) to 10.27 mg/kg(Spinach), Cu 0.55 mg/kg(Cabbage) to 6.8mg/kg(Spinach), Ni 0.013 mg/kg(Cauliflower) to 0.706 mg/kg(Fenugreek) ,Co 0.033 mg/kg (Brinjal) to 0.21 mg/kg (Fenugreek)and Hg 0.03 mg/kg (Radish) to 0.147 mg/kg(Spinach). Results showed that among all the edible part of plants grown in the study area, Spinach was the major accumulator compared to other vegetables. Further, on comparison with *FSSAI 2011* food standards, it was found that except for lead all the trace metals were within the standard limits. Amongst all Lead concentration was beyond the permissible limits and maximum was in Spinach followed by Brinjal and Coriander. A study carried out by *Aithani et al. 2024* found that vegetables in the Yamuna River floodplain in Delhi had varying degrees of trace element contamination in which the leafy vegetables had higher concentrations of Mn, Co and Ni while fruit and inflorescence vegetables had higher levels of Pb, Zn and Cr.

Bioaccumulation Factor (BAF) of Metals

BAF is one of the important indicators for the human exposure to heavy metal through food chain. It is calculated to identify efficiency of plant species to accumulate the respective heavy metal in its edible part.

It is calculated as the ratio of vegetable to soil content of the respective metal. Bioaccumulation Factor was calculated for the vegetables taken up in study as shown in Table 6. It has been observed that there was slight accumulation of lead (>1) in spinach, coriander, fenugreek, Brinjal and Radish as shown in Table 6. Studies carried out by *Kumar et al. 2020* reported that impact on Spinach cultivation at Haridwar by using integrated industrial wastewater greater build-up of HMs in spinach tissues with increased crop yield and growth. In present study there was accumulation of mercury in the all the vegetables also which shows that it is more mobile than other metals, however the concentration of Hg in edible part of plant and soil was very low and well within the standard limits.

Metal Pollution Index

Heavy metal contamination in the vegetables was assessed by using Metal Pollution Index (MPI) as shown in Figure 2. It has been seen that Spinach showed the maximum MPI followed by Fenugreek and coriander. It has been observed that leafy vegetables show higher MPI as compared to other vegetables. This could be due to higher biomass production than the fruiting vegetable. *(Shobhana Ramteke, et.al.2016),(Garg, V.k.et.al2014)*. Research studies carried out by *Kumar etal 2022* found that Cd concentrations exceeded permissible levels in most vegetables, with spinach and okra showing the highest metal pollution index in peri-urban and urban areas of Delhi.

Further the vegetables grown in Geeta colony and Usmanpur locations showed higher MPI than other two locations due to confluence of 10-12 drains containing industrial and domestic waster waters in the Yamuna river between Wazirabad bridge and ITO Barrage (*P.P.Patel et. al2020*). Also, agricultural fields at these two locations viz., Usmanpur and Geeta colony were very close to the river as compared to other two locations.

TABLE 5

Concentration of Heavy Metals (mg/Kg) in Dried Edible Portion of Vegetables Grown in the Study Area

Heavy Metals mg/Kg	Standard (FSSAI 2011)	Vegetables						
		Cabbage	Radish	Coriander	Spinach	Cauliflower	Brinjal	Fenugreek

	mg/Kg							
Cr	-	10.5±5.07	15.0±4.90	15.5±5.45	25.5±2.38	17.7±4.16	7.3±5.51	11.7±3.06
Fe	-	45.7±7.14	90.2±94.52	472.5±229.64	917.2±385.70	57.3±12.06	71.0±64.58	891.7±382.43
Cu	30	0.55±0.62	1.62±1.07	5.30±2.77	6.80±2.80	0.97±0.91	5.27±1.70	3.70±1.51
Zn	50	14.5±4.20	21.5±4.73	20.5±6.81	34.2±2.87	25.0±1.00	11.3±4.16	17.7±7.11
Cd	1.5	0.000±0.00	0.067±0.14	0.207±0.30	0.455±0.41	0.000±0.00	0.000±0.00	0.023±0.03
Pb	2.5	2.55±0.70	4.2±1.17	8.6±3.56	10.27±2.90	3.5±0.62	9.5±2.10	6.9±1.82
Co	-	0.04±0.01	0.032±0.03	0.065±0.05	0.202±0.08	0.067±0.04	0.033±0.01	0.21±0.13
Mn	-	17.7±2.63	8.75±1.89	30.7±3.50	67.7±20.45	17.0±2.00	11.0±1.73	32.3±7.69
Ni	1.5	0.045±0.07	0.04±0.08	0.33±0.21	0.385±0.23	0.013±0.02	0.13±0.12	0.706±0.21
Hg	1.0	0.035±0.01	0.030±0.01	0.059±0.04	0.147±0.09	0.056±0.02	0.030±0.03	0.119±0.12

TABLE 6

Bioaccumulation Factor of Heavy Metals in Vegetables Grown in the Study Area

Heavy Metals	Vegetables						
	Cabbage	Radish	Coriander	Spinach	Cauliflower	Brinjal	Fenugreek
Cr	0.173 (0.086-0.261)	0.301 (0.134-0.362)	0.281 (0.169-0.379)	0.436 (0.255-0.558)	0.323 (0.200-0.412)	0.162 (0.026-0.309)	0.197 (0.160-0.243)
Fe	0.002 (0.002-0.002)	0.004 (0.002-0.012)	0.019 (0.011-0.027)	0.0383 (0.021-0.049)	0.002 (0.002-0.003)	0.003 (0.001-0.006)	0.0413 (0.032-0.060)
Cu	0.043 (ND -0.100)	0.128 (0.023-0.310)	0.315 (0.161-0.657)	0.407 (0.092-0.817)	0.095 (0.085-0.106)	0.398 (0.124-0.700)	0.209 (0.106-0.263)
Zn	0.295 (0.200-0.421)	0.517 (0.327-0.629)	0.449 (0.283-0.604)	0.707 (0.500-0.861)	0.548 (0.491-0.595)	0.281 (0.161-0.470)	0.345 (0.313-0.367)
Cd	ND (0.00-0.00)	0.135 (ND-0.135)	0.169 (0.095-0.242)	0.198 (0.023-0.400)	ND (0.00-0.00)	ND (0.00-0.00)	0.033 (0.033-0.033)
Pb	0.359 (0.250-0.644)	1.168 (0.355-2.609)	1.539 (0.724-3.366)	1.517 (0.344-2.547)	0.695 (0.286-1.121)	1.651 (0.563-2.479)	1.485 (0.411-3.125)
Co	0.004 (0.003-0.007)	0.005 (ND-0.008)	0.007 (0.001-0.013)	0.022 (0.013-0.034)	0.008 (0.005-0.012)	0.003 (0.002-0.004)	0.023 (0.012-0.040)
Mn	0.046 (0.037-0.052)	0.027 (0.022-0.036)	0.087 (0.069-0.097)	0.176 (0.095-0.221)	0.050 (0.043-0.061)	0.031 (0.026-0.033)	0.095 (0.068-0.111)
Ni	0.005 (ND -0.009)	0.011 (ND-0.011)	0.020 (0.004-0.037)	0.022 (0.010-0.045)	0.002 (0.002-0.002)	0.009 (0.001-0.018)	0.042 (0.024-0.059)
Hg	3.453 (1.091-5.065)	3.401 (0.727-5.156)	7.869 (2.273-13.684)	23.138 (10.520-34.262)	6.624 (3.273-9.839)	5. 344 (2.100-10.161)	6.146 (2.544-9.109)

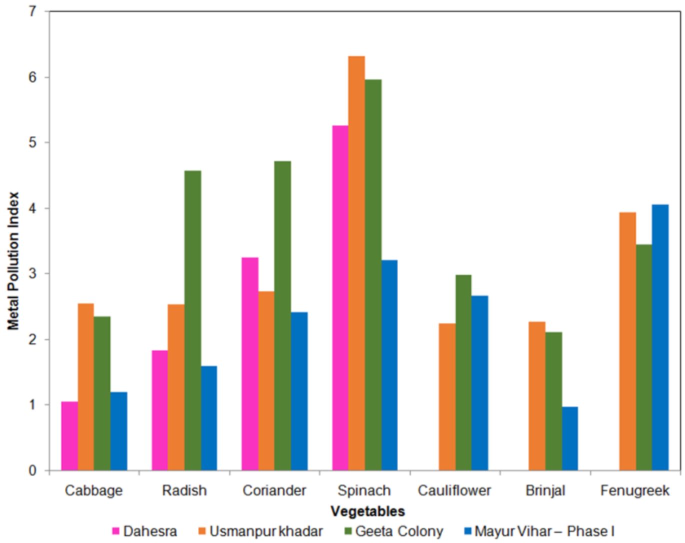
Health Risk Assessment on Consumption of Edible Part of Plant

The DIM (Daily intake of metals) derived from ingestion of vegetables grown in flood plains and the associated HRI (Health risk Index) is presented in Table 7. The DIM values of Fe were highest and ranged between 0.0194 in cabbage to 0.39 mg/person/day in Spinach. Among the vegetables, daily consumption of metals was highest in Spinach followed by Fenugreek. HRI assesses the risk associated with the consumption of individual heavy metal by consuming vegetables as dietary intake. HRI calculated for all the metals, undertaken in the present study, for edible part in vegetable was less than unity. Therefore all vegetables were safe to consume in diet per day except Pb whose HRI was >1 in case of Spinach and Brinjal, which was 1.09 and 1.01 respectively. Similar study was done by *Patel et al; 2019* in which he found HRI of four metals (Cu, Cr, Ni and Zn) was less than 1. However, HRI for Pb was more than 1 in all the crops except rice. Studies carried out at Jhansi by *Gupta etal 2021* supports that vegetables irrigated with wastewater/grown near industrial areas, particularly leafy varieties like spinach and fenugreek, accumulated hazardous levels of cadmium, manganese, and lead. The target hazard quotients for these metals exceeded unity, indicating significant non-carcinogenic health risks for regular consumers. Vegetables, especially spinach and okra, were identified as major contributors to dietary exposure of HMs. Cadmium and lead levels in vegetables, particularly in spinach samples, were found to be dangerously high as reported by *Jain et al. 2023*. Studies conducted by *Ghosh et al. 2024* in Kolkata revealed high levels of Pb, Cd, and Ni in commercially grown vegetables irrigated with wastewater and affected by solid waste dumping. Leafy vegetables-particularly red spinach, bathua, coriander, and mustard showed higher HM accumulation compared to fruit vegetables. Spinach, capsicum, and Malabar spinach from several zones demonstrated TF values > 1 for Cd and Pb, suggesting their potential as hyperaccumulators and their role in enhancing dietary exposure to toxic metals. Health risk assessments of red spinach, mustard and coriander showed hazard index values greater than 1. In the present study, Health index (HI) for all the vegetables was also calculated which suggested that Spinach had the highest HI followed by Fenugreek and Brinjal. Based on the study it may be inferred that the accumulation of heavy metals in the vegetables are unlikely to pose any adverse health effect as the HRI was less than 1 except in case of Pb in Spinach and Brinjal which is a matter of concern and requires regular monitoring.

TABLE 7

Daily Intake of Metals (DIM) (mg /Person/day) and Health Risk Index (HRI) of Heavy Metals from Vegetables Grown in the Study Area

Heavy Metals	DIM / HRI	Vegetables						
		Cabbage	**Radish**	**Coriander**	**Spinach**	**Cauliflower**	**Brinjal**	**Fenugreek**
Cr	DIM	0.00446±0.00215	0.00638±0.00208	0.0022±0.000772	0.0108±0.00101	0.00751±0.00177	0.00312±0.00234	0.00496±0.0013
	HRI	0.00298±0.00144	0.00425±0.00139	0.00146±0.000514	0.00723±0.000674	0.00501±0.00118	0.00208±0.00156	0.00331±0.000866
Fe	DIM	0.0194±0.00303	0.0384±0.0402	0.0669±0.0325	0.39±0.164	0.0244±0.00512	0.0302±0.0274	0.379±0.221
	HRI	0.0278±0.00433	0.0548±0.0574	0.0956±0.0465	0.557±0.234	0.0348±0.00732	0.0431±0.0392	0.541±0.316
Cu	DIM	0.000234±0.000263	0.000691±0.000453	0.000751±0.000393	0.00289±0.00119	0.000411±0.000386	0.00224±0.000723	0.00157±0.00066
	HRI	0.00584±0.00658	0.0173±0.0113	0.0188±0.00982	0.0723±0.0298	0.0103±0.00964	0.056±0.0181	0.0393±0.0165
Zn	DIM	0.00616±0.00179	0.00914±0.00201	0.0029±0.000964	0.0146±0.00122	0.0106±0.000425	0.00482±0.00177	0.00751±0.00354
	HRI	0.0205±0.00595	0.0305±0.00669	0.00968±0.00321	0.0485±0.00407	0.0354±0.00142	0.0161±0.0059	0.025±0.0118
Cd	DIM	0.00±0.00	0.0000287±0.0000574	0.0000294±0.0000421	0.000193±0.000175	0.00±0.00	0.00±0.00	0.00000992±0.0000172
	HRI	0.00±0.00	0.0287±0.0574	0.0294±0.0421	0.193±0.175	0.00±0.00	0.00±0.00	0.00992±0.0172
Pb	DIM	0.00108±0.000298	0.00182±0.000497	0.00122±0.000504	0.00437±0.00123	0.00149±0.000265	0.00404±0.000893	0.00293±0.0007
	HRI	0.271±0.0744	0.454±0.124	0.305±0.126	1.09±0.308	0.372±0.0664	1.01±0.223	0.733±0.175
Co	DIM	0.000017±0.000006	0.0000138±0.0000117	0.00000921±0.00000699	0.0000861±0.0000337	0.0000283±0.0000161	0.0000142±0.00000491	0.0000893±0.0000629
	HRI	0.000395±0.00014	0.000321±0.000272	0.000214±0.000163	0.002±0.000784	0.000659±0.000374	0.000329±0.000114	0.00208±0.00146
Mn	DIM	0.00754±0.00112	0.00372±0.000805	0.00436±0.000496	0.0288±0.00869	0.00723±0.00085	0.00468±0.000736	0.0137±0.00393
	HRI	0.0539±0.00798	0.0266±0.00575	0.0311±0.00354	0.206±0.0621	0.0516±0.00607	0.0334±0.00526	0.0982±0.028
Ni	DIM	0.0000191±0.0000304	0.000017±0.000034	0.0000468±0.0000295	0.000164±0.0000976	0.00000567±0.00000981	0.0000553±0.000051	0.0003±0.0000878
	HRI	0.000956±0.00152	0.00085±0.0017	0.00234±0.00147	0.00818±0.00488	0.000283±0.000491	0.00276±0.00255	0.015±0.00439
Hg	DIM	0.0000152±0.00000393	0.000013±0.00000629	0.00000846±0.00000525	0.0000732±0.0000159	0.0000241±0.00000802	0.0000139±0.0000114	0.0000225±0.0000144
	HRI	0.152±0.0393	0.13±0.0629	0.0846±0.0525	0.732±0.159	0.241±0.0802	0.139±0.114	0.225±0.144
Health Index (HI)		0.535±0.11	0.747±0.196	0.578±0.145	2.92±0.696	0.751±0.169	1.3±0.27	1.69±0.622



*Cauliflower, Brinjal & Fenugreek not grown at Dashera

Figure 2: Metal pollution Index in different vegetables collected from different sampling locations of Yamuna floodplains

IV. Conclusion

The soils of the studied area were moderately contaminated with low ecological risk at all the locations at the floodplains of the river. High correlation between the metal levels in soils of different locations suggested the possibility of similar anthropogenic source i.e. industrial, municipal wastewaters which enter in the river through drains and thereby reaching the agricultural floodplains by irrigation or flood.

Levels of metals present in vegetables were found within the FSSAI limits except for Pb which was more than the standard limit in all the vegetables taken up in study. There was slight accumulation of lead (BAF>1) in Spinach Coriander, Fenugreek, Brinjal and Radish and the metal pollution index was higher in leafy vegetables as compared to others due to higher biomass production.

HRI for all metals of vegetables from the study area was less than unity and the vegetables were safe for human consumptions except for HRI of Pb in Spinach and Brinjal that was slightly more than one which needs to be monitored regularly.

Monitoring and testing of heavy metals in vegetables as well as soils along with Yamuna river water should be carried out by concerned regulatory authorities on regular basis so as to ascertain the levels of metals within the safe limits of human consumption.

Acknowledgement

Authors are thankful to the support extended by the staff of CSIR-NEERI, Delhi Zonal Centre in collection of the soil and plant samples from the floodplains of river Yamuna.

V. References

A report on Toxicity Load of Yamuna River in Delhi Toxics Link, 2014

Alam, S., Rai, S., & Bajpai, S. P. (2017). Status of Heavy Metals and Pesticidels in Yamuna river: A review. *IJSDR* | Volume 2, Issue 5;215-219

D. Aithani, D. S. Jyethi, A. K. Yadav, Z. Siddiqui and P. S. Khillare, Risk assessment of trace elements in vegetables grown in river Yamuna Floodplain in Delhi, *Environ.Geochem.Health*, 2024, 46, 180.

Daulta, R., Prakash, M., & Goyal, S. (2023). Metal content in soils of Northern India and crop response: a review. *International Journal of Environmental Science and Technology,* 20(4), 4521-4548.

European Commission, Commission Regulation (EC) No. 466/2001(2002) Setting Maximum Levels for Certain Contaminants in Foodstuffs, USEPA, Risk Assessment Guidance for Superfund, Human Health Evaluation Manual (Part A). Interim Final, vol. I.Washington (DC), United States Environmental Protection Agency, EPA/540/1–89/002, 1989.

Food and Nutrition Board.. Dietary Reference Intakes [DRIs]: Recommended Intakes for Individuals. National Academy of Sciences, Washington, DC, USA, 2004.

Food Safety and Standards (Contaminants, Toxins and Residues) Regulation, 2011

Garg, V. K., Yadav, P., Mor, S., Singh, B., & Pulhani, V. (2014). Heavy metals bioconcentration from soil to vegetables and assessment of health risk caused by their ingestion. *Biological trace element research*, 157(3), 256-265.

P. Ghosh, A. Chatterjee, M. Sharaff and H. Pal, Unveiling the threat of lead, cadmium, and nickel toxicity in salient commercially grown vegetables in Kolkata, India, *Environ.Monit. Assess*., 2024, 197, 41.

N. Gupta, K. K. Yadav, V. Kumar, S. Krishnan, S. Kumar,Z. D. Nejad, M. A. Majeed Khan and J. Alam, Evaluating heavy metals contamination in soil and vegetables in the region of North India: Levels, transfer and potential human health risk analysis, *Environ. Toxicol. pharmacol.*2021, 82, 103563.

Hakanson L (1980) Ecological risk index for aquatic pollution control. A sedimentological approach. *Water Res* 14: 975-1001.

Hussain, A., Alamzeb, S., & Begum, S. (2013). Accumulation of heavy metals in edible parts of vegetables irrigated with waste water and their daily intake to adults and children, District Mardan, Pakistan. *Food chemistry*, 136(3-4), 1515-1523.

Iyengar V, Nair P (2000) Global outlook on nutrition and the environment;

meeting the challenges of the next millennium. *Sci Total Environ* 249:331–346

M. Jain, B. M. Sharma, S. Sachdeva, J. Kuta, R. ˇCervenka, L. Nizzetto, P. Kukreti, G. K. Bharat and P. Chakraborty,Occurrence, Source and Dietary Exposure of

Toxic and Essential Elements in the Indian Food Basket, Arch.*Environ. Contam. Toxicol*., 2023, 85, 466–484.

Kumar, A., Denre, M., & Prasad, R. (2017). Concentration of trace metals and potential health risk assessment via consumption of food crops in the South Chotanagpur of Jharkhand, India.*The pharma Innovation Journal*. 6(9):159-167.

S. Kumar, S. Prasad, M. Shrivastava, A. Bhatia, S. Islam, K. K. Yadav, S. K. Kharia, A. Dass, N. Gupta, S. Yadav and M. M. S. Cabral-Pinto, Appraisal of probabilistic levels of toxic metals and health risk in cultivated and marketed vegetables in urban and peri-urban areas of Delhi, India, *Environ. Toxicol. Pharmacol*., 2022, 92, 103863.

V. Kumar, R. K. Thakur and P. Kumar, Predicting heavy metals uptake by spinach (Spinacia oleracea) grown in integrated industrial wastewater irrigated soils of Haridwar, India, Environ. Monit. Assess. 2020, 192, 709.

Moefcc, 2015. Guidance document for assessment and remediation of contaminated sites in India Volume II – Standards and checklists 1st Edition.

Patel, N., Pal, S., Malik, A., & Singh, D. K. (2019). Impact assessment of contaminated River Yamuna water irrigation on soil and crop grown in peri-urban area of Delhi-NCR. *Environment Conservation Journal*, 20(3), 99-112.

Patel, P. P., Mondal, S., & Ghosh, K. G. (2020). Some respite for India's dirtiest river? Examining the Yamuna's water quality at Delhi during the COVID-19 lockdown period. *Science of the Total Environment*, 744,140851.

Pobi, K. K., Satpati, S., Dutta, S., Nayek, S., Saha, R. N., & Gupta, S. (2019). Sources evaluation and ecological risk assessment of heavy metals accumulated within a natural stream of Durgapur industrial zone, India, by using multivariate analysis and pollution indices. *Applied water science*, 9(3), 1-16.

Ramteke, S., Sahu, B. L., Dahariya, N. S., Patel, K. S., Blazhev, B., & Matini, L. (2016). Heavy metal contamination of vegetables. *Journal of Environmental Protection*, 7(7), 996-1004.

Santos-Francés, F., Martínez-Graña, A., Alonso Rojo, P., & García Sánchez, A. (2017). Geochemical background and baseline values determination and spatial distribution of heavy metal pollution in soils of the Andes mountain range (Cajamarca-Huancavelica, Peru). International journal of environmental research and public health, 14(8), 859.

Sehgal, M., Garg, A., Suresh, R., & Dagar, P. (2012). Heavy metal contamination in the Delhi segment of Yamuna basin. *Environmental monitoring and assessment*, 184(2), 1181-1196.

Sehgal Meena, Suresh R, Sharma Ved Prakash, Gautam Sumit Kumar. (2014). Study on heavy metal contamination of agricultural soils and vegetables grown in the Delhi segment of Yamuna river basin. *Global Health Perspectives*, Vol 2: xx–xxp.http:dx.doi.org/10.5645/ghp2014.01.001

Singh, S., & Kumar, M. (2006). Heavy metal load of soil, water and vegetables in peri-urban Delhi. Environmental Monitoring and Assessment, 120(1), 79-91.

Sumit Pal, Neelam Patel, Anushree Malik and D. K. Singh. (2018) Assessment of water and soil quality of River Yamuna irrigated agricultural land and the ultimate effect on the agriculture and Human health. Merit Research *Journal of Agricultural Science and Soil Sciences*. Vol. 6(10) pp. 145-156.

Usero J, Gonz - Lez-Regalado E, Gracia I (1996) Trace metals in the bivalve mollusc Chamelea gallina from the Atlantic coast of Southern Spain. *Mar Pollut Bull* 32:305–310

United States Environmental Protection Agency (USEPA) (2010) Region 9, Preliminary Remediation Goals. USEPA, Washington DC

USEPA (United States Environmental Protection Agency). USEPA Regional Screening Level (RSL) Summary Table: November 2011. Available at: http://www.epa.gov/regshwmd/risk/human/Index.htm.

USEPA (United States Environmental Protection Agency). EPA Region III Risk-Based Concentration (RBC) Table 2008 Region III, 1650 Arch Street, Philadelphia, Pennsylvania, 2012, 19103.

US EPA (United States Environmental Protection Agency). Reference dose (RfD): Description and use in health risk assessments, Background Document 1A, Integrated risk information system (IRIS); United States Environmental Protection Agency: Washington, DC, 15 March 2013, http://www epa.gov/iris/rfd.htm.

WHO (World Health Organization). Evaluation of Certain Food Additives and Contaminants. In: Forty-First Report of the Joint FAO/WHO Expert Committee on Food Additives, WHO, Geneva, Switzerland, 1993. (WHO Technical Series, 837).