Assessment of contaminant levels in locally cultivated vegetables using Agra Canal water and its associated health risks

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ABSTRACT
The global imperative to address food safety concerns has intensified, particularly concerning the potential contamination of crops through irrigation from Canal water.Soil samples were analyzed from Faridabad's agriculture site (S3). Tomato, Radish, and Spinach plants were selected for the experiment. Three water ratios were used: the first set of each plant was rinsed with 100%groundwater(GW), the second set of water was irrigated by mixing50% groundwater and 50% canal water(50% GW + 50% CW) and the thirdset was rinsed with 100% canalwater (CW)to determine the effect of water on Plant growth and yielding.Edible parts of harvested vegetables were evaluated for heavy metals.The best growth and yield in spinach and tomato were found in mixed water, while in radish, the best growth was in groundwaterThe highest metal accumulation factor(MAF)was obtained in 100% CW, then in 50% GW + 50% CW irrigated, followed by canal-side and none in 100% GW samples. On the canal side, 41.7% of samples, from 50% GW + 50% CW irrigated vegetables,50% of samples, and 100% CW samples, 83.3% had MAF >1. Health Risk Assessment(HRI) for Pbwas obtained more than 1in 50% GW+50% CWand in 100% CW-raisedveggies and for As incanal-side radishes. The health risk (HI) value was highest in canal water. However, mixed water irrigated veggies were good in yielding and production, but they are unsafe for human health based on MAF, HRI, and HI. This underscores the need for stringent monitoring and regulation to ensure the safety of vegetables for human consumption. The urgency and importance of this issue cannot be overstated. This research will be helpful for farm managers and policymakers.

Introduction

Human life is dependent on water for domestic and industrial purposes. It is one of the most precious assets on thisplanet(Bijekar et al., 2022).The Yamuna River in Okhla, Delhi's national capital territory, is the source of the Agra Canal. It has been chiefly utilized for irrigation since ancient times, primarily for crops cultivated in the rabi season. However, the Agra Canal's water quality is declining due to fast-risingurbanization, industrialization, and changing lifestyles.The increasing metal accumulation in soil and crops due to Agra Canal water poses a significant threat to living organisms, and this concern arises from the water's vulnerability to heavy metal contamination and the associated health risks (Bharti et al., 2019). It is well known that irrigation with polluted waterdramatically increases the number of Heavy metals in the soil because of their propensity to accumulate in various body parts, lengthy biological half-lives, and inability to biodegrade;theseHeavy metals are hazardous(Arora et al., 2008).Consuming untreatedwater-irrigated raw vegetables and fruits poses a severe risk to public health, requiring preventive solid measures. While using wastewater for irrigation enhances biomass production and yields by providing essential organic and inorganic constituents crucial for crop growth, it also leads to HM accumulation in crops (Naz et al., 2016).Physicochemical factors affect the accumulation of metal in plants. According to (Speir et al., 2003), soil pH is the main factor influencing the solubility and mobility of zinc (Zn), lead (Pb), and chromium (Cr) in sand-filled ground because HM properties and soil pH are closely related.Absorption and accumulation of metals in plants dependon many factors, such as pH, Electrical Conductivity (EC), clay content, organic matter content, and soil characteristics(Abou-Shleel & Abdel-Kareem, 2015).World Health Organization/Food and Agriculture Organization (WHO/FAO)lists four of the ten chemicals that are most harmful to humansasHeavy metals, specifically cadmium (Cd), Arsenic (As),Cobalt (Co),and mercury (Hg)(Massaquoi et al., 2015).Most human HM intake comes from fruits and vegetables, up to 90%. The remaining 10% is absorbed through skin contact and dust inhalation(Mawari et al., 2022).

Soil is a precious and complex natural resource representing a considerable reservoir of biodiversity,with several billion prokaryotic and eukaryotic microorganisms(Kazerooni et al., 2017).However,several things (weeds, pathogens, drought, salinity, Heavy metals, floods, temperature, etc.) affect the soil environment and prevent plants from growing(Safdar et al., 2022).Consuming vegetables containing Heavy metals may lead toaccumulation, posing long-term health risks to consumers (Jose Vazhacharickal et al., 2014). In many parts of the developing world, the irrigation of crops with untreated wastewater is widely practiced, resulting in adverse public health outcomes (Epa et al., 2004). The agricultural sector's reliance on irrigation water underscores its pivotal role in determining the suitability and success of crop cultivation. Factors such as water quality, soil type, salt tolerance of plants, climate, and drainage collectively influence the appropriateness of irrigation water in agriculture (Nagaraju et al., 2016). However, the potential risks associated with irrigation water quality, particularly in market gardens, pose a significant concern for public health.

Consuming vegetables contaminated with Heavy metals has been identified as a substantial health risk, with long-term exposure carrying potential dangers for consumers (Jose Vazhacharickal et al., 2014).According to WHO/FAO estimates, environmental factors, such as exposure to toxic chemicals, account for over 25% of the disease burden(Mamtani et al., 2011).Some research concluded that in trace concentrations, heavy metals like Copper (Cu),Zink(Zn), and Nickel(Ni) are helpful as micronutrients for human growth(Pandey, 2016). Still, some hazardous, non-essential Heavy metals, even at trace levels, including Pb, Cd, and As, are harmful to human health, especially in pregnant women and small children who are more vulnerable to their toxicity(Mawari et al., 2022). The study focuses on Tomato (*Solanum lycopersicum*), Radish (*Raphanus sativus*), and Spinach (*Spinacia oleracea*) plants, aiming to unravel the intricate connections between water quality, plant health, and their subsequent influence on nutritional value and Heavy metals content in the edible parts of the crops.(Patel et al., 2019)The experiments investigated the effects of different water ratios on plant growth, flower count, and yield. Three separate water sources were utilized: 100% Ground Water (GW), a blend of 50%groundwater +50% canal Water (GW+CW), and 100% canal water (CW). These analyses provided critical information regarding the potential contamination of the soil and plants, especially considering the implications for human health upon consumption of contaminated vegetables(Mahmood et al., 2020).Heavy metals accumulation in edible parts, compared to WHO/FAOguidelines, calculatesseveral ecological risk characteristics and takes into account, including the Metalaccumulation factor (MAF), Human Risk Index (HRI), Metal Pollution index (MPI), Daily Metal Intake (DMI), Hazardous Index (HI) are also calculated for the health risk assessment,(Verma et al., 2022), they can build up in vital organs and result in a variety of health issues(Jose Vazhacharickal et al., 2014). Research significantly contributes to understanding the complex relationships between crop contamination, irrigation water quality, and the implications for public health.

Materials and Methodology

Sampling Site

The study was conducted in the Agra Canal irrigated area in Faridabad, Haryana, India. There are two subdivisions within the district of Faridabad: Faridabad and Ballabhgarh.The length of the Agra Canal is 140 miles (230 km)-lock length is 120 feet,lock width 20 feet (6.1m),maximum height above sea level 659 feet (201m).The Agra Canal runs from Delhi to Agra.The climate of the Faridabad district is hot, semiarid, and tropical steppe, with the air being aridexcept for the monsoon season.Different crops are grown in the Faridabad district, such as gram,pulses, jowar, bajra, rice, and wheat.(Choudhary et al., 2022).It is well defined in three seasons. April through the end of June is when the sweltering summer months begin. July through September is when the rainy season occurs. Winter lasts from November through February.For the experimental setup, water and soil samples were taken fromthe agricultural site of Faridabad (28°14'49.7"N 77°21'09.5"E).(Fig. 1). Thesoil predominantly has sandy loam and clayey compositions.

Water and Soil sampling

Ground and canal water was collected from S3. Groundwaterwas collected from a hand pump near the canal. After 15 min. running of the hand pump water was collected in a plastic one-literbottle.For canal water sampling, the compositesamples were collected from the left, right, and mid-stream in high-grade plasticbottles. Inductively coupled plasma-optical emission spectrometer SOP-ICPMS analyzed heavy metals- Agilent Technology (7700X)). For other parameters pH, EC, and temperaturewere analysed on the spot (Sharma et al., 2021). pH was analyzed by a Digital pH meter (H196107), and EC was measured by EC meter-3 (Alobaidy et al., 2010). TDS was measured by 5 TDS-3 meters, the temperature was analyzed from a mercury thermometer (Dyna research German glass 50130718,0-50 C).

For soil Sampling, points were selected at distances of 50 m and 100 m away from the canal on both (left and right) sides. Samples were collected 20 inches deep from each sub-site, removing the pebbles and debris by hand, collecting soil in clean,labeled polythene bags with a zip lock (Kazerooni et al., 2017), marking the location and date, noting coordinates, and recording climatic conditions (Patel et al., 2019; Rahil et al., 2013). The Electric Conductivity(EC), carbonate, bicarbonate, Nitrogen(N),Phosphorus (P), Potassium(K), Calcium(Ca), Magnesium(Mg), and trace metals were analyzed (Pb, Cd, As, Cr, Fe, Co, Ni, and Cu), with test methods presented in Table 1. The samples were then taken to the lab for further analysis. Upon reaching the laboratory, the soil was air-dried, ground, sieved with a 2 mm sieve, and stored at room temperature (Mahmood et al., 2020). Soil samples weighing 1 g each underwent digestion with a 15 ml mixture of HNO3, H2SO4, and HClO4 in a 5:1:1 ratio at 80°C until a transparent solution was obtained, USEPA 3050 B digestion method used for heavy metals digestion (M. S. Islam et al., 2014; Kama et al., 2023).The Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Agilent 7500) was utilized to ascertain the concentrations of heavy metals in soil.

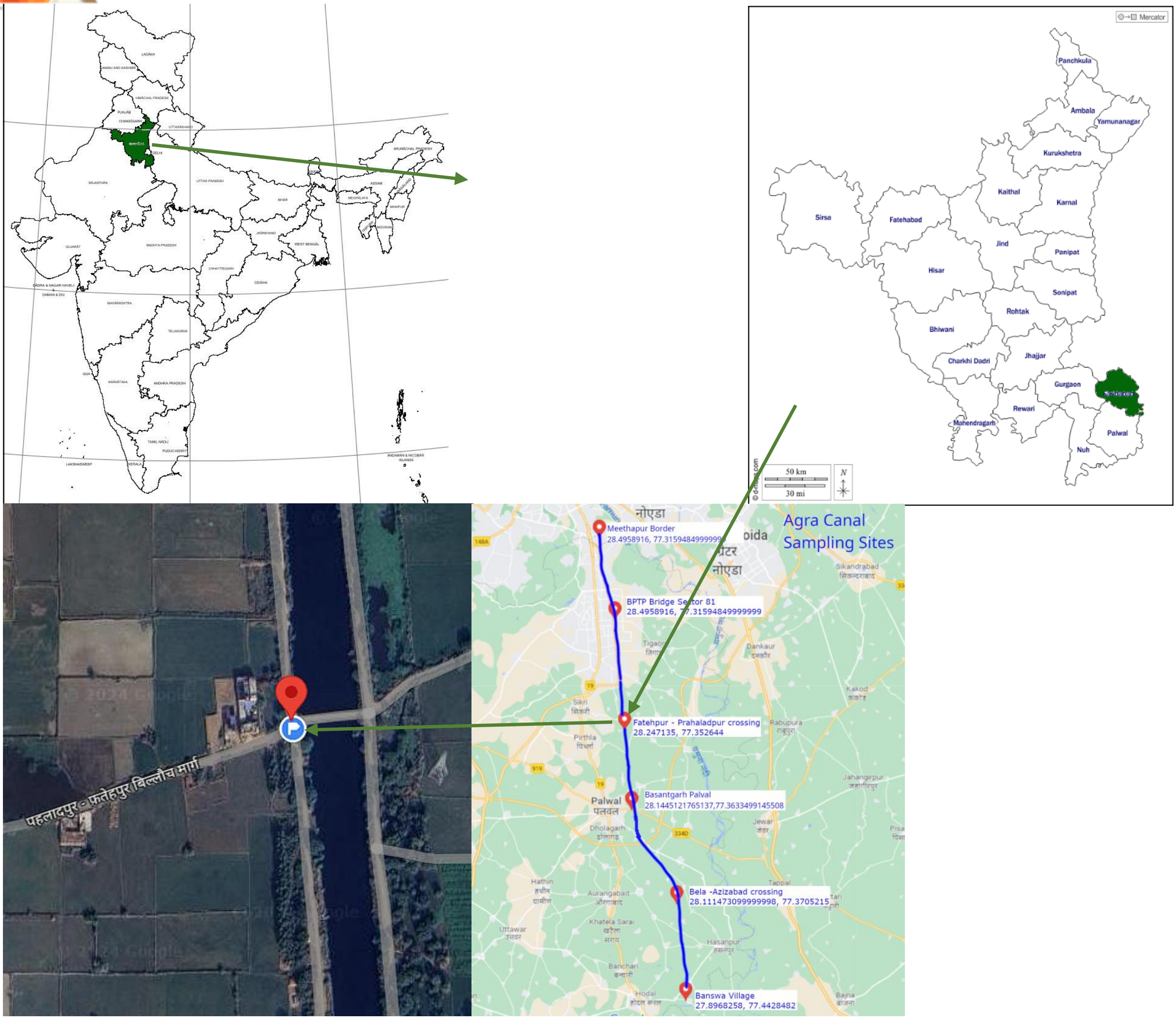
Experimental Design

For the experiment, three veggies were selected: spinach (leafy), tomato (fruit), and radish (root) (Hassan et al., 2024). The soil was taken from the same farm from which soil samples were taken, prepared, and organized in triplicate around the second week of September 2022. Ground Water and canal water for irrigation were also used from the same site (S3). 5 kg of soil was measured using a digital balance sterilized in an oven and placed in 12-inch pots. Irrigation was administered to each pot, as per requirement (Petrou et al., 2020). The first set of pots was irrigated with 100% GW, the second set with 50% GW + 50% CW, and the third set with 100% CW. Irrigate the plants at regular intervals(Kumari et al., 2024). Plant measurements were taken to assess total yield (Rahil et al., 2013) and assessed the number of germinating seeds, vegetative growth, flowers, fruit, and yielding. The pots were kept on the Floor terrace of RPS Palms, sector 88 Greater Faridabad, Haryana, India.

Vegetable Harvesting and Analysis

The events observed from germination to harvesting noted down the number of germinating seeds, growth of saplings, vegetative growth, and health of seedlings from time to time.All vegetables were harvested at optimal maturity, around 45 days for spinach and 60 days for radishes. The experiment was extended for 100 days for tomatoes, and other researchers observed a similar period Hassan et al., 2024). Vegetables were watered as per requirement. After maturation, cut the spinach with the help of a hand, two times harvest the spinach, uproot the radish, analyze the yielding of the radish, and pluck the Tomato fruit with the help of a hand to evaluate the total yielding. Samples were then identified, packed into sterile polythene bags, and sent to the sample in the lab, where samples were washed with tap water followed by double-distilled water. The samples were oven-dried at 60°C until a constant weight was obtained and ground for further analysis (Patel et al., 2019),(Mahmood et al., 2020).To homogenize the dried samples, they were crushed and powdered. Then, 15 ml of a tri-acid mixture (HNO3, H2SO4, and HClO4) was added in a 5:1:1 ratio (totaling 15 ml) at 80°C until a transparent solution was obtained(Gaurav et al., 2018). After cooling, the digested sampleswere filtered through the Whatman No. 42 filter paper. The Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Agilent 7500) was utilized to ascertain the concentrations of heavy metals in vegetables (Alkhatib et al., 2022)(M. S. Islam et al., 2014).

Figure 1 Sampling site of Faridabad District in Haryana, India



(Kumari et al., 2024)

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Estimation of potential health risk parameters

Metal Accumulation factor(MAF)

MAF is the ratio of metal concentration in plants to metal concentrations in soils(Massaquoi et al., 2015).MAF > 1 indicates that vegetables are enriched with heavy metals from the soil. MAF < 1 means the vegetables do not take much heavy metal from the soil(Gupta et al., 2022).
MAF = Cveg/ Csoil(Gaurav et al., 2018; Verma et al., 2022)
Cveg = Heavy metal in vegetable tissue, fresh weight
Csoil = Heavy metals in soil, mg/kg dry weight.(Hassan et al., 2024; Sabir et al., 2022a).

Metal Pollution Index (MPI).

The heavy metal concentrations (Pb, Cd, As, Cr,Co, Ni, and Cu) arecontained in vegetables and fruit. The MPI estimated samples. Thisindex was calculated using the equation:
MPI (mg/kg) = (Cf1x Cf2x…………Cfn)1/n.(Mawari et al., 2022).
Where Cfn = concentration of metal in the nth sample.
MPI values indicatethe lowest accumulation of heavy metals and lesser health risks(Garg et al., 2014)

Daily intake of metal (DIM)

The metals in vegetables consumed by individuals determine the estimation of daily intake of metals.
DIM = (Cm x Cf x IRveg) / Bw(Arora et al., 2008; Massaquoi et al., 2015).
Cm represents the concentration of heavy metals in contaminated vegetables measured in milligrams per kilogram (mg/kg).
Cf denotes the conversion factor (0.085) utilized to convert the fresh weight of vegetables to their dry weight.
IRveg stands for the ingestion rate of vegetables, with a value of 0.232 kg/day for children and 0.345 kg/day for adults(Hu et al., 2023). Finally, Bw represents the average body weight, 73 kg for adults(Verma et al., 2022).The daily intake of green vegetables was considered 200 g/person/day, which is the recommended amount from a nutritional point of view (Rattan et al., 2005).

The Health Risk Index (HRI)/HQ

It is also known as Hazard Quotient (HQ).It indicates potential hazards to human health.The index wascalculated using the equation.HRI = DIM / RfD.(Massaquoi et al., 2015; Mawari et al., 2022),.
The oral reference dose (RfD) of Astakenwas 0.001(Verma et al., 2022),and for Cu andNi,it was0.040and 0.02 mg per kg per day, respectively(M. S. Islam et al., 2023),(US EPA, 1991). For Cr, the RFD value was0.003 (US EPA, 1998)or Cd, 0.001 (US EPA, 1989), and for Pb, the RFD value was 0.0003 (US EPA, 2004). The RfD indicates the highest hazard level for each metal that can be considered safe for everyday exposure(Sabir et al., 2022b).

Hazard Index (HI)

The hazard index (HI) was created to assess the possible risk multiple heavy metals pose to human health(US EPA, 1987).The HI was calculated using the equation:
HI =∑HQ= HQCr+HQCd+ HQAs+ HQPb+HQ Cu +HQ Ni.(Mawari et al., 2022).
The adverse effect is expected to rise directly to the overall level of metal exposure. It is also assumed that similar operating mechanisms act linearly on the target organ.
There is a higher likelihood of non-carcinogenic health effects when HI < 1, and this likelihood rises as HI values rise. The current study has computed the HI for the elements (As, Cd, Ni, Cu,Cr, and Pb).

Results and Discussion

Growth Patterns

The best growth and yield of spinach and tomatoes were obtained in 50% GW + 50% CW water, and the best growth of radish was obtained in 100% GWirrigated pots(Kumari et al., 2024).Researchers used sewage water to obtain higher yields since sewage water contains many organic nutrients.Sewage enhances the production of vegetables(Hussain et al., 2019), excluding root crops, because of the abundance of organic matter. Although 100% CW has more nutrients, according to FAO, excessive nutrients reduce the yield and quality of crops (Ayers et al., 1985).CombiningGW and CW in a 1:1 ratio might provide an optimal water balance for the spinach and tomato which was the reason for good yielding.(Bakhsh & Hassan, 2005)obtained that root crops, such as radish, carrot, and turnip, are sensitive to water pollutants and poor groundwater quality, which affects the growth of vegetables, badly accumulates Cyanotoxins in root vegetables, and decreases yield, which may be the reason for poor yielding of radish in canal water.Many waterborne fungi can infect Radish roots, causing diseases such as root rot. Root rot pathogens thrive in wet or waterlogged conditions. They attack the Radish roots, leading to rotting, reduced nutrient uptake, and impaired water absorption. It can cause stunted growth, wilting, and poor overall plant health.

Soil Analysis

The soil Mean, Standard Deviation (SD), Median, Kurtosis, Skewness, units, and test methods are presented in Table 1.The pH value in the soil was 7.4± 0.32, similar to values reported by (Choudhary et al., 2022). The N content valuewasobtained at 135.00 ± 11.85 kg/ha by the method SOP/S-07. TheN values fall below the permissible range of 280 to 560 kg/ha outlined by the Ministry of Agriculture Manual 2011(Ministry of Agriculture, 2011).P value is determined through the SOP/S-03 test method, resulting in a value of 20.68 ± 1.79 kg/ha, which falls within the acceptable range of 10 to 24.6 kg/ha. The K value measured using the SOP/S-02 test method is 75.58 ± 4.31 kg/ha,below the permissible range of 108 to 280 kg/ha.Bicarbonate concentration is reported at 119.25 ± 6.70 mg/kg. Carbonatewasabsent in the soil. The Ca content is measured at 942.75 ± 81.11 mg/kg. Mg is reported as 282+10.71mg/kg. (Table 1).EC range was 131.85 ± 15.58µS/cm.The mean concentrationof Fe is reported as 39.41 ± 3.31, Cu (0.71 ± 0.12), Pb (0.92±0.05), Cr (0.64 ± 0.04), Cd (0.46 ± 0.10), Co (0.23 ± 0.02), Ni (0.45 ± 0.21), As (0.53 ± 0.20) (Table 1). All the metals were within the permissible limits as perthe Ministry of Agriculture Manual 2011(Ministry of Agriculture, 2011) and (DT et al., 2015). Other researchers (Emurotu & Onianwa, 2017), the heavy metals range obtained from Nigeria is Cd 0.07–9.80, Co 0.05–38.1, Cu 0.33–16.9, Ni 3.81–93.1, and Pb 4.45–47.7.The agricultural soil of the study areafollowed the trend: Fe>Pb>Cu>Cr>As>Cd>Ni>Co and(Kumar et al., 2019)found the trendFe> Mn> Ni> Cr> Zn> Cu> Pb> As> Co> Cd from north India soil.

Table 1 GeneralParameters andHeavy Metalin Soil

Parameters field	Units	Test Methods	Mean ± SD	Median	Kurtosis	Skewness	Permissible limits
soil pH	NA	IS: 2720 (P-26)	7.41 ± 0.32	7.47	1.70	-0.97	6.0-8.5[a]
Nitrogen	kg/ha	SOP/S-07	135 ± 11.85	135.90	0.24	-0.41	280 - 560 [a]
Phosphorus	kg/ha	SOP/S-03	20.68 ± 1.79	21.05	1.60	-1.12	10 - 24.6 [a]
Potassium	kg/ha	SOP/S-02	75.58 ± 4.31	75.70	1.25	-0.17	108 - 280
Bicarbonate	mg/kg	SOP/S-17	119.25 ± 6.7	120.50	2.04	-1.06	NA
Calcium	mg/kg	SOP/S-08	942.75 ± 81.11	966.50	2.68	-1.52	NA
Magnesium	mg/kg	Agriculture Manual 2011	282 ± 10.71	281.00	1.50	0.55	NA
Electrical Conductivity	µs/cm	IS: 2720 (P-21)	131.85 ± 15.58	134.95	0.58	-0.98	NA
Iron	mg/kg	USEPA 3050 B	39.41 ± 3.31	39.29	-5.55	0.05	5000
Copper	mg/kg	USEPA 3050 B	0.71 ± 0.12	0.70	1.07	0.37	36 [b]
Lead	mg/kg	USEPA 3050 B	0.92 ± 0.05	0.92	-2.36	-0.21	85 [b]
Chromium	mg/kg	USEPA 3050 B	0.64 ± 0.04	0.63	-1.29	0.85	100 [b]
Cadmium	mg/kg	USEPA 3050 B	0.46 ± 0.1	0.44	0.79	1.14	1

Cobalt	mg/kg	USEPA 3050 B	0.23 ± 0.02	0.23	-4.92	-0.05	NA
Nickel	mg/kg	USEPA 3050 B	0.45 ± 0.21	0.48	1.89	-0.84	35[b]
Arsenic	mg/kg	USEPA 3050 B	0.53 ± 0.2	0.58	-1.12	-0.89	NA

[a](Ministry of Agriculture, 2011),
[b](DT et al., 2015),The permissible limits of Heavy Metals in Soil - Cu (36), Cr (100), Pb (85), and Ni (35).

Heavy Metal Concentrations in water samples

Variations in the concentration of different metals in groundwater and canal water, in comparison to the standard limits set by the World Health Organization (WHO, 2011) and the United States Environmental Protection Agency (USEPA) for surface water.Groundwater iron levels are well below the WHO and USEPA limits for all the metals, indicating no concern. However, canal water contains iron at a level (2.3440 mg/L) significantly exceeding the WHO and USEPA guidelines (0.3 mg/L), which may pose potential health risks. Canal water Ni concentration (0.0213 mg/L) slightly exceeds the WHO guideline of 0.02 mg/L, which might be a concern for long-term exposure. Pb in canal water (0.0507 mg/L) significantly exceeds the WHO (0.01) and USEPA limits (0.015). This is a critical concern, as lead exposure can lead to severe health issues, particularly in children. Cd, As, Cr, and CO, values were within the permissible limits in canal water (Table 2).

Table 2 Heavy metal concentration in the groundwater and canal waterand comparison with surface waterpermissible limits by WHO and USEPA

Parameter	Ground Water	Canal Water	WHO (2011)	USEPA
Iron (as Fe)	0.03	2.3440	0.3 [b]	0.3 [b]
Copper (as Cu)	<0.005	0.0301	2 [b]	1.3 [b]
Nickel (as Ni)	<0.005	0.0213	0.02 [b]	NA
Lead (as Pb)	<0.005	0.0507	0.01[a]	0.015 [b]
Chromium (as Cr)	<0.005	0.046	0.05 [a]	0.1 [b]
Cadmium (as Cd)	<0.005	0.001	0.003 [a]	0.005 [b]
Arsenic (as As)	<0.005	0.005	0.01 [a]	0.01 [b]
Cobalt (Co)	<0.005	0.005	NA	NA

[a](Badamasi et al., 2023), [b](Zhou et al., 2020). Unit mg/kg

Heavy Metal Concentrationsin vegetables

Chromium (Cr)

Cr inSpinach irrigated with 100% GWwas measured at 0.1218 ± 0.09, while Spinach with 50% GW + 50% CW exhibited a higher Crrange of 0.594± 0.93. Spinach irrigated with 100% CW showed an even higher Cr content of 1.463± 0.88, while cultivated on the canal sidewas unreachable.For radish, those irrigated with 100% GW exhibited aCr content of 0.153± 0.2, and 50% GW + 50% CW had a higher Cr range of 1.07 ± 0.72. Radish irrigated with 100% CW showed a further increase in Crcontent, measuring 1.52± 0.45, while radish grown in canal-side fields exhibited the highest Cr concentration of 1.477±1.18.

In the case of tomatoes, those cultivated with 100% GW had aCr content of 0.2±0.57, and the 50% GW + 50% CW Tomato showed a slightly higher Cr of 0.9 ± 0.3. Tomato irrigated with 100% CW exhibited a further increase in Cr content, measuring 1.12 ± 0.92, whiletomatoes grown onthe canal side had no detectable Cr.Radishaccumulates the highest Cr concentration,followed by spinach and then tomato. Except forthe canal side spinach and tomato,in others, the Cr contentwas more thanthe WHO standard (0.10), but these valueswere less than the Indian standard (IS), which is 20.0.Many researchers concluded that leafy vegetables have more heavy metal deposition. (Naz et al., 2016).Other researchers found the Cr levels in bay leaf (31.99 ± 3.97), coriander leaf (27.58 ± 1.50), and cardamom(25.19 ± 2.26) from Bangladesh(M. S. Islam et al., 2023).Similar values of Cr in beetrootwere 1.3-12.7, in carrot 1.1-14.1, in Radish 0.1-0.9, and turnip1.1-11 in sewage-irrigated veggies(Khalid Iqbala et al., 2009).Under 100% CW irrigation, the Cr concentration reaches its highest levels for all three crops, indicating a potential influence of irrigation water source on Cr uptake.

Iron (Fe)

The Fe content in spinach irrigated with 100% GWwas measured at 34.25 ± 11.38. In comparison,spinach with a 50% GW + 50% CW exhibited a slightly higher Fe concentration of 38.93 ± 13.03. Spinach irrigated with 100% CW showed a further increase in Fe content, measuring 42.152 ± 11.14. In contrast,spinach cultivated on thecanal side had a relatively lower Fe concentration of 19.464± 2.78.For Radish, those irrigated with 100% GW exhibited a Fe content of 38.39 ± 7.46, and the 50% CW + 50% GW displayed a slightly higher Fe concentration of 40.53 ± 13.18. Radish irrigated with 100% CW showed a further increase in Fe content, measuring 54.4 ± 0.86, while radish grown in canal-side fields had aFe concentration of 37.56 ± 9.22.

In the case of tomatoes, those cultivated with 100% GW hadaFe content of 38.42 ± 14.38, and the 50% GW + 50% CW irrigated Tomato showed a slightly higher Fe concentration of 40.56 ± 7.92. Tomato irrigated with 100% CW exhibited a further increase in Fe content, measuring 52.10 ± 20.46, while Tomatoes grown onthe canal side had the highest Fe concentration of 54.43 ± 14.18. Leafy vegetables are rich inFe; however, the limit given by WHO/FAO is 425 (Alkhatib et al., 2022).

It is important to note that vegetables are considered safe sources of Fe, and the values presented in the data fall within the typical range forFe concentrations in vegetables. It isan essential nutrient for human health, and consuming vegetables with such Fe concentrations is generally considered beneficial for meeting dietary requirements.Black pepper hadthe most significant Fecontent, at 9.29 ± 1.72, followed by green chili and branded chili powder, with concentrations of 35.46 ±3.94 and 34.02 ± 3.18, respectively ((M. S. Islam et al., 2023)and similar values of Fewere also obtained from Saudi Arabia (31.96–543.2)(Ali & Al-Qahtani, 2012).Other studies showed that the maximum accumulation of Fe was found in Rohinullahvegetable samples, the order being 105-210 in beetroot> 71-110 in turnip > 55-97 in radish> 25-40 in carrot(Khalid Iqbala et al., 2009).

Cobalt(Co)

The Co content in spinach,radish, and tomatoirrigated with 100% GW wasabsent (0.00). In contrast, spinach with a 50% CW + 50% GW exhibited a low Co concentration of 0.01± 0. Spinach irrigated with 100% CW showed a higher Co content, measuring 0.1± 0.04, while spinach cultivated on thecanal side had a Co concentration of 0.04± 0.It was also perceived that leafy vegetables are more inclined towardmetal accumulation than tuber(Mahmood et al., 2020). Radish which was irrigated with GW Cowas found nil, and those irrigated with50%GW + 50%CWexhibited a higher Co concentration of 0.09± 0.04. Radishirrigated with CW showed a further increase in Co content, measuring 0.14± 0.05, while radish grown in canal-side fields had a Co concentration of 0.06± 0. (Table 2). In the case of Tomatoes, all water ratiosshowed no detectable Co (0.00). However, tomatoes grown oncanal sides exhibited a minimal Co concentration of 0.01± 0.The Coconcentration obtained by other researchers was 0.002 in Spinach from Iran(Rahmdel et al., 2018).Cois an essential micronutrient in trace amounts and is generally considered safe in the concentrations observed in these vegetables.(Hassan et al., 2024).

Nickel(Ni)

Ni content in spinach irrigated with 100% GW was measured at 0.09 ± 0.02, while Spinach 50% GW + 50% CWexhibited a higher Ni concentration of 0.69± 0.28. Spinach irrigated with 100% CWshowed a further increase in Ni content, measuring 1.031± 0.21, while spinach cultivated on the canalsidehad a Ni concentration of 0.61± 0.05.For Radish, those irrigated with 100% GW displayed a Ni content of 0.10 ± 0.05, and 50% GW + 50% CWexhibited a higher Ni concentration of 0.72± 0.16. Radish irrigated with 100% CW showed a further increase in Ni content, measuring 0.84 ± 0.33, while Radish grown in canal-side fields had a Ni concentration of 0.751 ± 0.1.In the case of Tomato, those cultivated with 100% GW had a Nicontent of 0.09± 0.14, and the 50% GW + 50% CWirrigated tomato showed a slightly higher Ni concentration of 0.81± 0.14. Tomato irrigated with 100% CW range obtained 0.86± 0.24, while tomato grown on canal-sidehad a Ni concentration of 0.12± 0.01.A mean Ni concentration of plants from 1.50 in tubewell-irrigated soils of the site(Gangia) to 4.78 mg kg-1 in sewage-irrigated soils was observed by researchers(Ashiq et al., 2013), and 0.005 obtained from the Iran area by other researchers(Rahmdel et al., 2018). The value of the Ni heavy metal in all the vegetable sampleswas less than WHO permissible limits (1.50). Ni is essential in trace quantities for RBC processing; however, its accumulation beyond requisite levels induces toxicity. Prolonged exposure to elevated Ni concentrations may result in diminished body mass, cardiac and hepatic impairment, and dermal irritation.(Pandey, 2016).

Table 3Comparison of WHO/FAO and IS values with the Heavy metal and MAF values in vegetable samples.

Metal	water Ratio	Spinach Mean±SD	Radish Mean±SD	Tomato Mean±SD	WHO/FAO	IS	MAF Spinach	MAF Radish	MAF Tomato
Chromium	100% GW	**0.12** ± 0.09	**0.15** ± 0.2	**0.2** ± 0.57	0.10	20.00	0.19	0.24	0.31
	50% GW + 50% CW	**0.59** ± 0.93	**1.07** ± 0.72	**0.9** ± 0.3			0.93	**1.67**	**1.41**
	100% CW	**1.463** ±0.88	**1.52** ± 0.45	**1.12** ± 0.92			**2.29**	**2.37**	**1.75**
	Canal Side	0 ± 0	1.48 ± 1.18	0 ± 0			0.00	**2.31**	0.00
Iron	100% GW	34.25 ± 11.38	38.39 ± 7.46	38.42 ± 14.38	425	NA	0.87	0.97	0.97
	50% GW + 50% CW	38.93 ± 13.03	40.53 ± 13.18	40.56 ± 7.92			0.99	**1.03**	**1.03**
	100% CW	42.15 ± 11.14	54.4 ± 0.86	52.1 ± 20.46			**1.07**	**1.38**	**1.32**
	Canal Side	19.46 ± 2.78	37.56 ± 9.22	54.43 ± 14.18			0.56	**1.07**	**1.55**
Cobalt	100% GW	0 ± 0	0 ± 0	0 ± 0	NA	NA	0.00	0.01	0.00
	50% GW + 50% CW	0.01 ± 0	0.09 ± 0.04	0 ± 0			0.06	0.52	0.00
	100% CW	0.1 ± 0.04	0.14 ± 0.05	0 ± 0			0.54	0.76	0.00
	Canal Side	0.04 ± 0	0.06 ± 0	0.01 ± 0			0.21	0.34	0.06
Nickel	100% GW	0.09 ± 0.02	0.1 ± 0.05	0.09 ± 0.14	1.50	NA	0.20	0.22	0.20
	50% GW + 50% CW	0.69 ± 0.28	0.72 ± 0.16	0.81 ± 0.14			**1.52**	**1.59**	**1.80**
	100% CW	1.03 ± 0.21	0.84 ± 0.33	0.86 ± 0.24			**2.29**	**1.87**	**1.91**
	Canal Side	0.61 ± 0.05	0.75 ± 0.1	0.12 ± 0.01			**1.36**	**1.67**	0.26
Copper	100% GW	0.13 ± 0.1	0.55 ± 0.7	0.49 ± 0.45	40.00	30.00	0.19	0.77	0.69
	50% GW + 50% CW	0.56 ± 0.97	1.52 ± 0.11	0.71 ± 0.05			0.79	**2.13**	**1.00**
	100% CW	1.16 ± 0.93	2.17 ± 1.44	1.42 ± 1.21			**1.64**	**3.06**	**2.00**
	Canal Side	1.24 ± 0.37	1.07 ± 0.35	1.66 ± 0.19			**1.75**	**1.51**	**2.34**
Arsenic	100% GW	**0.12** ± 0	**0.18** ± 0.01	**0.12** ± 0.03	0.10	1.10	0.23	0.34	0.23
	50% GW + 50% CW	**0.4** ± 0.09	**0.43** ± 0.04	**0.49** ± 0.16			0.76	0.82	0.92
	100% CW	**0.54** ± 0.18	**1** ± 0.04	**0.54** ± 0.19			**1.01**	**1.88**	**1.02**
	Canal Side	**0.21** ± 0.08	**0.95** ± 0.12	**0.34** ± 0.08			0.40	**1.79**	0.64
Cadmium	100% GW	0 ± 0	0 ± 0	0 ± 0	0.20	1.50	0.00	0.00	0.00
	50% GW + 50% CW	0.19 ± 0.06	0.02 ± 0	**0.42** ± 0.09			0.43	0.05	0.93
	100% CW	**0.83** ± 0.1	0.04 ± 0	**0.83** ± 0.02			**1.85**	0.10	**1.84**
	Canal Side	0.05 ± 0.01	0.03 ± 0	0.01 ± 0.01			0.12	0.06	0.02
Lead	100% GW	0.2 ± 0.11	0.3 ± 0	0.2 ± 0.01	5.00	2.50	0.22	0.32	0.22
	50% GW + 50% CW	1.2 ± 0	1.28 ± 0.52	1.29 ± 0.25			**1.30**	**1.39**	**1.40**
	100% CW	**2.51** ± 1.07	2.02 ± 0.81	2.43 ± 1.22			**2.73**	**2.19**	**2.64**

	Canal Side	0.49 ± 0.16	0.21 ± 0.01	1.17 ± 0.32			0.53	0.23	**1.27**

Limits:Indian Standards(IS), Cd (1.5), Cu (30.0), Cr (20.0), Pb (2.5), Ni (1.5), WHO/FAO (2007), limits: Cd (0.2), Cu (40.0), Cr (0.1) Pb (5.0) (Gaurav et al., 2018). As (0.1)(WHO), As (1.1)(IS)(Khan et al., 2015a), the bold value represents the value above the permissible limit.

Copper (Cu)

The Cu content in spinach irrigated with 100% GWwas measured at 0.13± 0.1, while spinach with a 50% canal and 50% groundwater mix exhibited a higher Cu concentration of 0.56± 0.97. Spinach irrigated with 100% CW showed a further increase in Cu content, measuring 1.163± 0.93, while spinach cultivated on the canal side had a Cu concentration of 1.24± 0.37.For Radish, those irrigated with 100% GWdisplayed a copper content of 0.55± 0.7, and the 50% GW + 50% CW showed a higher Cu concentration of 1.52± 0.11. Radish irrigated with 100% CW showed a further increase in Cu content, measuring 2.17± 1.44, while radish grown in canal-side fields had a Cu concentration of 1.07± 0.35.A similar range obtained by other researchers from the Hisar district of Haryana Cu concentrations vegetable range of 0.36– 2.99 mg kg−1(Garg et al., 2014), Cu (2.06–33.22 kg/mg) obtained from Saudi Arabia(Ali & Al-Qahtani, 2012).In the case of Tomatoes, those cultivated with 100% GW had a Cu content of 0.49 ± 0.45, and the 50% GW + 50% CW irrigated tomatoes showed a slightly higher Cu concentration of 0.71± 0.05. Tomato irrigated with 100% CW exhibited a further increase in Cu content, measuring 1.42± 1.21, while tomatoes grown onthe canalside had a Cu concentration of 1.66± 0.19.The Cu value in all the spinach Radish and Tomato samples is within the permissible limit of WHO (40) and IS (30) (Table 3).The Cu concentration was obtained in spinach 0.004(Rahmdel et al., 2018).Human health depends on Cu, but excessive amounts can harm the liver, kidneys, stomach, and intestines and cause anemia(M. S. Islam et al., 2023).Other researchersobtained Cu values indried chili (18.84 ± 1.97), non-branded chili powder (15.36 ± 2.28), and branded cumin (13.81 ± 2.38) had high concentrations of Cu in the Bangla Desh research area (Hassan et al., 2024).

Arsenic(As)

The As content in spinach irrigated with 100% GWwas measured at 0.12± 0. In comparison,spinach with a 50%GW+50%CW exhibited a higher As concentration of 0.40± 0.09. Spinach irrigated with 100% CW showed a further increase in As content, 0.54± 0.18, while spinach cultivated on the canalside had an Asconcentration of 0.21± 0.08.Forradishes, those irrigated with 100% GW displayed an As content of 0.18± 0.01, and the 50%GW+ 50%CWshowed ahigherAsconcentration of 0.43± 0.04. Radish irrigated with 100% CW showed a further increase in As content, measuring 0.99± 0.04, while radish grown in canal-side fields had the same As value (0.95± 0.12)(Table 3). In the case of tomatoes, those cultivated with 100% GWhad an As content of 0.12± 0.03, and the 50%GW+50%CWirrigated Tomatoes showed a higher As (0.49 ± 0.16). Tomato irrigated with 100% CW exhibited a further increase in As, measuring 0.54± 0.19, while tomatoes grown on canalsides had an As concentration of 0.34± 0.08.All the values were abovethe permissible limit of WHO (0.1)and within the limits as per IS(1.1)(Khan et al., 2015b). Elevated As levels in vegetables can pose health risks, and monitoring and regulating As in agricultural practices is crucial.

Cadmium (Cd)

The Cd content in Spinach, Radish, and Tomato irrigated with 100% GW wasabsent. Spinach irrigated with 50%GW+50%CW hada Cd rangeof 0.19± 0.06, while spinach irrigated with 100% CW showed a further increase in Cd content, measuring 0.83± 0.1. Spinach cultivated on the canalsidehad a lower Cd concentration of 0.05 ± 0.01. Radish irrigated with 50%GW + 50%CWshows 0.02±0,and100% CWshowed a further increase in Cd content, measuring 0.04 ± 0, while Radish grown in canal-side fields had a concentration of 0.03 ± 0. In Dhaka,(M. A. Islam et al., 2018) reported the Cd in coriander leaf (1.65 ± 0.01), non-branded turmeric powder (1.49 ± 0.02), and branded turmeric powder (1.43 ± 0.01), even at low concentrations,Cd consumption can result in severe illnesses by building up in the kidneys and liver(Hassan et al., 2024), similar cd values obtained by Ali from Saudi Arabia(0.92–4.13,(Ali & Al-Qahtani, 2012).50%GW + 50%CWirrigated tomatoes showed a Cd concentration of 0.42 ± 0.09. Tomatoes irrigated with 100% CW exhibited a further increase in Cd content, measuring 0.83 ± 0.02, while tomatoes grown on the canal side had a Cd concentration of 0.01 ± 0.01. The WHO sets a permissible limit of 0.2 for cadmium in leafy vegetables, 100% CW irrigated spinach, tomato,and 50% GW + 50% CW irrigated tomato have valuesabove the WHO Permissible limits (0.2); however, all the values within \the limits as per IS (1.5).

Lead (Pb)

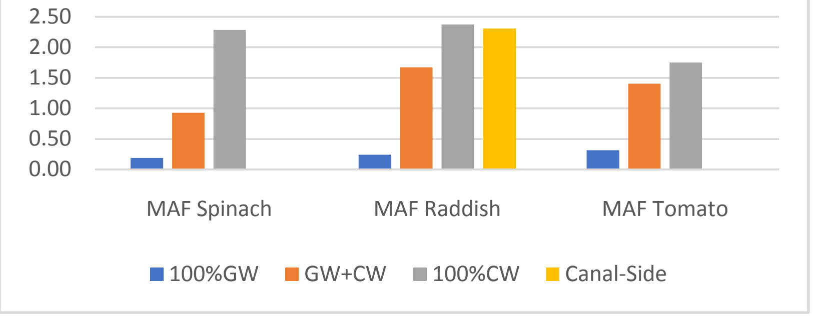
The Pb content in spinach irrigated with 100%GW was measured at 0.2± 0.11. In comparison, spinach with a 50% GW + 50% CW exhibited a higher Pb concentration of 1.2± 0. Spinach irrigated with 100% CW showed a further increase in Pb content, measuring 2.51± 1.07, while spinach cultivated on the canalside had a lower Pb concentration of 0.49± 0.16. Pb concentration was highest obtained in spinach. Another researcher also proposed a similar statement: grain or fruit crops and leafy vegetables are more easily contaminated with heavy metals(Arora et al., 2008).For Radish, those irrigated with 100% GWdisplayed a Pb content of 0.3± 0, and in 50% GW + 50% CW, a higher Pb concentration of 1.28± 0.52. Radish irrigated with100% CW showed a further increase in Pb content, measuring 2.02± 0.81, while radish grown in canal-side fields had a lower Pb concentration of 0.21± 0.01.In the case of tomato, those cultivated with 100% GWhad a Pb content of 0.2 ± 0.01, and 50% GW + 50% CWirrigatedtomato showed a higher Pb concentration of 1.29± 0.25. Tomato irrigated with 100% CW exhibited a further increase in Pb content, measuring 2.43±1.22, while tomatoes grown on canalsides had a Pb concentration of 1.17± 0.32.In all three vegetable samples, Pb was within the permissible limit of WHO (5.0) but spinach rinsed with 100% CW was found with higher Pbas per the IS standardof(2.5).When compared to studiesdone in other countries, in Dhaka Cardamom, the Pb content was high (15.47 ± 1.93), and cinnamon (10.05 ± 1.22) (M. S. Islam et al., 2023), similar values were obtained from SaudiArabiaPb (0.54–6.98)(Ali & Al-Qahtani, 2012).Other researchers found thatthe Pb concentration in spinachis 0.025 (Rahmdel et al., 2018). Elevated levels of Pb in vegetables can pose health risks, and monitoring and regulating Pb concentrations in agricultural practices is crucial to ensure food safety. Increased levels of Pb in plants cause more reactive oxygen species (ROS) to be produced, which damages lipid membranes and ultimately destroys chlorophyll, as well as the metabolic and photosynthetic processes that support plant growth(Naz et al., 2016). Higher Pb concentrations hinder treatment plant growth by reducing plant biomass and lower plant quality by altering quality features, according to (Wu et al., 2011).

Human health risk assessment

Metal Accumulation Factor (MAF)

MAF is a crucial parameter in environmental science and toxicology that measures the concentration of a particular substance in an organism relative to its concentration. According to (Verma et al., 2022), soil physicochemical characteristics of the Agracanal collectively impactMAF values. The highest MAF was obtained in 100% CW, then in 50% GW + 50% CW irrigated, followed by canal-side and nonein 100% GW samples.Onthe canalside,41.7% of samples, from 50%GW + 50% CWirrigated vegetables,50%of samples, and 100% CW samples,83.3%hadMAF >1 (Table 2).The MAF >1 shows the activetransfer of heavy metal from soil to vegetables(Khan et al., 2015a; Nazir et al., 2015).

Figure 2 shows the MAF in various water ratios.



Other researchers found that the MAF of Cu 0.52 indicates that anthropogenic activities have started contaminating the site(Gupta et al., 2022). Notably, the MAF values for all vegetables are lower than the 100% CW condition, with similar results obtained by other researchers in various vegetables(Massaquoi et al., 2015),(Arora et al., 2008). 100% CW contributes to bioaccumulation in the highest amount.(Chang et al., 2014)obtained MAF of Pb,Cr, and As in vegetables varied inranges, i.e.,0.0001–0.0648, 0.0002–0.027, and 0.0001–0.103, respectively,in South China.The MAF values were observed by(Sabir et al., 2022a) for Pb (0.81), Zn (0.74), Fe (0.61), Cr (0.59), andNi (0.54)in different vegetables.(Emurotu & Onianwa, 2017)observed that the MTF for heavy metalswere Cd (0.21–1.68), Co (0.07–2.48),Cu (0.38–1.01), Ni (0.11–2.21), Pb (0.01–0.03) and Zn(0.51–1.96) in research of Nigeria.

Table 4 Values of DIM, HRI, MPI, HI in Spinach

Parameters	RfD	Metals 100% GW	DIM	HRI /HQ	Metals 50% GW+50 %CW	DIM	HRI /HQ	Metals 100 % CW	DIM	HRI /HQ	Metals Canal Side	DIM	HRI /HQ
Cr	3.00E-03	1.21E-01	4.86E-05	1.62E-02	5.94E-01	2.39E-04	7.95E-02	1.46E+00	5.88E-04	1.96E-01	0.00E+00	0.00E+00	0.00E+00
Fe	7.00E-01	3.43E+01	1.38E-02	1.97E-02	3.89E+01	1.56E-02	2.23E-02	4.22E+01	1.69E-02	2.42E-02	1.95E+01	7.82E-03	1.12E-02
Co	3.00E-04	0.00E+00	0.00E+00	0.00E+00	1.10E-02	4.42E-06	1.47E-02	9.80E-02	3.94E-05	1.31E-01	3.86E-02	1.55E-05	5.17E-02
Ni	2.00E-02	9.00E-02	3.62E-05	1.81E-03	6.86E-01	2.76E-04	1.38E-02	1.03E+00	4.14E-04	2.07E-02	6.13E-01	2.46E-04	1.23E-02
Cu	4.00E-02	1.34E-01	5.38E-05	1.35E-03	5.60E-01	2.25E-04	5.62E-03	1.16E+00	4.67E-04	1.17E-02	1.24E+00	4.98E-04	1.24E-02
As	3.00E-04	1.20E-01	4.82E-05	1.61E-01	4.02E-01	1.61E-04	5.38E-01	5.35E-01	2.15E-04	7.16E-01	2.10E-01	8.44E-05	2.81E-01
Cd	1.00E-03	0.00E+00	0.00E+00	0.00E+00	1.92E-01	7.71E-05	7.71E-02	8.31E-01	3.34E-04	3.34E-01	5.30E-02	2.13E-05	2.13E-02
Pb	3.00E-04	2.00E-01	8.03E-05	2.68E-01	1.20E+00	4.82E-04	1.61E+00	2.51E+00	1.01E-03	3.36E+00	4.86E-01	1.95E-04	6.51E-01
MPI		0.00E+00			5.55E-01			1.30E+00			0.00E+00		
HI				4.68E-01			2.36E+00			4.80E+00			1.04E+00

Metal Pollution Index (MPI)

MPI is a critical tool for metal assessment. In Spinach,MPI ranged from 0.00 -1.2986, in the order 100% CW>50% GW + 50% CW>canal-side / 100% GW.The highestMPI was obtained in 100% CW-irrigated spinach.In tomatoes,MPI ranged from 0.00 in all the samples. In Radish,the MPI Ranged from 0.1167 -1.0755.(Fig3D).The order of MPIin vegetablesis higher in spinach >radish >tomato.Other researchers obtained MPI values ranging from 2.4 to 10.1 in the background vegetables andfrom 12.8 to 27.5 in those sampled from the vicinity of the powerplants.

DIM (Daily Intake of Metals)

Estimating DIM is based on the amount of metals present in vegetables that individuals consume.In SpinachDIM ranged from 0 to 0.017in the following order 100% CW>50% GW + 50% CW> Canal Side >100 GW. In Radish,it ranges from0 to 0.0219, the highest in 100%CW. In tomato,it ranged from 0.000 to 0.021in the order 100% CW > Canal Side > 50% GW +50% CW > 100 GW.In thisresearch, it was concludedthat the adult population's DIM values of metals for all studied vegetables are considerably lower than their prescribed maximum tolerable daily intake values, a result of something similar to what was reported by (Gebeyehu and Bayissa, 2020). In 100%GW,the DIM ranged from 0 to 0.0002.In mixed water it ranged from 0to 0.0006, and in 100% CW it rangedfrom 0 to 0.0010. In canal-sideirrigated plants it rangedfrom 0 to 0.0007.The order of DIM as permetalin Spinach obtained Fe>Pb>Cr>Cu>Ni>Cd>As>Co, (Table 4), in RadishFe>Cu>Pb>Cr>As>Ni>Co>Cd, (Table 5) and in Tomato Fe>Pb>Cu>Cr>Cd/Ni>As>Co (Table 6).

Table 5 Values of DIM, HRI, MPI, HI in Radish

Parameters	RfD	Metals 100% GW	DIM	HRI/ HQ	Metals 50:50% CW+GW	DIM	HRI/ HQ	Metals 100 % CW	DIM	HRI/ HQ	Metals Canal Side	DIM	HRI/ HQ
Cr	3.00E-03	1.53E-01	6.15E-05	2.05E-02	1.07E+00	4.30E-04	1.43E-01	1.52E+00	6.10E-04	2.03E-01	1.48E+00	5.93E-04	1.98E-01
Fe	7.00E-01	3.84E+01	1.54E-02	2.20E-02	4.05E+01	1.63E-02	2.33E-02	5.44E+01	2.19E-02	3.12E-02	3.76E+01	1.51E-02	2.16E-02
Co	3.00E-04	2.00E-03	8.03E-07	2.68E-03	9.30E-02	3.74E-05	1.25E-01	1.37E-01	5.50E-05	1.83E-01	6.10E-02	2.45E-05	8.17E-02
Ni	2.00E-02	1.00E-01	4.02E-05	2.01E-03	7.15E-01	2.87E-04	1.44E-02	8.43E-01	3.39E-04	1.69E-02	7.51E-01	3.02E-04	1.51E-02
Cu	4.00E-02	5.45E-01	2.19E-04	5.47E-03	1.52E+00	6.09E-04	1.52E-02	2.17E+00	8.73E-04	2.18E-02	1.07E+00	4.31E-04	1.08E-02
As	3.00E-04	1.80E-01	7.23E-05	2.41E-01	4.32E-01	1.74E-04	5.78E-01	9.96E-01	4.00E-04	1.33E+00	9.50E-01	3.82E-04	1.27E+00
Cd	1.00E-03	1.00E-03	4.02E-07	4.02E-04	2.10E-02	8.44E-06	8.44E-03	4.30E-02	1.73E-05	1.73E-02	2.50E-02	1.00E-05	1.00E-02
Pb	3.00E-04	2.98E-01	1.20E-04	3.99E-01	1.28E+00	5.12E-04	1.71E+00	2.02E+00	8.09E-04	2.70E+00	2.11E-01	8.48E-05	2.83E-01
MPI		1.17E-01			6.89E-01			1.08E+00			5.85E-01		
HI				6.93E-01			2.61E+00			4.51E+00			1.89E+00

Table 6 Values of DIM, HRI, MPI, HI in Tomato

Parameters	RfD	Metals 100% GW	DIM	HRI/HQ	Metals 50:50% CW+GW		HRI/HQ	Metals 100 % CW	DIM	HRI/HQ	Metals Canal Side	DIM	HRI/HQ
Cr	0.0030	2.00E-01	8.03E-05	2.68E-02	9.00E-01	3.62E-04	1.21E-01	1.12E+00	4.50E-04	1.50E-01	0.00E+00	0.00E+00	0.00E+00
Fe	0.7000	3.84E+01	1.54E-02	2.20E-02	4.06E+01	1.63E-02	2.33E-02	5.21E+01	2.09E-02	2.99E-02	5.44E+01	2.19E-02	3.12E-02
Co	0.0003	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	4.02E-06	1.34E-02
Ni	0.0200	9.00E-02	3.62E-05	1.81E-03	8.10E-01	3.25E-04	1.63E-02	8.60E-01	3.45E-04	1.73E-02	1.17E-01	4.70E-05	2.35E-03
Cu	0.0400	4.90E-01	1.97E-04	4.92E-03	7.10E-01	2.85E-04	7.13E-03	1.42E+00	5.70E-04	1.43E-02	1.66E+00	6.68E-04	1.67E-02
As	0.0003	1.20E-01	4.82E-05	1.61E-01	4.90E-01	1.97E-04	6.56E-01	5.40E-01	2.17E-04	7.23E-01	3.40E-01	1.37E-04	4.55E-01
Cd	0.0010	0.00E+00	0.00E+00	0.00E+00	4.20E-01	1.69E-04	1.69E-01	8.30E-01	3.33E-04	3.33E-01	1.00E-02	4.02E-06	4.02E-03
Pb	0.0003	2.00E-01	8.03E-05	2.68E-01	1.29E+00	5.18E-04	1.73E+00	2.43E+00	9.76E-04	3.25E+00	1.17E+00	4.68E-04	1.56E+00
MPI		0.00E+00			0.00E+00			0.00E+00			0.00E+00		
HI				4.84E-01			2.72E+00			4.52E+00			2.08E+00

Health Risk Index/ Hazard Quotient (HRI/HQ)

In Spinach HRI/HQ value ranged from 0to3.3623.In 50%GW + 50%CW Irrigated Spinach, HRI for Lead was >1 (1.607). HRIwas obtained for pb in 100% of CW irrigated (3.362) (Fig-5A). Similar findings were found by other researchers from the Ganga Yamuna Doab region regarding the health risks associated with the consumption of spinach (Gaurav et al., 2018; Hassan et al., 2024).In radishHRI/HQ value ranged from .0004 to 2.6982, In 50% GW+50% CW,the HRI value for the lead was >1 (1.7073). In 100% CW irrigated radish, the HRI value of Arsenic (1.33), and lead (2.698), was >1, and for canal side samples, for As was >1 (1.2721) (Table 5).InTomatoes, HRI/HQ ranged from 0 to 3.2539.In50% GW+50% CWwas (1.727),100% CW irrigated tomatoes (3.2539), and in the canal side (1.5601)wherethe HRI value for Pb was >1(Fig.3B,C). In all the samples the order of values was 100% CW >50% GW + 50% CW > canal side> 100 GW.According to the current standards, an HRI value < 1 does not pose any health hazards,obtained in all 100% GW samples, while HRI values > 1 indicate potential risks associated with overexposure (Khillare et al., 2012; USEPA, 2004; Verma et al., 2022). HRI values for Ni (1.48), cowpea (3.27), bitter gourd (3.89) and ridge gourd (1.17) samples from power plant sites, and Cd (8.54), Cu (2.21), Zn (2.24) and Ni (3.27), Cd (1.26), Cu (1.48) and Zn (1.21) in cowpea from another site of Delhi NCR(Khillare et al., 2012).Other researchers found that Pb exerts toxiceffects on various body organs like the spleen, kidneys, liver, and lungs by inducing biochemical disruptions(Verma et al., 2022). Metal HRI value was obtained water ratio wise obtained the sequence 100% CW> 50% GW + 50% CW >100% GW> Canal Side.(Fig.5C)The hazard quotient surpassed the safe threshold for Cd (1.05–8.54) and Nickel (1.17–3.89) in vegetables cultivated near thermal power plants in Delhi, India, signaling potential non-carcinogenic health hazards from consuming them(Khillare et al., 2012).

Figure 3shows the HRI, MPI, and HI values of Spinach, Radish, and Tomato**.**

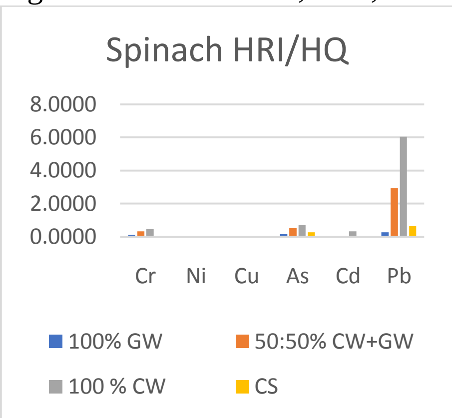


Fig-A

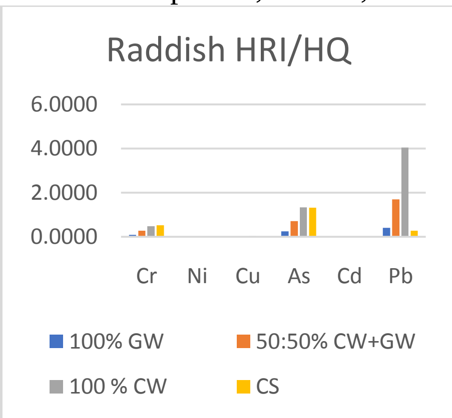


Fig-B

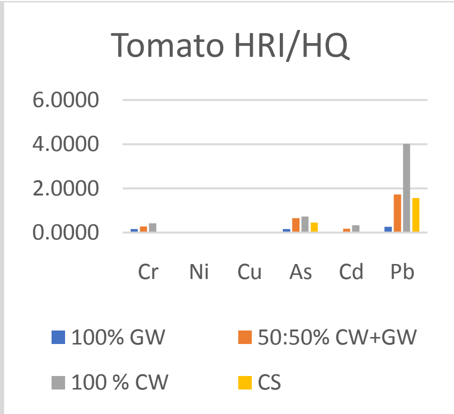


Fig-C

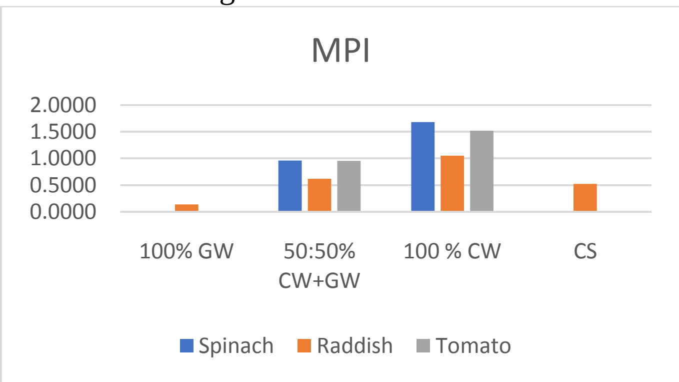


Fig-D

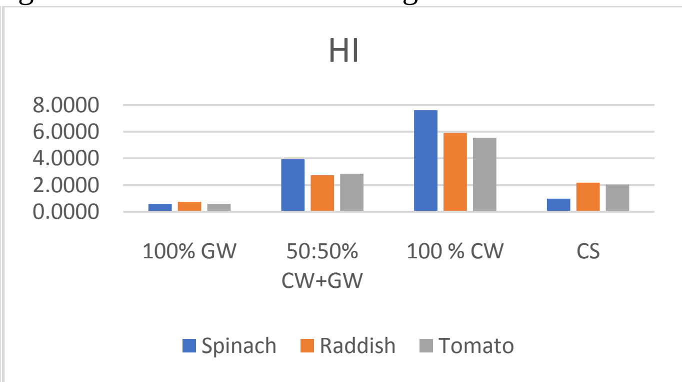


Fig-E

Hazard Index (HI)

The Environmental Protection Agency (EPA) disseminates risk assessment guidelines and reference doses for diverse chemical compounds via its Integrated Risk Information System (IRIS) repository. This database contains data about toxicity and reference values utilized in deriving HI metrics(Epa et al., 2004). HI value ranged from 0.4675-4.7962 in spinach. In radishes,HI ranged from 0.6931 to 4.5060,and in tomatoes, it ranged from 0.4841 to 4.5218(Fig. 3E). Furthermore, radish irrigated with 100% CW displayed an HI of

4.5060, contrasting with an HI value of1.8916 in Canal-side irrigation. Similarly, an HI> 1 (4.5218) in tomatoes was observed in plants irrigated with 100% CW,in mixed water it was found > 1 (2.7194) in Canal Side it was 2.0831,which may have accumulated from soil, and water, indicating a potential health hazard. Conversely, tomatoes irrigated with 100% CW exhibited a notably higher HI of 4.5218, whilein mixed water HI of 2.7194, further suggesting a health risk. (Table 6).In spinach, 100% CW irrigation resulted in an HI of 4.796, in 50%GW+ 50% CW yielded it was 2.3583. Tomato plants grown near canals also displayed HI,highest in 100% CW surpassing 1, posing a potential health risk. In all vegetables HI, influenced by water composition, exhibited variability that followed the same pattern in all vegetables, i.e., 100% CW >50% GW+50% > canal-side >100% GW. The highest HI value was observed in Spinach> Tomato> Radish. Generally, in agreement with the fact that leafy vegetables accrue toxic metals to a larger degree than non-leafy vegetables, health index (HI) was associated with \spinach ingestion,(Bayissa & Gebeyehu, 2021). The results of the present study revealed that daily intake of heavy metals through the diet of vegetables causes health risks to the target population as HI for all the studied heavy metals is less than unity and ranged from 0.077 for Radish from Hisar District, and 0.846 of *Brassicacampestris* leaves (Garg et al., 2014). When HI value> 1, it indicates a safe range, while an HI >1 designates the potential of non-carcinogenic risks(Sabir et al., 2022b). The majority of previous studies have stated that the PbHRIvalue is higher than 1.0 and reported it as a potent toxic metal closely linked to elevated health risks (Verma et al., 2022).

Conclusion

The best growth and yielding of Spinachand Tomatowas found in 50% GW + 50% CW,followed by 100% GW and 100% CW. Radish's best growth was obtained in 100% GW,followed by50% GW + 50% CW,and 100% CW a. The heavy metals Pb, and As,concentrationswere tested higherthan the WHO/ FAO permissible limits in 50% GW + 50% CW and 100% CW irrigated vegetables. TheMAF washighestin 100% CW, then in mixed water, canal-side, and not found in 100% GW. Health risk assessment revealed considerable health risks for Pb,and the As—HQ index for Pb and As was observedto be beyond the safe limit. The data suggests a correlation between irrigation water quality and heavy metal concentrations. Crops were irrigated with 100% CW, followed by50% GW+50% CW, having high MPI, HRI, and HI values, and demonstrated higher heavy metal levels, posing potential health risks to consumers. The conclusion is that 100% CW and 50% GW + 50% CWirrigated vegetables are unsafe for human health.Although50% GW + 50% CW irrigated veggies are good in yielding,they are unsuitable foranimal and human consumption.Based on the health risk assessment, it was concluded that Agra Canal water is not safe for irrigation.This research is valuable for farm managers and policymakers for decision-making. Agra Canal Waterunderscores the need for stringent monitoring and regulation to ensure the safety of vegetables for human consumption. There is a need to investigate more factorsrelated to the Agra Canal water for crop productiondegradation.

Abbreviations: World Health Organization (WHO), Food and Agriculture Organization (FAO), lead (Pb), Cadmium (Cd), Arsenic (As), Chromium (Cr), Ground Water (GW), Canal Water (CW), Not Applicable (NA), Daily intake of metal (DIM), The Health Risk Index (HRI), Daily intake of metal (DIM), Hazard Index (HI), Figure (Fig.), Metal accumulation Factor (MAF).

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