Heavy metal toxicological analysis of vegetables cultivated in sewage-irrigated soil in the Indian metropolis of Ahmedabad City, Gujarat

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Abstract: Using wastewater for irrigation poses a significant health risk. We measured the concentration of (cobalt, chromium, copper, manganese, nickel, lead, and zinc) in wastewater, soil, and vegetation at 8 sites along a 60 km stretch of the Sabarmati River in Ahmedabad city. An evaluation of the potential danger from consuming contaminated vegetables was conducted using Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Target Cancer danger (TCR).
The average concentration of the metals Co, Cr, Cu, Mn, Ni, Pb, and Zn exceeds the maximum permitted limits for irrigation purposes as established by regulatory bodies. The heavy metals in the collected soil sample are ranked in descending order of concentration as follows: Zn > Mn > Cu > Cr > Ni > Pb > Co. The average metal concentrations in vegetables range from 0.10-11.3 µg g-1 for Co, 5.2-11.8 µg g-1 for Cr, 0.04-9.9 µg g-1 for Cu, 12.3-110 µg g-1 for Mn, 0.7-4.2 µg g-1 for Ni, 0.4-8.4 µg g-1 for Pb, and 4.4-44 µg g-1 for Zn. The mean content of heavy metals (µg g-1) in the collected vegetable samples is highest in spinach, followed by brinjal, cabbage, tomato, and cauliflower. The Hazardous Quotient (THQ) shows a high health risk for Pb (6.1) and Mn (1.02), and a medium health risk for Cr (0.9). The Target Cancer Risk (TCR) emphasized the cancer risk posed by Chromium (Cr) and Nickel (Ni), following with Lead (Pb). The study indicates a link between health risks and consuming vegetables grown in the study area. It recommends improving wastewater treatment facilities and monitoring heavy metal levels in vegetables grown in soil irrigated with wastewater at regular intervals.

Keywords: Wastewater irrigation. Target Hazard quotient, Heavy metals, Cancer risk, Bio concentration factor

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I. INTRODUCTION

Unregulated discharge of untreated or inadequately treated wastewater from municipal and industrial facilities into water bodies and soil is a major environmental concern in numerous metropolitan and semi-urban areas across different countries. Farmers are turning to other sources of irrigation water, like household, municipal, or industrial wastewater, due to the less available of fresh water. Farmers are using wastewater for irrigation because it is rich in important NPK minerals, which has been made possible by the higher agricultural yield.

Continuous use of wastewater for irrigation typically leads to increased concentrations of chromium, copper, lead, nickel, zinc, mercury, cobalt, and manganese metals in both soils and plants. Heavy metals can pose a threat to people by being transferred through the food supply chain (Akpor, 2014; Mohanty et al. 2021). Certain heavy metals like Zn, Mn, Ni, Cu, and Cr are necessary for humans in relatively small amounts. Surpassing the allowable thresholds of these heavy metals can lead to cardiovascular, neurological, kidney, and bone issues (WHO, 1998; Jarup, 2003). Cadmium, arsenic, and chromium are carcinogenic, whereas mercury and lead are linked to abnormal growth in children and decreased haemoglobin synthesis (Chetan, 2015). Vegetables are important providers of carbohydrates, proteins, minerals, and fibres, which are essential components of the human diet. Therefore, the accumulation of high concentrations of heavy metals in vegetables presents a health hazard to humans, as indicated by various studies (Chary et al. 2008; Tiwari et al. 2011). It is essential to assess the quantities of heavy metals in vegetable crops grown in croplands irrigated with wastewater based on the provided data.

Urbanisation in India has resulted in a significant increase in population density in medium to large cities. The increased demand for wastewater treatment in urban areas has resulted in the need for more advanced processing capabilities in treatment facilities, prompting the spread of wastewater irrigation in the vicinity of cities (Chary et al., 2008). Multiple studies conducted in Indian cities have investigated the impact of using wastewater for irrigation on the build-up of heavy metals in soils and vegetables (Ghosh et al., 2012; Sharma et al., 2016; Jaramillo and Restrepo, 2017). Vegetables grown in Kolkata, the third most populous city in India, were found to have higher levels of Pb and Cd than the limits specified by FAO/WHO due to being irrigated with sewage water, as reported by Saha et al. in 2015. Chopra et al. (2015) conducted a study on the distribution of trace metals in different parts of plants: lead in flowers, copper and zinc in leaves, and nickel, cadmium, and chromium in roots. Plants grown in soil irrigated with wastewater had elevated heavy metal concentrations compared to those watered with tube well water, suggesting a potential health hazard if consumed (Rattan et al. 2005; Tiwari et al. 2011).

The primary goals of this study are: (i) to collect preliminary data on particular heavy metals (Co, Cr, Cu, Mn, Ni, Pb, and Zn) found in commonly eaten vegetables such as brinjal, tomato, cabbage, cauliflower, and spinach, obtained from different areas where wastewater irrigation is common, (ii) to assess the transfer of metals quantitatively using bioconcentration factor, and (iii) to quantitatively evaluate the effects on health using target hazard quotient and cancer risk linked to consuming vegetables for the larger population of Ahmedabad city.

II. MATERIALS AND METHODS

A. Study Area

The site is located in close proximity to the Sabarmati River and the Vasna Sewage Treatment Plant (STP) discharge point in Ahmedabad, Gujarat, India. Ahmedabad, with a population of almost six million people, is the seventh largest city in India. India's rapidly expanding city covers an area of 464 square kilometres. The sewage treatment capacity of Ahmedabad is 1075 Million Litres per Day (MLD), which falls short of the 1186 MLD necessary according to the 2011 Ahmedabad Municipal Corporation report. According to a study conducted by the International Water Management Institute in New Delhi in 2012, an estimated 9450 hectares of land surrounding Ahmedabad are irrigated using wastewater. This accounts for 45% of the total irrigated area, which measures 21,086 hectares.

The Vasna Sewage Treatment Plant (STP) located on the banks of the Sabarmati River has a capacity of 240 million litres per day (MLD). The wastewater generated by residential areas and small businesses within the Ahmedabad Municipal Corporation (AMC) is subjected to treatment. Narol and Vatva, two semi-industrial zones next to the Sabarmati River catchment area, host a variety of industries including plastics manufacturing, small-scale chemical production, metal and alloy processing, electrochemical processing, dye and paint production, as well as wood and paper mills. Two channels transport industrial waste into the designated research zone. Initially, these industrial companies release wastewater into the Sabarmati River using small channels or sub-channels. The Gujarat Pollution Control Board mandates the purification of industrial effluents prior to their discharge. A significant number of industrial sites neglect to adhere to specified protocols, resulting in the discharge of untreated effluents into the environment. Drainage channels are used to transport industrial effluents into sewage networks and the Vasna Sewage Treatment Plant (STP). The croplands in the research region are irrigated with effluent from the Sabarmati River, which contains high levels of heavy metals originating from residential and industrial sources. This approach indicates that contaminants have the potential to contaminate the plants in the croplands of the research region.

B. Collection and Preparation of samples

The collection phase involved gathering three discarded sewage samples, eight soil samples, and thirty-eight vegetable samples. The samples were thoroughly mixed and appropriately maintained to prevent any contamination.

Three 500 ml wastewater samples were collected in HDPE bottles from three distinct disposal places. In order to prevent degradation caused by microbial activity, 2 ml of concentrated HN03 was added. On-site measurement of pH, electrical conductivity, total dissolved solids, and temperature was conducted at the location where the sample were collected. In order to trace metal analysis, the sample was diluted until it reached a conductivity of 300 µs. The samples were stored at a temperature of 4ºC until they were ready for further analysis.

A total of eight soil samples were obtained from the agricultural field where sewage is utilised for irrigation purposes. The collected samples were homogenised and then subjected to sieving using a 1-mm screen (100 mesh) to eliminate undesired particles. Subsequently, the samples were dried at a temperature of 105 º C for duration of 24 hours. The specimens were preserved in sealed zip pouches at ambient temperature. In order to perform trace element analysis on soil samples, a quantity of 0.3 gm of the sample was combined with 6 ml of nitric acid (HNO3) and 1 ml of hydrofluoric acid (HF). The samples were subsequently processed in the Titan MPS Direct Temperature Control™ digester manufactured by Perkin Elmer.

A total of thirty-eight vegetable samples were obtained from the field where sewage was utilised for irrigation. A total of five distinct samples, including Brinjal, Tomato, Cabbage, Cauliflower, and Spinach, were collected. The specimens were rinsed with tap water and inedible sections were discarded. The samples were subjected to oven drying at a temperature of 80 ºC for duration of 24 hours. The dried materials were pulverised using an agate mortar and pestle. To extract trace elements, 0.3 gm of samples were subjected to digestion with 6 ml of HNO3 at a temperature of 175 º C for duration of 10 minutes at a pressure of 30 bar. This was followed by a subsequent treatment at a temperature of 50 º C for 10 minutes under the same pressure conditions. Following the process of digestion, the samples were diluted to a volume of 30 ml using a 2% solution of nitric acid (HNO3). The processed samples were retained for the analysis of chromium, nickel, copper, lead, manganese, zinc, and cobalt.

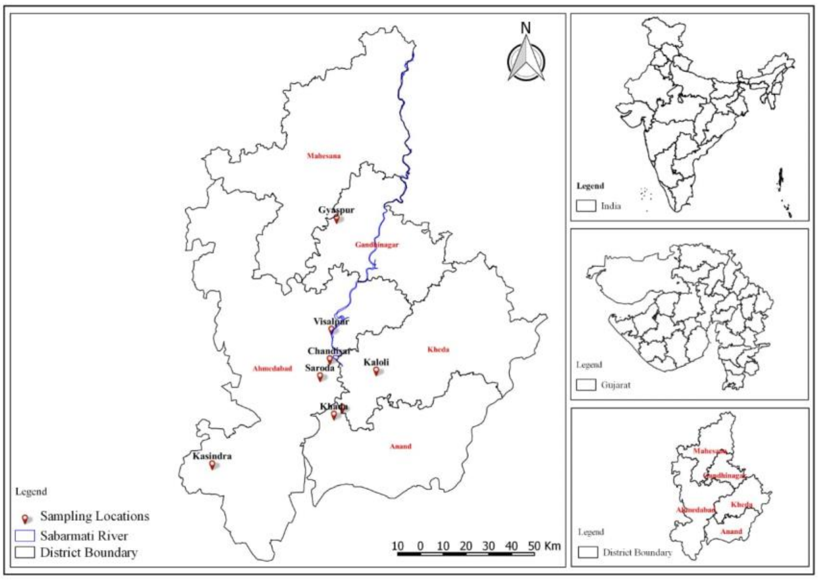

Figure-1: Study area showing the sampling locations

C. *Analysis of Samples*

The concentrations of metals in digested samples were measured by inductively coupled plasma mass spectrometry (ICP-MS) (PerkinElmer, Thermo-X series2) in Physical Research Laboratory, Ahmedabad. Analysis of trace elements by ICP source is one of the most powerful accepted techniques. The ICP source converts the atoms of the elements in the sample to ions, which are then separated and detected by the mass spectrometer. The multi-elemental analysis methods offer the potential to analyze the whole suite of elements in a single run. High linear dynamic range (HDLR) allows for simultaneous detection of major and trace elements in one run up to a wide range of matrices from parts per trillion to low percentage level. The blanks were separately digested and tested for soil and plant samples analysis. High purity chemicals were used (HNO3 65%, Merck). The instrument reproducibility was determined by carrying out a replica analysis of the analyzed samples. The pH, electrical conductivity, total dissolved solids, and temp. of disposed sewage samples were measured by instrumental analysis. The soil pH value was also determined with the help potentiometer by preparing a mixture of 10 gm of air-dried and sieved soil sample with 10 ml of deionized water.

D. *Bio-concentration factor (BCF)*

Commonly employed in the field of environmental biogeochemistry (Wang et al., 2005; Khan et al., 2008; Sharma et al., 2018; Yang et al., 2018). The Bioconcentration Factor (BCF) is a crucial metric that determines the transfer of harmful pollutants, such as heavy metals, from the soil to plants. Transfer factor (TF) and metal transfer factor (MTF) are alternative words used interchangeably with bioconcentration factor (BCF) in scientific literature (Khan et al., 2013).

$$\mathrm{BCF} = \frac{\mathrm{C}^{\mathrm{M}}_{\mathrm{Plant}}}{\mathrm{C}^{\mathrm{M}}_{\mathrm{Soil}}} \qquad (1)$$

E. *Estimated daily intake (EDI)*

The daily intake of vegetables is calculated from the below equation

$$\mathrm{HQ}_M = \frac{C_m \times C_{\mathrm{f}} \times FIR \times E_f \times D_e}{\mathrm{BW} \times T_{\mathrm{av}}} \times 10^{-3} \qquad (2)$$

Cm indicates the concentration of metal in mg per kg of dry weight. Ef represents the frequency of exposure, which is 365 days per year. De represents the duration of exposure, which is 70 years. Tav is the average time of exposure, calculated by multiplying 365 days by 70. The acronym FIR stands for the average food intake recommended by the World Health Organisation, which is between 300 and 350 gm per person per day. In this study, the average daily consumption of vegetables was 325/115 g/person/day. The conversion factor (Cf) utilised to convert vegetable weight into dry weight was 0.085 (Arora et al., 2008). The average body weight (BW) of the consumers in the Indian situation was 58 kg.

F. *Target hazard quotient (THQ)*

The THQ is calculated by using the equation:

$$\mathrm{THQ} = \frac{\mathrm{EDI}}{\mathrm{D_f}} \tag{3}$$

EDI stands for estimated daily intake, while Df indicates the reference dosage. If the THQ value exceeds one, there is a possibility of a noncarcinogenic effect associated with the data. If the THQ value is below one, it will be considered safe in terms of noncarcinogenic effects (Antoine et al., 2017).

G. Cancer Risk

It can be calculated by using following equation:

$$\mathrm{CR_{Veg}} = \mathrm{EDI} \times \mathrm{CPSo} \tag{4}$$

$$\mathrm{TCR} = \sum \mathrm{CR} \tag{5}$$

Where EDI represents the estimated daily intake and CPSo represents the oral cancer slope factor.

III. RESULTS AND DISCUSSION

A. Trace elements concentration in sewage

The pH, total dissolved solids (TDS), temperature, and amounts of heavy elements in three wastewater samples were analyzed. These metrics provide data on the quality of a significant point-source (namely, sewage) that pollutes the chemical composition of the river water. The pH levels in the samples ranged from nearly neutral to highly alkaline, with values ranging from 7.1 to 8.4. The temperature of the samples varied between 32.0 ºC and 32.7 ºC. A significant range, almost six-fold, was noted in both the electrical conductivity (ranging from 2117 to 12750 µs cm-1) and the total dissolved solids (ranging from 1061 to 6360 ppm).

The concentrations of heavy metals in the sewage water samples ranged Co (2.1-2.2 µg ml-1), Cr (1.4-1.9 µg ml-1), Cu (0.1-0.9 µg ml-1), Mn (0.2-3 µg ml-1), Ni (1-1.9 µg ml-1), Pb (0.4-1.6 µg ml-1), and Zn (5.1-19 µg ml-1). All of these results exceed the recommended safe limits for heavy metals used in irrigation, as set by the Indian standard, World Health Organisation (WHO), and European Union standards. When comparing to the Indian Standard values, the average Cr is approximately three times higher, while Pb is approximately twelve times higher, Cu is around two times higher, Mn is approximately thirteen times higher, and Zn is approximately two and a half times higher. The Indian standard value for Ni is not available, but when compared to the EU value, the average Ni concentration is around six times greater. It is not possible to make such a comparison for Co because the permitted limits set by the Indian, WHO, and EU has not been revealed.

B. Heavy Metals in Wastewater Irrigated Soils

For collected soil samples, the pH was measured, which varied from 6.53 to 7.80. Along with pH, the concentrations of Cr, Ni, Cu, Pb, Mn, Zn and Co metals were analyzed. The movement of metal in soil is regulated by adsorption, precipitation, and complexation mechanisms, with soil pH playing a crucial role in controlling these processes. The management of soil pH is intricate and is affected by exchangeable cations in soils, the chemical composition of water moving through soil zones, the presence of ligands, and soil carbonates. The high metal concentration µg/g for Cr (109), Pb (50), Ni (64), Cu (255), Mn (425), Zn (535) and Co (11). The concentration of Cu, Mn and Zn was observed maximum in the soil collected soil samples with compare to Cr, Pb, Ni and Co. Similar type of observation was reported by Krishna and Govil (2007), the concentration of Cu and Zn was found maximum in the soil of Surat industrial area of western India. The data reported by Sharma et al., (2007), Zn was found at maximum concentration in the soil of Dinapur area of Varanasi, India, where sewage was used for irrigation purpose.

Among the eight different locations of soil sample collection sites, the sample which collected from Gyaspur had the maximum concentration of all analyzed metals compared to other sampling points. Gyaspur is the area where the effluents from Vasana treatment plant get disposed and it used for irrigation purpose which leads to the accumulation of these metals in the agricultural field.

C. Heavy Metals in Vegetables

The concentrations of Co, Cr, Cu, Mn, Ni, Pb, and Zn in the edible parts of vegetables varied significantly among different vegetables and metals, indicating that each plant and element has a distinct absorption pathway reported in Table-1. Tiwari et al. (2011) observed that the accumulation and transportation of metals in different regions of plants are specific to each metal and do not follow a regular pattern. The discussion will assess the levels of components in different vegetables and compare them with data from prior research.

TABLE I
HEAVY METAL CONCENTRATIONS (µg/g; DRY WEIGHT BASIS) IN VEGETABLE SAMPLES

Plant species	**Co**	**Cr**	**Cu**	**Mn**	**Ni**	**Pb**	**Zn**
Brinjal	0.09- 4.2 0.66± 1.4	5.6- 8.8 6.7± 1.1	0.04- 9.3 7.1± 3.1	12.3- 106.7 30.3± 32.9	0.7- 4.1 2.9± 1.0	0.5- 6.9 1.5± 2.2	11.4- 44.1 17.1± 11
Tomato	0.121- 2.2 0.55± 0.7	5.4- 9.0 6.6± 1.2	0.04- 9.9 6.2± 2.9	13.5- 25.0 18.6± 3.7	1.2- 4.2 3.0± 0.9	0.8- 5.6 3.2± 1.9	9.0- 21.5 13.6± 4.4
Cabbage	0.124- 2.2 0.62± 0.8	5.3- 7.8 6.2± 1.1	2.0- 3.3 2.4± 0.5	15.3- 60.14 31.5± 16.5	2.8- 4.2 3.3± 0.6	0.4- 4.5 1.7± 1.5	4.4- 13.9 9.8± 3.1
Cauliflower	0.142- 2.2 0.43± 0.7	5.2- 7.8 6.1± 0.9	0.07- 3.7 2.3± 1.1	13.0- 20.43 17.0± 3.0	0.8- 3.9 2.8± 1.0	0.4- 1.7 1.0± 0.4	9.5- 18.7 14.8± 2.6
Spinach	0.126- 11.3 1.6± 3.9	5.3- 11.8 7.3± 2.5	0.067- 9.8 6.6± 3.0	15.0- 109.8 62.5± 38.9	2.3- 4.1 3.0± 0.6	0.6- 8.4 2.1± 2.6	11.3- 32.5 19.1± 8.3
Guideline for safe limits of heavy metals in agricultural products (µg/g)							
Indian Standard (2000) a	-	20.0	30.0	-	1.5	2.5	50.0
WHO/FAO (2007) a	-		40.0	-	-	5.0	60.0
European Standard(2006) a	-	-	-	-	-	5.0	
Mean TE concentrations in food crop and Vegetables grown in various countries b	0.005-0.27	0.01-0.41	3-8	-	0.06-1.3	0.2-2.4	1.2-2.7

a Singh et al. (2010)
b Kabata-Pendias and Mukherjee (2007)

D. Bio-concentration factor (BCF)

The primary pathway for heavy metals to enter the food chain is through the deposition and transfer of these metals from the soil to the edible portions of vegetables. The heavy metal transferability of soil to plants for the vegetables utilised in this investigation has been estimated and is presented in Table 2. When the bio concentration factor (BCF) is below one, it signifies that these metals are not being accumulated in the plant through the soil. BCF greater than one shows the plant's build-up of heavy metals.

The study found that the computed values of bio concentration factor (BCF) for heavy metals ranged from <0.00 to 0.40, with a particularly high value of 1.01 seen in a spinach sample collected from the Gyaspur location.

TABLE II
BIO-CONCENTRATION FACTOR OF HEAVY METALS IN VEGETABLE GROWN IN WASTEWATER IRRIGATED SOILS.

Plant	**Co**	**Cr**	**Cu**	**Mn**	**Ni**	**Pb**	**Zn**
Brinjal	0.01 – 0.30 0.06 ± 0.10	0.07 – 0.10 0.09 ± 0.02	0.01 – 0.05 0.03 ± 0.01	0.03 – 0.30 0.09 ± 0.10	0.01 – 0.10 0.06 ± 0.02	0.01 – 0.10 0.03± 0.04	0.02 – 0.80 0.03± 0.01
Tomato	0.01 – 0.10 0.05 ± 0.02	0.06 – 0.10 0.09 ± 0.02	0.01 – 0.05 0.03 ± 0.01	0.04 – 0.06 0.05 ± 0.01	0.01 – 0.10 0.06 ± 0.02	0.02 – 0.10 0.07 ± 0.04	0.01 – 0.05 0.03 ± 0.01
Cabbage	0.01 – 0.10 0.06 ± 0.02	0.04 – 0.10 0.07 ± 0.03	0.01 – 0.10 0.01 ± 0.003	0.04 – 0.20 0.08 ± 0.05	0.04 – 0.07 0.05 ± 0.01	0.01 – 0.10 0.04 ± 0.03	0.008 – 0.03 0.02 ± 0.008
Cauliflower	0.01 – 0.10 0.04 ± 0.06	0.05 – 0.10 0.08 ± 0.01	0.001 – 0.01 0.01 ± 0.006	0.03 – 0.06 0.05 ± 0.01	0.01 – 0.07 0.05 ± 0.02	0.01 – 0.03 0.008 ± 0.02	0.01 – 0.05 0.03 ± 0.01
Spinach	0.01 – 1.00 0.15 ± 0.30	0.08 – 0.10 0.10 ± 0.01	0.001 – 0.04 0.03 ± 0.01	0.03 – 0.30 0.20 ± 0.10	0.04 – 0.07 0.06 ± 0.01	0.01 – 0.10 0.04 ± 0.05	0.02 – 0.07 0.04 ± 0.01

E. Estimated daily intake (EDI)

EDI stands for estimated daily intake. The computation is performed using the average concentration of each metal in food and the corresponding consumption rate, as described by Equation (2). After comparing these findings with the reference value, we found that the EDI values for the heavy metals Arsenic (As), Cobalt (Co), and Mercury (Hg) were elevated in both adults and children. According to the New York State Department of Health (NYSDOH), if the EDI/Df ratio is less than or equal to D^f, it is associated with the lowest level of health risk. If the value is 1–5 times greater than Df, it indicates a modest health risk. If the value is 5–10 times greater than Df, it indicates a moderate health risk. If the value is ten times greater than Df, it indicates a significant health risk (McGrath et al. 2001). Based on the EDI/Df ratio, it can be inferred that the levels of Cr, Pb, and Mn metals in the gathered vegetables (both leafy and non-leafy) are more than 10 times greater than the Df. Consequently, these vegetables cultivated in this location pose a significant health risk.

F. Target hazard quotient (THQ)

The THQ is associated with the noncarcinogenic health risk, and its acceptable threshold is equal to or less than 1.

Ambedkar and Muniyan (2011) determined that exceeding the threshold values of THQ is linked to potential health hazards. In equation-3, the assignment of a representative value for the metal concentration in vegetables (μg g-1) is a crucial parameter that affects the calculated value of THQ. To analyse the sensitivity of this parameter, a sensitivity analysis was conducted. The analysis involved selecting a set of 38 vegetables without considering their consumption pattern, and assuming a daily consumption of 300 gm of fresh vegetables for the calculation. The THQ values for Pb (6.1) and Mn (1.02) in all vegetables are higher than 1, whereas Cr (0.9) is close to 1. Therefore, the THQ values of the study region population could potentially represent the noncarcinogenic risk.

G. Cancer Risk

In general, it is believed that exposure to toxic metals can have negative health effects. Prolonged contact with some cancer-causing metals can raise the risk of developing cancer, and this risk becomes greater over time. TCR stands for the estimation of the foreseeable malignancies. Furthermore, it also indicates the potential for the development of cancer-causing hazards in an individual. The cause of TCR is the ingestion of contaminated vegetables containing harmful metals such as chromium (Cr), nickel (Ni), lead (Pb), manganese (Mn), and zinc (Zn). The New York State Department of Health (NYSDOH) has indicated that TCR levels equal to or less than 10^{-6} correspond to low cancer-causing risks. TCR values ranging from 10^{-5} to 10^{-4} indicate moderate cancer-causing risks, while those between 10^{-3} and 10^{-1} indicate high stakes (McGrath et al. 2001). The CPSo values utilised for Chromium (Cr), Nickel (Ni), and Lead (Pb) are 0.5, 1.7, and 0.0085, respectively, among the analysed heavy metals. The TCR values for chromium (Cr) and nickel (Ni) in all vegetables remain at 10^{-3}, which indicates a significant carcinogenic risk. Pb has a TCR value of 10^{-5}, indicating a moderate cancer risk.

IV. CONCLUSION

The levels of heavy metals (Cobalt, Chromium, Copper, Manganese, Nickel, Lead, and Zinc) in wastewater, soil, and vegetation from croplands irrigated with wastewater in Ahmedabad city, India, were quantified using high-precision ICP-MS. Concentrations of heavy metals, such as cobalt (Co) ranging from 2.1 to 2.2 μg ml-1, chromium (Cr) ranging from 1.4 to 1.9 μg ml-1, copper (Cu) ranging from 0.1 to 0.9 μg ml-1, manganese (Mn) ranging from 0.2 to 3 μg ml-1, nickel (Ni) ranging from 1 to 1.9 μg ml-1, lead (Pb) ranging from 0.4 to 1.6 μg ml-1, and zinc (Zn) ranging from 5.1 to 19 μg ml-1, in wastewaters, exceed the maximum allowable concentrations (MACs) for irrigation purposes as determined by Indian, WHO, and European agencies. The average contents (μg g-1) of metals in the eight soil samples can be ranked as follows: Zn (421±62)> Mn (336±49)> Cu (201±30)> Cr (71±20)> Ni (51±8) >Pb (42±6) > Co (9±1). The average values are significantly different with a confidence level greater than 90% ($p<0.01$). The analysed metals show strong inter-correlations, indicating that they likely have common sources or processes contributing to their presence. This is mostly due to enrichment from wastewater irrigation. With the exception of chromium (Cr), all metals exhibit a decline in concentrations as we move downstream. The concentrations of metals in vegetables can vary between the following ranges: Cobalt (Co) - 0.10 to 11.3 μg g -1, Chromium (Cr) - 5.2 to 11.8 μg g -1, Copper (Cu) - 0.04 to 9.9 μg g -1, Manganese (Mn) - 12.3 to 110 μg g -1, Nickel (Ni) - 0.7 to 4.2 μg g -1, Lead (Pb) - 0.4 to 8.4 μg g -1, and Zinc (Zn) - 4.4 to 44 μg g -1. These measurements are based on the dry weight of the vegetables. The variation in concentration, however, is peculiar to each plant species. The bio-availability of metals plays a crucial role in the process of metal assimilation in plants. The pH of the soil-water system appears to control the bio-availability of copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn) at the very least. The THQ results indicate that Co, Cu, Ni, and Zn have negligible risk. However, Pb and Mn are connected with high risk, and it is probable that Cr also poses a significant risk. It is recommended to improve the efficiency of wastewater treatment facilities and regularly evaluate the presence of heavy metals in soils and vegetation in the vicinity. The TCR values for chromium (Cr) and nickel (Ni) (10–3) suggest a high level of carcinogenic risk, whereas lead (Pb) (10–5) is associated with a moderate level of carcinogenic risk. The overall health risk assessment indicated that the consumption of vegetables in the Ahmedabad area and its vicinity poses a health risk.

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Declarations:

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