Heavy metals abundance and distribution in soil, groundwater and vegetables in parts of Aligarh, Uttar Pradesh, India: implication for human health risk assessment

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Anthropogenic activities impact the natural environment, leading to the deterioration of its suitability for living organisms and human health. The present study investigated the concentration and distribution of potentially harmful elements Fe, Cr, Cu, Mn, Ni, Pb and Cd in the soil, groundwater and vegetables, and the consequent human health risk effects. Results revealed high content of Cu (mean = 331 mg kg^{-1}) and Zn (mean = 348.4 mg kg^{-1}) in the soils and exceeded permissible limits. Geo-accumulation Index (I_{geo}) values were high in respect of Cu (I_{geo} = 3.86, 3.16), and Zn (I_{geo} = 2.4, 1.6), indicating pollution in the industrial training institute (ITI) and Gular areas in Aligarh respectively. Groundwater from ITI and Gular recorded maximum content of Cr, Cu, Ni, Mn, Zn, Pb and Cd. Ni and Pb contents exceeded the highest permissible limits. Heavy metal pollution index (HPI) with mean HPI = 806.08 indicated serious groundwater contamination in the ITI and Gular areas. Content of heavy metals in vegetables appeared to be under permissible limit with some exception for Ni and Zn. Finally, the assessment of hazard index (HI) indicated that there was no potential risk to human health upon consumption of vegetables, whereas water ingestion posed serious human health hazard (HI = 2.62) in parts of Aligarh.

Keywords: Groundwater, hazard index, heavy metals, human health risk, soil, vegetables.

HEAVY metal contamination is a matter of serious concern in different countries of the world[1]. The environmental deterioration due to heavy metal contamination, has intensified with the rapid increase of the global population and growth of industrial, agricultural and domestic activities[2]. Diversity and enhancement of heavy metal contamination is concomitant with the industrial revolution, massive urbanization and economic globalization, leading to food security and human health issues[3].

Some heavy metals such as Fe, Cu and Zn are essential for living organisms; but excessive content of these metals may be detrimental to living organisms including the human beings[4,5]. Heavy metals may get enriched due to natural processes such as chemical weathering of minerals or volcanic activity and reach bioavailable levels[4]. However, the most concerning origin of heavy metal pollution is attributed to anthropogenic activities and high levels of contamination that are mainly reported from industrial areas[6,7].

Non-enforcement of strict regulations and/or high cost of treatment processes have prompted most factories, particularly in the densely populated countries not to treat their waste before discharging it into an open land or water bodies. Furthermore, agriculture-related activities such as irrigation from wastewater, addition of sewage sludge (biosolids) and manures to agriculture fields, enhance the bioavailability of heavy metals from the soils and get ultimately transferred to vegetables and/or through groundwater, thus entering the human body via food chain and causing harm to human health[8].

Aligarh has a population of around 1,211,000 (ref. 9). Due to its location in the Indo-Gangetic basin, the primary activity of the population in Aligarh is agriculture, and the total harvested area is around 565,553 ha. However, in recent decades urbanization and industrial activities have rapidly increased. By the end of 2018, large factories and small scale industries numbering 5506 have led to an increase in the built-up area by 6.85% within a span of 15 years[9]. Impact of this increase in industries and urbanization has not been examined in terms of heavy metal contamination and its potential risk to human health. This study assesses the heavy metal pollution in soil, water and plants in Aligarh region and the hazard that may arise from human exposure to heavy metals.

Materials and methods

Study area

Aligarh city lies in the western part of Uttar Pradesh, India (27°35′N and 28°10′N and 77°29′E and 78°36′E). The geographical area is ~3650 sq. km. The study area is an alluvial plain comprising clay, silt, sand and gravels of

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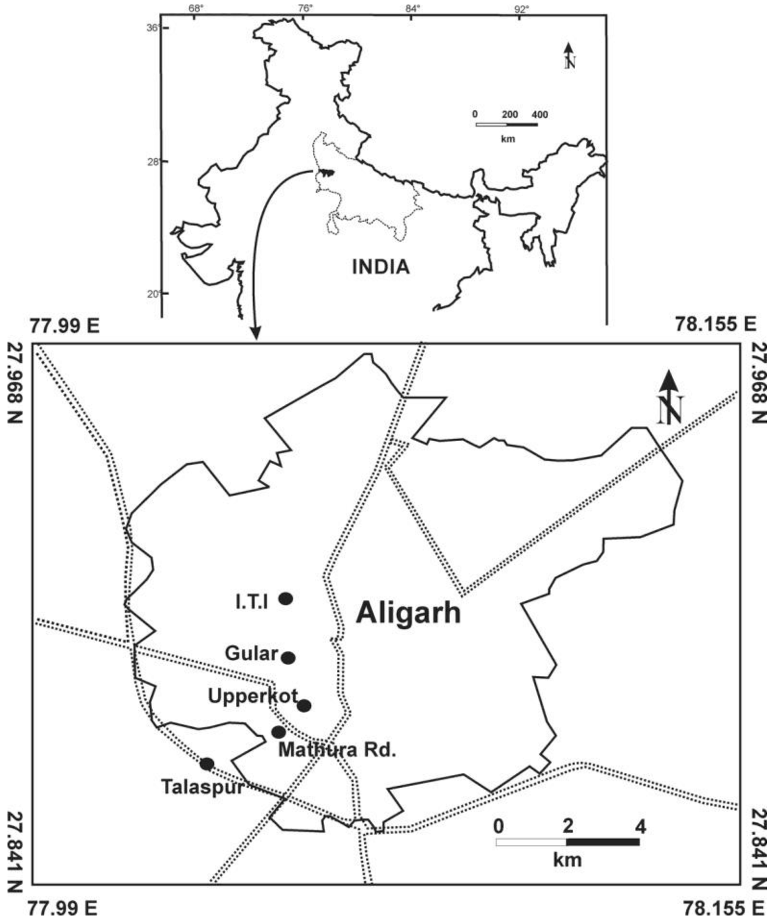

Figure 1. Study area and sample locations.

Quaternary age. Climate is humid, subtropical (typical of North Central India), with monsoon season between June and September. Temperature varies widely from 41°C in June (summer) to 7.6°C in January (winter). The area receives an annual average precipitation of around 750 mm and most of the rainfall (~89%) occurs between July and August during south-west monsoon season.

Sample collection

The field work and sample collection were carried out in February 2018. Soil samples were collected from five locations; Industrial Training Institute (ITI) (S1 and S2), Gular (S3, S4 and S5), Mathura Road (S6), Upperkot (S7) and Talaspur (S8) (Figure 1). These places have different densities of industries with ITI being the densest to Talaspur area being sparse. Soil samples were collected from a depth of about 20–25 cm, each weighing 500 g and stored in clean plastic bags. While collecting the samples, care was taken to remove plant roots and pebbles.

Groundwater samples were collected from dug wells located in the immediate vicinity of the factories. All samples were collected and stored in clean polyethylene bottles of 1 litre capacity and 2–3 drops of HNO_3 were added to the water samples to acidify them (pH <2) to prevent precipitation and adsorption on the bottle walls[10].

The vegetable samples were collected using stainless steel trowel and knife, from the fields. They were also sampled from nearby markets. Approximately 500 g of each vegetable of seven species, namely *Spinacia oleracea* (spinach), *Pisum sativum* (peas), *Solanum tuberosum* (potato), *Brassica oleracea* var. *capitata* (cabbage), *Brassica oleracea* var. *botrytis* (cauliflower), *Chenopodium album* (Bathua) and *Coriandrum sativum* (coriander) were collected. All samples were stored in sealed plastic bags and taken to laboratory for further analysis.

Sample analysis

Soil samples were kept in plastic trays in dust-free place for 2–3 days to dry at room temperature. Dried soil samples were sieved to < 2 mm grain size and powdered using agate mortar for further analysis[11]. Each soil sample (0.5 g) was digested in 10 ml HF, 5 ml HNO_3 and 1 ml $HClO_4$ acid mixture in covered crucibles for 4 h at 90°C on a hot plate. After drying, 5 ml HNO_3 was added to the residue and allowed to dry at the same temperature. After that, 20 ml 1 N HCl was added and heated at 90°C for 30 min. Finally, sample solution was filtered and diluted to 100 ml with double-distilled water.

Vegetables were cleaned using running tap water to remove dust and extraneous particles and chopped into small pieces after removing the non-edible parts. After that, they were dried in an oven at 90°C until a constant weight was achieved[12]. Then, the sample was powdered, homogenized and later ashed in a muffle furnace at 350–400°C. Later, 1 g of sample was mixed with 10 ml HNO_3, 3 ml $HClO_4$ and 2 ml HCl and heated on hot plate (at 60°C) for 30–45 min. Later, 10 ml of 1 N HCl was added to sample, and reheated until the mixture became transparent and was semi-dried. After cooling, the sample was filtered and diluted to 50 ml with double-distilled water.

Content of heavy metals (Fe, Cu, Zn, Pb, Ni, Mn and Cd) in the soil, groundwater and vegetables was determined by atomic absorption spectrometry (Thermo Scientific, M series) at the School of Environmental Sciences, Jawaharlal Nehru University (JNU), New Delhi. For the equipment calibration, certified single element standard solutions (Merck) were used. Additionally, reagent blanks were also used to measure the accuracy and precision of the analysis.

Data analysis

Geo-accumulation index (I_{geo})

The geo-accumulation index (I_{geo}), proposed by Muller[13], is widely applied for assessing and quantifying heavy metal concentration in the sediments[6]. The I_{geo} is calculated using the equation

$$I_{geo} = \log_2(C_n/1.5 \times B_n), \tag{1}$$

where C_n is the concentration of metal in the soil sample, B_n geochemical background value of metal n, after Turekian and Wedepohl[14], and 1.5 was used as a correction factor for possible lithological variations. According to Muller[13], there are seven classes of contamination based on I_{geo} values, viz. class 0 ($I_{geo} \leq 0$) indicating unpolluted, class 1 ($0 < I_{geo} > 1$) unpolluted to moderately polluted, class 2 ($1 < I_{geo} > 2$) moderately polluted, class 3 ($2 < I_{geo} > 3$) moderately to strongly polluted, class 4 ($3 < I_{geo} > 4$) strongly polluted, class 5 ($4 < I_{geo} > 5$) strongly polluted to extremely polluted, and class 6 ($I_{geo} \geq 5$) extremely polluted.

Heavy metal pollution index

This index is normally utilized for evaluating and assessing the overall impact of heavy metals on water quality. Heavy metal pollution index (HPI) is computed using eq. 3 (ref. 15)

$$\text{HPI} = \sum_{i=1}^{n}(W_iQ_i) / \sum_{i=1}^{n}W_i, \tag{2}$$

where W_i is the unit weight of heavy metal, n the number of heavy metals considered, and Q_i is the sub-index of the ith heavy metal and is computed as

$$Q_i = \sum_{i=1}^{n}\left(\frac{M_i}{S_i}\right) \times 100, \tag{3}$$

where M_i is the examined value of the heavy metal, S_i is the recommended standard value for drinking water according to WHO guidelines[16]. The threshold value of HPI is 100, hence HPI value less than 100 can be considered low pollution of heavy metal, whereas HPI value greater than 100 may be considered as polluted water and harmful for human health.

Transfer factor

Transfer factor (TF) is used to evaluate the heavy metal transfer from soil to plants. Other terms, such as bioconcentration factor and the plant uptake factor, are used in quantifying heavy metal uptake by edible parts of the plants[3,11,12]. The heavy metal transfer from soil to plant can be quantified using eq. (4)

$$\text{TF} = \frac{C_p}{C_s}, \tag{4}$$

where C_p is concentration of heavy metal in the plant, C_s is the concentration of heavy metal in the soil. TF > 1 indicates high metal accumulation in plant, TF ≈ 1 indicates non-influential metal uptake and TF < 1 indicates metal is excluded from plant uptake[11].

Health risk assessment

The US environmental protection agency (USEPA) has evaluated the human health risk caused by the daily consumption of contaminated water and vegetables[17]. The exposure of human body to heavy metal occurs via different routes such as via ingestion, inhalation and dermal absorption[12,15]. In this study we only assessed the human health risk due to exposure to heavy metal by direct ingestion of water and vegetables. The exposure assessment is quantified as

$$\text{ADI}_v = \frac{[C \times F \times IR \times E_f \times E_d]}{[BW \times AT]}, \tag{5}$$

$$\text{ADI}_w = \frac{[C \times IR \times E_f \times E_d]}{[BW \times AT]}, \tag{6}$$

where ADI_v (mg/kg/day) and ADI_w (mg/kg/day) reflect average daily intake of metal via ingestion of vegetables

Table 1. Heavy metal concentration in soil, groundwater and vegetables in Aligarh city

	Site no.	Fe	Cr	Cu	Mn	Ni	Zn	Pb	Cd
Soil (mg kg^{-1})	S1	24549	8.34	980.4	563.8	79.2	751.2	125.4	0.11
	S2	34137.6	16.5	435.6	535	75.4	621.4	102.4	0.32
	S3	25851	22.6	209.2	438.6	70.2	255	38.6	0.314
	S4	26976.6	12.73	125.6	563	27.6	157.6	18.4	0.16
	S5	23163	23.89	581.4	599.2	34.6	435	36.6	0.41
	S6	33810	37.9	96.8	550.4	46.2	192.8	42.2	0.461
	S7	30332.4	21.4	27.6	588.4	140.4	242.6	27.6	0.36
	S8	25195.8	26.2	191.4	561.2	33.4	131.8	63.2	0.332
	Mean ±	28001.9 ±	20.32 ±	331 ±	549.95 ±	63.38 ±	348.43 ±	56.8 ±	0.29 ±
	SD	4237.6	9.88	320	49.3	37.18	230.44	38	0.14
	EU[a]	–	140	150	–	75	300	300	3
	ISI[b]	–	–	135–270	–	75–150	300–600	250–300	3–6
Groundwater (mg l^{-1})	S1	–	0.077	0.481	0.015	0.087	2.121	0.03	0.04
	S2	–	0.069	0.435	0.015	0.074	2.00	0.03	0.015
	S3	–	0.054	0.41	0.003	0.065	0.198	0.09	0.00
	S4	–	0.049	0.31	0.003	0.073	0.178	0.08	0.00
	S5	–	0.067	0.27	0.386	0.072	0.423	0.12	0.02
	S6	–	0.062	0.21	bdl	0.051	0.37	0.01	0.00
	S7	–	0.073	0.25	0.349	0.057	0.756	0.1	0.00
	S8	–	0.068	0.36	0.002	0.066	0.138	0.034	0.00
	Mean ±	–	0.6 ±	0.34 ±	0.11 ±	0.07 ±	0.77 ±	0.06 ±	0.01 ±
	SD		0.01	0.10	0.18	0.01	0.82	0.04	0.01
	WHO[c]	0.1	0.5	1.5	1	0.07	5	0.01	0.003
	USEPA[d]	3	0.1	1.3	0.05	0.1	5	–	0.005
	ISI[e]	0.3	–	0.05	0.1	–	5	0.1	0.01
Vegetables (mg kg^{-1})	Peas	127.9	bdl	11.1	21.8	2.05	52	1.4	bdl
	Potato	82.2	bdl	2.6	11.1	bdl	12.5	0.2	0.05
	Cabbage	33.4	0.57	2.45	30.35	0.91	23.25	2.1	0.33
	Cauliflower	103.75	0.88	9.15	38.45	48.95	88.05	0.78	0.126
	Bathua	168	bdl	9.6	78.3	bdl	40.25	bdl	bdl
	Spinach	205.45	0.66	7.4	69.4	1.37	35.05	1.9	0.205
	Coriander	135.35	3.3	4.8	30	9.21	18.5	3.89	bdl
	Mean ±	122.29 ±	0.70 ±	6.73 ±	39.91 ±	13.32 ±	38.51 ±	1.24 ±	0.22 ±
	SD	56.36	0.15	3.48	24.81	23.75	25.69	0.85	0.10
	FAO/WHO[f]	450	–	40	–	–	60	5	0.2
	IS[b]	–	20	30	–	1.5	50	2.5	1.5

bdl, Below detection limit, [a]EU[19], [b]IS[20], [c]WHO[16], [d]USEPA[21], [e]ISI[22] and [f]FAO/WHO[23] are the permissible limit values set by these organizations.

and water respectively, C is the heavy metal concentration in vegetable (mg kg^{-1}), F, conversion factor (0.085) used to convert vegetable from fresh weight to dry weight, IR represents ingestion rate for adults ($0.240 \text{ kg day}^{-1}$ and 2.5 l day^{-1} for vegetable and water respectively), E_f represents the exposure frequency ($365 \text{ days years}^{-1}$), E_d, the exposure duration (70 years), BW, the body weight, and AT represents the average exposure time for noncarcinogens.

Hazard quotient (HQ) is applied to determine the non-carcinogenic risk of heavy metals on human health[17]. The HQ can be quantified as the ratio between estimated dose and reference oral dose of the metal (RfD). The overall non-carcinogenic risk caused by more than one heavy metal can be assessed by Hazard index (HI), which is the summation of non-carcinogenic effects of heavy metals[18].

$$HQ_v = \frac{\mathrm{ADI}_v}{RfD_v}, \tag{7}$$

$$HQ_w = \frac{\mathrm{ADI}_w}{RfD_w}, \tag{8}$$

$$HI = \sum HQ, \tag{9}$$

where RfD_v and RfD_w represent ingestion reference of vegetable and water respectively, HQ_v and HQ_w are the hazard quotients through ingestion of vegetable and water respectively, HI is hazard index and categorized into two levels – $HI < 1$ represents safe or low impact of heavy metals on human health, whereas $HI \geq 1$ indicates greater detrimental risk on human health[12,15].

Results and discussion

Concentration of heavy metals in soil

Soil samples were analysed to determine the concentration of Fe, Cr, Cu, Mn, Ni, Zn, Pb and Cd. The results are shown in Table 1 and Figure 2*a*. The Cu, Zn and Pb, along with Fe showed maximum concentration at the ITI site. The high abundance of these metals may be linked with the waste (solid and/or liquid) produced by lock

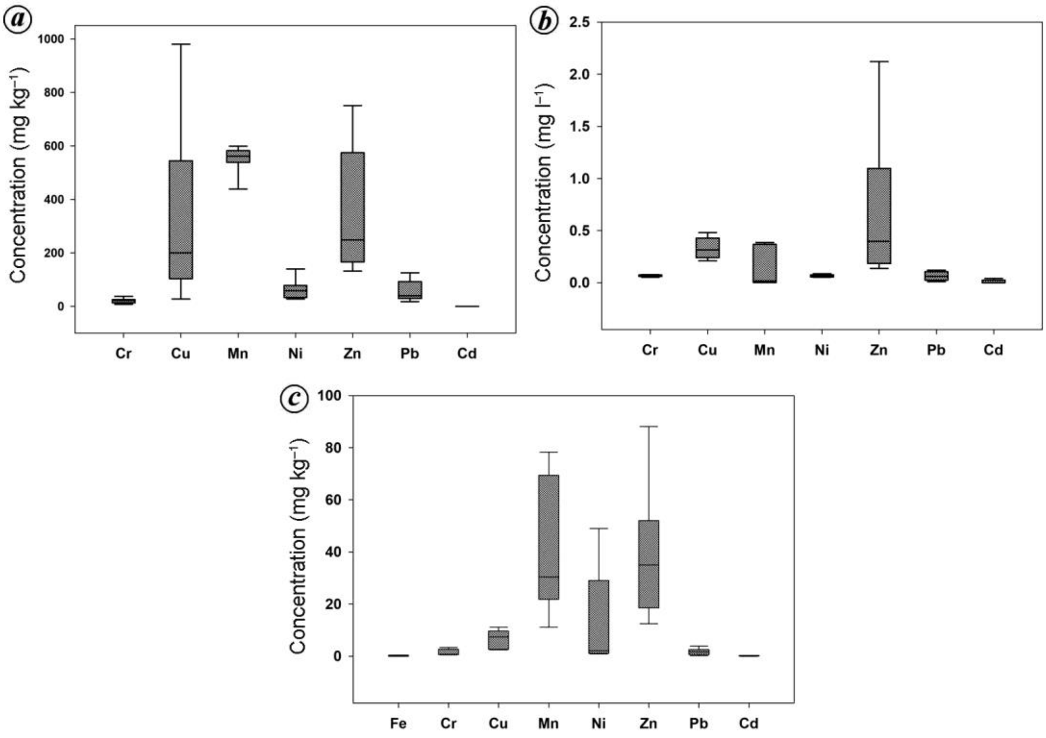

Figure 2. Concentration of heavy metal in (***a***) soil, (***b***) water, (***c***) vegetables.

manufacturing industries in the area. Other metals, viz. Mn, Ni, Cr and Cd recorded their maximum concentrations in other sites (Gular, Talaspur and Mathura Road). However, when compared to the guidelines from standard agencies such as EU[19] and Indian standard (IS)[20], the heavy metal contents in these areas were found to be within standard limits except for Cu and Zn. The Cu concentration exceeded by 62.5%, the standard prescribed by EU and by 37.5% by the IS. The enrichment of Cu in ITI was approximately 5 times the standard limit and two times in Gular. Zn exceeded the standard limit by two times in ITI.

Soil pollution assessment

The I_{geo} is applied for quantifying the intensity of anthropogenic activity contaminating the surface and subsurface soil[6,11]. The result of I_{geo} calculations is given in Supplementary Table 1 and presented in Figure 3 *a*. The calculations revealed that the soil depicted uncontaminated to moderately contaminated status for Cd (0.03) in Mathura Road (S6); Pb content of 0.49 was obtained in Mathura Road (S6), and 0.36 and 0.28 in Gular area (S3 and S5 respectively). The Pb content was classified as moderately polluted in the ITI (S2: 1.07) and Talaspur (S8: 1.7). The highest I_{geo} value of Pb observed was 2.06 (class 3; moderately to heavily polluted) which was recorded in S1 of ITI area. The Zn concentration had maximum I_{geo} values in ITI area, i.e. moderately to heavily contaminated soil. Zn recorded low grade pollution in Gular area (S5), and uncontaminated to moderately contaminated in rest of the sites. However, Talaspur sample (S8) did not show any contamination of Zn. The Ni content in Upperkot area corresponded to uncontaminated to moderately contaminated values. Cu was the most contaminant metal in the soils of the study area. Its I_{geo} values ranged from uncontaminated in Upperkot soil (S7) to heavily contaminated soil with $I_{geo} = 3.8$ and 3.1 in the ITI and Gular areas respectively. In Talaspur and Mathura Road, the soil was moderately polluted to unpolluted with reference to Cu.

The quality of soil indicated serious level of contamination, particularly in case of Cu, Zn and Pb, and to a lesser extent of Cd. This can be directly linked with the industrial activities in the area. Cu and Zn are the primary raw materials used for brass used for lock manufacturing; hence they are the main contaminants in the soils of Aligarh. Paint industry along with deposition from air contributes to the contamination of Pb. Mathura refinery is the major contributor of Pb contaminant via air in the study area.

Concentration of heavy metals in groundwater

Water contaminated by heavy metals could adversely affect human health either by direct ingestion of contaminated water or via the food chain. The results of heavy metal analysis of groundwater are shown in Table 1 and Figure 2 *b*. The maximum content of Cd, Cu, Cr, Ni and Zn was found in the samples from ITI area, and maximum

Table 2. HPI resulting from various heavy metals in groundwater

Heavy metals	Mean (Mi) (mg l^{-1})	Highest permitted value (Si)	Unit weight (W_i = K/Si)	Sub-index Q_i	$W_i \times Q_i$
Cr	0.067	0.1	0.026	58.57	1.54
Cu	0.330	2	0.001	14.73	0.019
Mn	0.151	1	0.003	5.66	0.015
Ni	0.066	0.07	0.038	92.66	3.49
Zn	0.668	5	0.001	116.61	0.061
Pb	0.064	0.05	0.053	135	7.12
Cd	0.01	0.003	0.879	1305	1146.79

$\sum W_i = 1.0$, $\sum W_i \times Q_i = 806.08$, $\sum \text{HPI} = 806.08$.

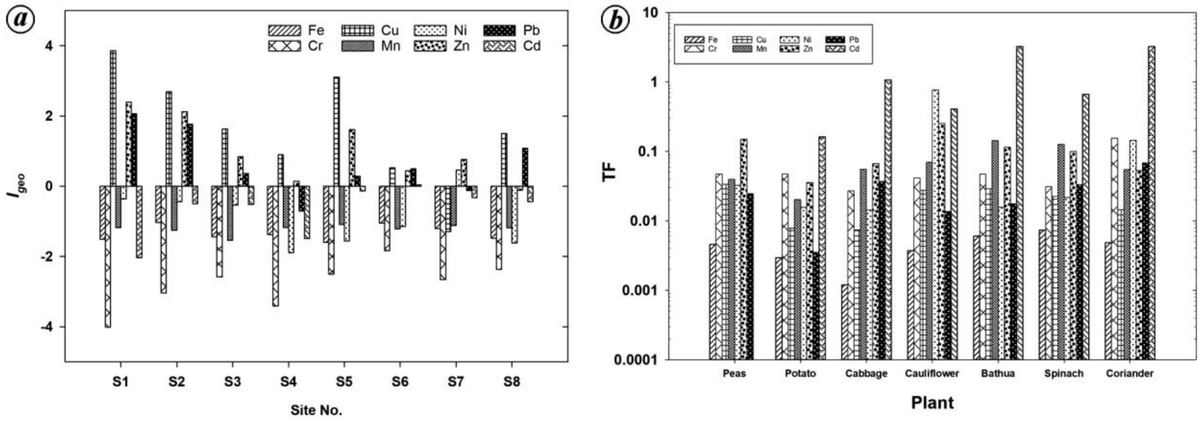

Figure 3. (***a***) Geo-accumulation index (I_{geo}) and (***b***) transfer factor of heavy metals from soil to vegetables.

concentration of Mn was found in water from Gular area. With exceptions for Ni and Pb, the mean value of the other metals were all under permissible limits given by WHO[16], USEPA[21] and the Indian Standard Institution (ISI)[22]. The Ni content recorded in the ITI area was 17% above the highest permissible limit, and Pb content recorded in the Gular area was 28% above the highest permissible limit.

Water pollution assessment

HPI is an effective tool for assessing water quality in any area[15]. The anthropogenic source of contamination is the discharge of industrial and domestic wastewater into rivers or open areas, which could reach the groundwater aquifer via direct percolation or influent process. The HPI value in the study area was 806.08 (Table 2), which exceeded the threshold value of 100 (ref. 11). Accordingly, the HPI calculations indicated critical contamination of groundwater by metals. Consequently, based on the guidelines given by USEPA[21], the water was considered unsuitable for potable use.

Concentration of heavy metals in vegetables

The vegetable samples were analysed to determine the toxicity transferred to the plants from soil, and the results are shown in Table 1 and represented in Figure 2 *c*. The mean metal content values, except for Ni, in different vegetables were under the permissible limits recommended by FAO/WHO[23] and IS[20]. Ni showed concentration above the permissible limit set by IS. This excessive content of Ni was detected in cauliflower, coriander and peas (48.95 mg kg^{-1}, 9.21 mg kg^{-1} and 2.05 mg kg^{-1} respectively). Zn content in cauliflower, compared to FAO/WHO guideline values[23], was found to be above the permissible limit by 46% , and in peas by 4% based on IS guidelines[20]. The maximum content of Pb was detected in coriander and was the only value that exceeded the admissible limit by 55%. Maximum concentration of Cd was found in cabbage in which it exceeded the FAO/WHO[23] guidelines by 65%.

Pollution assessment in vegetables

In order to assess contamination in plants, TF was applied to determine the enrichment of heavy metal from soils to plants (Supplementary Table 2). Cd had the highest TF value among the heavy metals and its maximum content was found in cabbage (1.07), followed by spinach and cauliflower (0.66 and 0.40 respectively). Cauliflower also showed high TF ratio of Ni (0.77). However, the calculated TF ratios for different plants investigated in this study indicated low uptake of heavy metals by plants from soils[24].

Table 3. Potential health risks posed by heavy metals in vegetables and groundwater

Heavy metal	ADI$_v$	ADI$_w$	RfD$_v$	RfD$_w$	HQ$_v$	HQ$_w$
Fe	0.042		0.7		0.059	
Cr	0.0005	0.002	1.5	0.003	0.0003	0.743
Cu	0.002	0.011	0.04	0.04	0.057	0.275
Mn	0.014	0.005	0.14	0.023	0.097	0.219
Ni	0.004	0.002	0.02	0.02	0.212	0.111
Zn	0.013	0.022	0.3	0.3	0.044	0.074
Pb	0.001	0.002	0.004	0.004	0.145	0.533
Cd	0.00005	0.0003	0.001	0.0005	0.048	0.667

$\mathrm{HI}_v = \sum \mathrm{HQ}_v = 0.66$, $\mathrm{HI}_w = \sum \mathrm{HQ}_w = 2.62$.

Human health risk assessment

Human health risk due to exposure to heavy metals was evaluated in the present study following the guidelines of USEPA[17], and the results are presented in Table 3. In this study, it was considered that the human health risk was caused by direct ingestion of water and vegetables. Accordingly the results showed that HQ due to vegetable consumption was less than 1, and the maximum value obtained was for Ni (0.83, with ingestion via cauliflower). The results also indicated non-significant detrimental impact on human health through vegetable consumption, as HI for most metals was less than 1 (HI < 1), except for cauliflower whose composition accounted for human health risk HI = 1.7. Similar results regarding food contamination (HI > 1) were reported from other cities in India and Pakistan due to anthropogenic intervention[25,26]. On the contrary, the assessment of water pollution revealed high risk via water ingestion. Despite HQ values of almost all heavy metals being less than unity (HQ < 1), Cd had recorded HQ values greater than unity in the ITI and Gular areas (2.4 and 1.3 respectively). Further, the HI values calculated from the metal abundances in groundwater were higher than 1 in all the locations (average HI = 2.6) indicating risk to human health. Groundwater in the study area was unsuitable for drinking and domestic use. Groundwater in ITI and Gular areas in particular recorded the highest HI values (4.5 and 4.02 respectively). This might be due to the density of industries in these two locations in comparison to other areas[7].

Conclusion

Investigation of heavy metals in soil, groundwater and vegetables of Aligarh area leads to the conclusion that soil contains the highest proportion of heavy metals followed by plant and groundwater (Supplementary Figure 1). Amongst the five locations from where samples were collected, the soil samples from ITI and Gular recorded higher levels of Cu and Zn contamination. The soil contamination assessed by I_{geo} index confirmed high contamination level in the ITI and Gular areas indicating that contamination might be arising from lock manufacturing industries. Groundwater from ITI area recorded maximum content of Cd, Cu, Cr, Ni and Zn, whereas the maximum content of Mn and Pb was detected in groundwater from Gular area. Among these metals, only Ni and Pb contents exceeded the highest permissible limits set by WHO, USEPA and ISI. Nonetheless, HPI calculations revealed critical contamination of groundwater and unsuitability for domestic use. In the case of vegetables, all heavy metals except for Ni and Zn, were within permissible limits. Ni and Zn exceeded IS and FAO/WHO standard values in cauliflower, coriander and peas. However, TF ratios for different plants investigated in this study indicated low uptake of heavy metals by the plants from the soils. Thus, human health risk assessment from the data leads to the conclusion that HI less than 1 in case of vegetables indicates abundance of heavy metal in the vegetables of the study area, and has non-significant detrimental impact on human health except from cauliflower. On the contrary, the assessment of water pollution revealed high risk on human health via water ingestion. HI values for water samples were higher than 1 in all the locations (average HI = 2.6) indicating that well water in the study was unsuitable for domestic use.

Declaration of interests. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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1. Golia, E. E., Dimirkou, A. and Mitsios, I. K., Influence of some soil parameters on heavy metals accumulation by vegetables grown in agricultural soils of different soil orders. *Bull. Environ. Contam. Toxicol.*, 2008, **81**, 80–84.
2. Goudie, A. S., *Human Impact on the Natural Environment*, John Wiley, 2018.
3. Rai, P. K., Lee, S. S., Zhang, M., Tsang, Y. F. and Kim, K.-H., Heavy metals in food crops: Health risks, fate, mechanisms, and management. *Environ. Int.*, 2019, **125**, 365–385.
4. Antoniadis, V., Golia, E. E., Liu, Y.-T., Wang, S.-L., Shaheen, S. M. and Rinklebe, J., Soil and maize contamination by trace elements and associated health risk assessment in the industrial area of volos, Greece. *Environ. Int.*, 2019, **124**, 79–88.
5. Khalid, S., Shahid, M., Niazi, N. K., Murtaza, B., Bibi, I. and Dumat, C., A comparison of technologies for remediation of heavy metal contaminated soils. *J. Geochem. Explor.*, 2017, **182**, 247–268.

6. Dotaniya, M. L., Meena, V. D., Rajendiran, S., Coumar, M. V., Saha, J. K., Kundu, S. and Patra, A. K., Geo-accumulation indices of heavy metals in soil and groundwater of Kanpur, India under long term irrigation of tannery effluent. *Bull. Environ. Contam. Toxicol*., 2017, **98**, 706–711.
7. Dwivedi, A. K. and Vankar, P. S., Source identification study of heavy metal contamination in the industrial hub of Unnao, India. *Environ. Monit. Assess.*, 2014, **186**, 3531–3539.
8. Rezaei, A., Hassani, H., Hassani, S., Jabbari, N., Fard Mousavi, S. B. and Rezaei, S., Evaluation of groundwater quality and heavy metal pollution indices in bazman basin, southeastern Iran. *Groundwater Sustain. Dev.*, 2019, **9**, 100245.
9. Thukral, R. K., *Uttar Pradesh District Factbook: Aligarh District*, Datanet India Pvt Ltd, New Delhi, 2020.
10. WEF, Standard methods for the examination of water and wastewater. American Public Health Association (APHA), Washington, DC, USA, 2005.
11. Alam, R., Ahmed, Z. and Howladar, M. F., Evaluation of heavy metal contamination in water, soil and plant around the open landfill site Mogla Bazar in Sylhet, Bangladesh. *Groundwater Sustain. Dev*., 2020, **10**, 100311.
12. Garg, V. K., Yadav, P., Mor, S., Singh, B. and Pulhani, V., Heavy metals bioconcentration from soil to vegetables and assessment of health risk caused by their ingestion. *Biol. Trace Elem. Res.*, 2014, **157**, 256–265.
13. Muller, G., Index of geoaccumulation in sediments of the rhine river. *Geojournal*, 1969, **2**, 108–118.
14. Turekian, K. K. and Wedepohl, K. H., Distribution of the elements in some major units of the earth’s crust. *GSA Bull.*, 1961, **72**, 175–192.
15. Kumar, V. *et al.*, Global evaluation of heavy metal content in surface water bodies: a meta-analysis using heavy metal pollution indices and multivariate statistical analyses. *Chemosphere*, 2019, **236**, 124364.
16. WHO, Guidelines for Drinking-Water quality: First Addendum to the Fourth Edition, Geneva, 2017.
17. USEPA, Regional Screening Level (RSL) Summary Table, Washington DC, USA, 2013.
18. USEPA, Guidelines for the Health Risk Assessment of Chemical Mixtures. Federal Register, 1986, vol. 51, pp. 34014–34025.
19. Holm, O., Hansen, E., Lassen, C., Stuer-Lauridsen, F. and Kjolholt, J., European Commission, Directorate General for Environment, E3, Heavy Metals Waste–Final Report, 2002.
20. Awashthi, S. K., Prevention of food adulteration act no 37 of 1954. In *Central and State Rules as Amended for 1999*, Ashoka Law, New Delhi, 1999.
21. USEPA, Drinking water standards and health advisories. In *EPA 822-R-09-011* (ed. Water, O. O.), Washington, DC, USA, USEPA, 2009.
22. Kumar, M. and Puri, A., A review of permissible limits of drinking water. *Indian J. Occup. Environ. Med*., 2012, **16**, 40–44.
23. FAO/WHO, Joint FAO/WHO food standard programme codex alimentarius commission (report of the thirty eight session of the codex committee on food hygiene). In *Codex*, Codex, Adhoc Intergovernmental, Task Force On, Houston, USA, 2007.
24. Mirecki, N., Agic, R., Šunić, L., Milenkovic, L. and Ilic, Z., Transfer factor as indicator of heavy metals content in plants. *Fresen. Environ. Bull*., 2015, **24**, 4212–4219.
25. Khan, K. *et al.*, Heavy metals in agricultural soils and crops and their health risks in swat district, northern Pakistan. *Food Chem. Toxicol*., 2013, **58**, 449–458.
26. Singh, A., Sharma, R. K., Agrawal, M. and Marshall, F. M., Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. *Food Chem. Toxicol*., 2010, **48**, 611–619.

ACKNOWLEDGEMENTS. The authors are thankful to the Chairperson, Department of Geology, AMU, Aligarh and Dr N. Siva Siddaiah and Ms Prerna Joshi, School of Environmental Sciences, JNU, New Delhi for analytical work and cooperation in the lab. We thank the anonymous reviewer for his thorough reading of our article and for his valuable comments and suggestions.

Received 24 May 2021; revised accepted 23 August 2021

doi: 10.18520/cs/v121/i8/1056-1063