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Mobility and health risk assessment of heavy metal contamination in drinking water of peri urban areas of District Muzaffargarh, Pakistan

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Abstract

The present study was conducted to evaluate the status of heavy metals in underground drinking water sources. The health risks of taking heavy metals along with other dissolved elements in drinking water were assessed. A total of 60 underground water samples were collected from the three study sites (Kot Addu, Muzaffargarh, and Alipur). Heavy metals consisting of Pb, Cd, Cr and Nickel along other dissolved elements including cations and anions were determined in underground drinking water samples with the help of 'Inductively Coupled Plasma Mass Spectrometry' and observed results were compared with permissible limits revealed by the World Health Organization (WHO). Beside of these, health risk indicators such as the chronic daily intake (CDI) and the health risk index (HRI) were determined. Our results showed that the concentrations of Cadmium (Cd), Lead (Pb), Chromium (Cr), Nickel (Ni), and Manganese (Mn) which were slightly higher than the permissible limits suggested by the WHO. The values of CDI and the health risk index (HRI) values exceeded the safe limits (>1) in all the water samples collected from three study sites. The above-mentioned analysis shows that ingesting of heavy metals contaminated drinking water causes an incipient health danger to the populations of these localities. Furthermore, it has been observed that both anthropogenic and geologic activities were primary sources of drinking water contamination in the investigated areas.

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Introduction

The whole world is facing three major challenges: a continuously increasing human population, environmental pollution, and the scarcity of pure drinking water. The last serious problem in developed countries and underdeveloped countries is more dangerous because uncontrolled industrial and municipal waste is discharging in water reservoirs, including rivers and canals. Though often overlooked, water is a limited and non-renewable resource that is crucial, basic compounds for the existence of every life on earth, without which life in any form is not possible. The groundwater and surface water resources are interact with each other. Surface water consists of rivers and streams attain significant amount of their flow from groundwater. However, precipitation in the form of rain water is the major source of recharge of ground- water (Yesmeen *et al.* 2018; Abbas *et al.* 2023). Therefore, the two sources of supply are interrelated and the use of one may encounter the water availability from the other source. In Pakistan, drinking water supply is entirely based on ground- water sources. Apart from drinking, it is obvious that groundwater utilization for agricultural practices is increasing exponentially in all over the country. The utilization of ground- water for irrigation has been increased consistently over the years from forty percent during the early 1980s to about eighty percent in recent past (Zakir *et al.* 2020; Tansar *et al.* 2023). While the surface water resources are mostly derived through river systems and their tributaries, which are mostly consumed for irrigation drives. But unfortunately the degree of level of deterioration of surface water bodies is comparatively higher because bulk of untreated sewage sludge from industries and municipal wastes are released in to aquatic ecosystem (Tabassum *et al.* 2019; Shams *et al.* 2020). Similarly, application of pesticides and fertilizers in agricultural drives also cause deposition of metal element in aquatic ecosystems (Ogunlade and Agbeniyi, 2011; Gebeyehu and Bayissa, 2020; Abbas *et al.* 2021). Therefore, quality evaluation for both groundwater and surface is crucial before their utilization. Physio-chemical investigation of water is an imperative part of hydrogeological research work. Currently, contamination of ground and surface water by different inorganic elements is a serious risk for all over the world. Most of published research work reported that Cd, Pb, Zn, Cr, As, Cu, As, K, Mn, Fe, K, Cl, HCO 3 and Sulphar dioxides are inorganic pollutants in the surface and groundwater of Pakistan (Mehmood *et al.* 2019). Third-world countries have limited resources in term of disposing properly their sewage waste. Pakistan is also facing number of environmental issues consisting of contamination of water quality and aquatic ecosystem. Traditional remediation procedure could not eliminate these heavy metals. When contaminated water is used for irrigation purposes, these heavy metals are accumulated in food crops (Siddiqui *et al.* 2017). Humans receive these toxic metals through diverse exposures. i.e. ingestion, breathing and dermal contact. Beside of these, some heavy metals are essential for human health and balance nutrition (Aftab *et al.* 2023), surplus usage of these heavy metals and other toxic elements can cause adversarial health effects, like cancer, lungs disease, hypertension, gastrointestinal hemorrhage, renal problems and neurological disorder (Khan *et al.* 2015; Zakir *et al.* 2020). Therefore, numerous scientists, all over the world studied on impact of heavy metals on quality of water and human health risks caused by contaminated waters: Gelaye and Musie, (2023) conducted research work in Ethopia; Briffa *et al.* (2020) documented inorganic pollutants that discarded in water reservoirs, soils and atmosphere from industries causing hazardous impacts on human health. Batool *et al.* (2023) made studies in Sahiwal to examine the health risk associated with heavy metal contaminated water used for agriculture drives; Khan *et al.* (2023) conducted research work in Bakhar, Pakistan to evaluate effect of sewage wastewater irrigation on food crops and human health; Atta *et al.* (2023) established field trail to evaluate the effect of wastewater irrigation on vegetables and human health; Abbas *et al.* (2021) established experiment to evaluate the health risk assessment of trace elements in ground/surface water of Kot Addu, Pakistan. However, Muzaffargarh district is prominent and well known in South Punjab, Pakistan, for the production of various kinds of cash crops and vegetables. Agrarian concerns in this area utilize both surface and groundwater. Moreover, most of the people in this area depend on reservoirs of groundwater as a source of drinking water. Previous investigations described that Mn and Fe are naturally occurring and predominant contaminants in groundwater (Akter *et al.* 2018; Zakir *et al.* 2018). Most of the researchers have categorized both surface and groundwater on the bases of presence of cations, anions and pH of water. Despite of these, current research work has been conducted to provide a complete picture of the quality of surface and groundwater and to evaluate the carcinogenic and non-carcinogenic health risk to the peoples harboring in the area under observation.

Materials and methods

Water sampling

Before sampling, a comprehensive survey of all the sites was conducted to meet the objectives of the research. A total of 60 samples were collected from various sites of the study area for water quality analysis during morning hours. The geo-climatic data were collected from each study site. The water samples were taken in PVC vitreous silica transparent bottles of 500mL (APHA , 1936), each bottle was the marked and washed with distilled water and sterilized (acid-washed) by following method described by Aftab *et al.* (2023). HNO_3 (2ml drops) was used to preserve the water samples for heavy metals digestion and other laboratory analysis. Nitric acid commonly retarded the adsorption of heavy metal ions (Kumari *et al.* 2014). The water samples were placed in a cool place in the study area and then transported to the Soil and Water Testing Lab, Govt. of Punjab Dera Ghazi Khan. The water samples were filtered through Whatman filter paper (Daud *et al.* 2017) and digested through the methods described by Asante *et al.* (2007) and Momodu and Anyakora, (2010). The water samples were tested for heavy metals (Pb, Cd, Cr, and Cd) by following Li & Zhang, (2010). The Atomic Absorption Spectrophotometer (FAAS; AA6300 Model Japan) was used to analyze the concentration of heavy metals (Cr, Cd, and Pb) by their default option (Tiwari *et al.* 2015). The physicochemical parameters pH, EC was also analyzed according to methods (Hashim *et al.* 2023). Conductivity meter (Jenway- 4510) was used to determine electrical conductivity of water. Its electrode bulb sensor was first calibrated by using standard solution.

Then samples were used for analysis. It was estimated with the help of turbidity meter (HI- 93703) in the field. Each water sample was poured in sample holder and kept for few minutes. When the reading becomes stable, then value was noted. Soluble Phosphates and Sulphate ions were determined by following the standard procedures (Aftab *et al.* 2023).

Human Health risk assessment

Heavy metals pollutants enters into human body through diverse sources, like eating heavy metals contaminated vegetables or taking contaminated drinking water (Ahmad *et al.* 2021a). The 'CDIs' of contaminated was determined by using equation (Daud *et al.* 2017).

'CDI = C × DI / BW'

Health risk Indices (HRI)

"Chronic Health risks' HRI of heavy metals were estimated by using standard equation (Muhammad, N., and Nafees, 2018; Ahmad *et al.* 2021a).

HRI = CDI × RfD.

Determination of Ground Water Contamination Risk

Standard method of determination of 'hazard vulnerability factor (HVF)' was used to delimit the ground water contamination health risk by following Nag *et al.* (2022).

Application of Statistical Approaches

The data obtained from the experiment were statistically analyzed by Minitab, (Version 17.1.0) computer program, for determination of impact of heavy metals on quality of water to describe pictorial water situations (Abbas *et al.* 2023). The presence of heavy metals and health risks were statistically evaluated (Adeel *et al.* 2019).

Results and discussion

Impact of Heavy Metals on Drinking water Quality

Comparisons were made between the chemical analysis results and the drinking water standards set by the Pakistan Environmental Protection Agency and the World Health Organization. As per the findings, the drinking water of Kot Addu (KA), Muzaffargarh (MZ), and Alipur (AP) is free of color, taste, and odor, satisfying the requirements set by the Pakistan Environmental Protection Agency and WHO, and it also has beautiful aesthetic qualities (Table 1). Table 1 presents the variations in cations, anions, and accessible heavy metal content (mg L-1) among the drinking water sources in Kot Addu (KA), Muzaffargarh (MZ), and Alipur (AP). The chemical analysis results showed that differences in the depth of the water source's vicinity among the three locations (KA, MZ, and AP) can be largely responsible for the changes seen in the chemical reactions of water.

Table 1. Descriptive statistical reviews of the mean values and standard deviation (SD) of cations, anions and heavy metals element compositions in water samples collected from Kot Addu (KA), Muzaffargarh (MZ) and Alipur (AP).

		Kot Addu (KA)				Muzaffargarh (MZ)				Alipur (AP)				WHO Standards
Parameters	Units	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	
pH		6.99	8.75	7.64	± 0.51	7.12	8.84	7.74	± 0.59	6.89	8.15	7.34	±0.37	6.5–8.5
EC	(µS/cm)	321	1419	810.12	± 195.5	414	1134	873.5	±215.6	484	1541	927.5	±215.8	400
TDS	(mg/L)	178	1350	538.95	185.42	195	1375	529.5	±215.72	156	950	448.5	±139.5	1000
Ni	(mg/L)	0.027	0.051	0.039	± 0.029	0.014	0.072	0.044	± 0.017	0.013	0.055	0.034	±0.014	--
HCO_3^-	(mg/L)	205	565	153.5	± 90.93	235	558	103.5	±80.5	278	487	159	±97.3	250
NO_3^-N	(mg/L)	0.25	4.7	0.6	± 0.55	0.35	4.25	0.7	±0.25	0.4	4.95	0.75	±0.23	10
Na^+	(mg/L)	55	348	93.87	± 35.06	115	345	88.75	±25.6	55	385	103.87	±26.17	200
K^+	(mg/L)	0.9	34	6.42	± 5.07	2.49	18	7.5	±7.07	5.5	18.2	7.02	±3.07	12
Mg^{2+}	(mg/L)	16	68	15.38	± 18.35	16	68	15.38	±18.35	16	68	15.38	±18.35	50
Fe^{2+}	(mg/L)	0.5	4.86	0.63	± 0.37	0.75	6.65	1.13	±0.57	0.27	3.36	0.87	±0.42	0.3
F^-	(mg/L)	0.14	3.2	1.8	± 0.37	2.12	7.34	3.88	±0.43	0.01	2.15	0.74	±0.23	1.5
Pb	(mg/L)	0.007	0.065	0.049	± 0.012	0.013	0.067	0.039	±0.014	0.005	0.055	0.045	±0.05	--
Cd	(mg/L)	0.05	0.039	0.038	± 0.013	0.09	0.048	0.069	±0.011	0.009	0.069	0.039	±0.014	--
Cl^-	(mg/L)	10.6	195	39.07	± 22.15	23.5	172	45.5	±28.5	18.5	235	54.7	±43.5	250
Cr	(mg/L)	0.034	0.048	0.043	± 0.018	0.029	0.059	0.043	±0.012	0.009	0.054	0.032	±0.011	--
SO_4^{2-}	(mg/L)	72	518	177.6	± 46.32	145	478	247.6	±56.3	92.5	348	176.5	±46.32	250
TH	(mg/L)	28	560	175.8	± 77.33	55	498	185.5	±90.2	45	615	225.3	±185.2	300
Turbidity	(NTU)	0.23	7.12	3.01	± 1.54	0.93	7.28	4.25	±1.54	0.73	6.11	3.47	±1.88	5

The three types of research sites' pH fluctuations were shown to be significantly influenced by the vicinity of the water source, as evidenced by the considerable differences in water's chemical reactions (Table 1; St Dev = ± 0.51, ± 0.59, ± 0.37). In all three research sites, including Kot Addu, a distinct pattern of pH drift was seen in the chemical interactions of drinking water. The drinking water obtained from the three distinct research locations had exchangeable cations (EC µS/cm) ranging from 810.12 to 927.5 µS/cm (Table 1), indicating salty ground water. The WHO (2004) established a tolerable limit of EC 400 µS/cm, which was exceeded by the majority of the studied samples. In Kot Addu, the mean EC value was 810.12 (µs/cm), with a range of 321 to 1419 µs/cm. (KA, Table 1). High EC values (935.5, µs/cm) in Alipur were studied. The results for Muzaffargarh exchangeable cations in subterranean drinking water showed levels that were in between those of the peaks (Table 1). It is not advised to use water as excellent water, even if the WHO and other organizations have not indicated any fresh water permitted limitations for the EC for 2022.

The WHO has set a 200 mg/L Na+ tolerance limit for drinking water. As a result, Table 1 shows that the Na+ of all three locations is within the allowed range. Drinking water collected from three distinct research locations had soluble cations (K+ mg/L) ranging from 0.9 to 34 mg/L, with a mean value of 6.42 mg/L in Kot Addu (KA) KW (Table 1), indicating that the ground water was classed as brine. The majority of the samples that were seen were below the WHO-established acceptable level of 20 mg/L (2004). In Muzaffargarh (MZ), the K+ levels ranged from 2.49 to 18 mg/L, with a mean highest value of 7.5 mg/L recorded there (Table 1). In Alipur, intermediate levels (7.02 mg/L) were noted.

Table 2. Calculated average daily metal intake (ADI) due to ingestion exposure of waters collected from Kot Addu (KA), Muzaffargarh and Alipur area.

		ADI ($x10^{-3}$)											
Variable	Description	Kot Addu (KA) Tehsil				Muzaffargarh				Alipur			
		MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Cd	Adult	0.029	1.943	0.414	±0.582	0.086	1.634	0.456	±0.441	0.029	0.486	0.202	±0.138
	Children	0.036	2.465	0.496	±0.738	0.109	2.073	0.542	±0.559	0.036	0.616	0.256	±0.176
Pb	Adult	0.600	9.343	4.00	±2.838	0.514	15.571	4.137	±4.108	0.486	7.629	1.712	±1.897
	Children	0.761	11.853	5.007	±3.601	0.652	19.755	5.248	±5.211	0.616	9.678	2.433	±2.407
Cr	Adult	0.000	4.257	1.033	±1.280	0.000	6.686	2.186	±1.782	0.000	3.029	0.928	±0.886
	Children	0.000	5.401	1.311	±1.623	0.000	8.482	2.773	±2.260	0.000	3.842	1.177	±1.123
Ni	Adult	0.257	12.714	2.194	±2.934	1.143	17.514	4.319	±4.864	0.171	4.571	1.568	±1.213
	Children	0.326	16.130	2.784	±3.722	1.450	22.220	5.486	±6.171	0.217	5.800	1.989	±1.539
Fe	Adult	1.657	20.400	8.643	±5.446	2.229	19.229	8.612	±5.261	1.600	15.286	7.690	±4.627
	Children	2.102	25.881	10.965	±6.909	2.827	24.394	10.926	±6.674	2.030	19.392	9.755	±5.870
Mn	Adult	1.667	21.799	12.445	±6.153	2.242	19.344	9.072	±5.782	1.610	15.377	7.736	±4.655
	Children	2.115	27.656	15.788	±7.806	2.844	24.541	11.509	±7.336	2.042	19.509	9.814	±5.905

Among these variables, Fe^{+2} values ranges between 0.5 – 4.86 mg/ L and 0.63 mg/L minimum mean value was observed in Kot Addu (KA), similarly maximum values for Fe^{+2} (1.13 mg/L) was recorded in Muzaffargarh and intermediate in Alipur(Table 1). The tolerance limit of Fe^{+2} for drinking water is exceeding according to WHO recommended values (0.3 mg/L; Table 1). As scarcity of pure drinking water, most of population has no preference but to use groundwater considerably for drinking drives without knowing to its appropriateness for drinking. The inadvisable use of the brackish ground water pumped out through tube wells is progressively loading up of a variety of salts including Ca^{+} in our daily food stuff and agro product. The results showed that Ca^{+2} found in all forty five drinking water samples. All water samples showed concentration of iron below the detection limit (Table 1). Considerable Ca^{+2} concentration ranged from 24 mg/L to 152 mg/L with mean concentration of 44.57 mg/L samples collected from Kot Addu (KA). Similar results were recorded in all the water samples collected from the rest. There was no significant differences were detected among sample concentration of Fe^{+2}. Cl , SO4, HCO3 and NO3-N detected in 45 all drinking water samples. Maximum mean values (Table 1, Cl^{-} = 54.7) for Cl ions were recorded in Alipur with ranging from while in 18.5 minimum values - 234 maximum values (St Dev = ± 43.5, Table 1). Minimum mean values were recorded in Kot Addu (KA) for Cl,= 39.07 mg/L (Table 1). The intermediate values were observed in Muzaffargarh (45.5 mg/L). Similarly SO_4, HCO_3 and NO_3^-N were also observed. None of the water sample crossed WHO permissible limit (Table 1). Table (1) describes the concentration of available heavy metals Lead (Pb, mg L^{-1}) present in the drinking water of Kot Addu (KA), Muzaffargarh (MZ) and Alipur (AP). Results of chemical analysis described that much of the variations exist in Pb values detected in drinking water samples collected three sites (*KW, KB and MC*). It was observed that maximum values of Pb concentration (0.049 mg/ L, *St D* = ± 0.012) were recorded in Kot Addu (KA). The values Lead were intermediate in Alipur (0.045 mg/L, *St D* = ± 0.05). It was found minimum in Muzaffargarh (0.039 mg/L, *St D* = ± 0.014; Table 1). The tolerance limit of Pb for drinking water range exceeded from limit guided by WHO. Table (1) describes the concentration of available heavy metals Cadmium (Cd, mg L^{-1}) detected in the drinking water of Kot Addu (KA), Muzaffargarh (MZ) and Alipur (AP). Results of chemical analysis demonstrate that maximum (0.069 mg/L) Cd values was observed in drinking water samples collected from Muzaffargarh study site (*KW*). It was observed that minimum values of Cd concentration (0.038 mg/ L) were recorded in Kot Addu (KA). The tolerance limit of Cd for drinking water range exceeded from limit guided by WHO. Table (1) describes the concentration of available heavy metals Nickel (Ni, mg L^{-1}) detected in the drinking water of Kot Addu (KA), Muzaffargarh (MZ) and Alipur (AP). Results of chemical analysis exhibited that maximum (0.044 mg/L) Ni values was observed in drinking water samples collected Muzaffargarh study site (*KW*). It was observed that minimum values of Ni concentration (0.029 mg/ L) were recorded in Alipur. The values Nickel were slightly higher than Alipur in Kot Addu (KA) (0.039 mg/L). The tolerance limit of Ni for drinking water range exceeded from limit guided by WHO.

Table 3. Calculated Hazard quotients (HQ) values due to intake of heavy metal polluted drinking water samples collected from Kot Addu (KA), Muzaffargarh and Alipur.

		HQ											
		KOT ADDU (KA)				MUZAFFARGARH				ALIPUR			
VARIABLES	DESCRIPTION	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Fe	Adult	0.002	0.029	0.012	±0.0082	0.003	0.027	0.012	±0.0082	0.002	0.022	0.011	±0.0071
	Children	0.003	0.037	0.016	±0.0101	0.004	0.035	0.016	±0.0101	0.003	0.028	0.014	±0.0082
Mn	Adult	0.003	0.044	0.025	±0.0122	0.004	0.039	0.018	±0.0121	0.003	0.031	0.015	±0.0091
	Children	0.004	0.055	0.032	±0.0161	0.006	0.049	0.023	±0.0153	0.004	0.039	0.020	±0.0123
Cr	Adult	0.000	0.003	0.001	±0.0011	0.000	0.004	0.001	±0.0011	0.000	0.002	0.001	±0.0011
	Children	0.000	0.004	0.001	±0.0012	0.000	0.006	0.002	±0.0021	0.000	0.003	0.001	±0.0012
Ni	Adult	0.013	0.636	0.110	±0.1471	0.057	0.876	0.216	±0.2432	0.009	0.229	0.078	±0.0611
	Children	0.016	0.807	0.139	±0.1861	0.072	1.111	0.274	±0.3091	0.011	0.290	0.099	±0.0771
Pb	Adult	0.150	2.336	0.987	±0.7102	0.129	3.893	1.034	±1.0271	0.121	1.907	0.480	±0.4741
	Children	0.190	2.963	1.252	±0.9001	0.163	4.939	1.312	±1.3032	0.154	2.420	0.608	±0.6021
Cd	Adult	0.029	1.943	0.414	±0.5821	0.086	1.634	0.456	±0.4411	0.029	0.486	0.202	±0.1381
	Children	0.036	2.465	0.496	±0.7382	0.109	2.073	0.542	±0.5591	0.036	0.616	0.256	±0.1761

Assessment of human health risk

Taxation of human health risk consists of the determination of the nature and magnitude of adverse health effects in humans because of exposure to toxic contaminants. In the current investigation, carcinogenic and non-carcinogenic health risks assessment through ingestion of water were done and calculated the average chronic daily metal intake (CDI) due to ingestion of waters collected from the study area. In the present research work the results exhibits the values for the chronic daily intake (CDI), the average daily intake dose, (ADI) for the ingestion pathway in the three study sites: Kot Addu (KA), Muzaffargarh and Alipur in Table 2 for both children and adults. The results presented that the ADI values were considerably high than the reference dose as recommended by WHO or other international agencies. Results (Table 2) exhibited that ADI for Cd was highest in the water samples collected from Muzaffargarh (0.456) in adults and (0.496) in children. Minimum vales of ADI were recorded in water samples collected from Kot Addu (KA) and in between values for Cd were in Alipur. ADI values for Pb were recorded maximum (4.137) in Adults, taking the water of the Muzaffargarh, lower values for Childs were found in Alipur (1.712) and intermediate values for Pb were observed in Adults harboring in Kot Addu (KA) (4.000). Similar trends were also observed in Childs, maximum ADI values were 5.248 among the Muzaffargarh (Table 2).

Evaluation of non-carcinogenic health risk

Using the Hazard Quotients Equation (HQ), the possible non-cancer health hazards associated with consuming heavy metal-polluted waterways were ascertained. In order to observe the non-carcinogenic impacts on health, adults and children were chosen. The target group was thought to consist of adults and children. The Pb values for HQ measured in Muzaffargarh varied from 0.086-1.634 with an average of 0.456, St Dev.0.441, while the estimated HQ oral values observed by the current research ranged from 0.029-1.939 with an average of 0.347 of Pb in Kot Addu (KA) (Table 3). Because of its anionic nature, chromium may be eliminated from water samples with an acidic pH. Therefore, it was discovered that the concentration of chromium (Cr) was significantly lower in Kot Addu (KA) and Muzaffargarh than it was at Kot addu. Water samples with significant concentrations of nickel ions are contaminated with heavy metals.

The nickel content analysis results for the water samples taken from three distinct research locations were displayed in Table 3. On the other hand, Muzaffargarh demonstrated high nickel values in terms of HQ indicators. Higher intake concentrations of nickel relative to the recommended levels (HQ > 1) may be the cause of non-carcinogenic health problems in the adult and pediatric populations. There were notable variations between "Fe" and "Mn" in terms of daily consumption.

Table 4. Calculated Cancer Risk (CR $\times 10^{-3}$) per unit time (1 L/day for a child and 2.2 L/day for an adult) values due to intake of heavy metals polluted drinking water samples collected from Kot Addu (KA), Muzaffargarh and Alipur.

		Kot Addu (KA) District				Muzaffargarh				Alipur			
		MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Cd	Adult	0.17	11.85	2.12	±2.66	0.52	9.97	2.60	±2.69	0.17	2.96	1.23	±0.84
	Children	0.22	15.04	2.69	±3.37	0.66	12.65	3.30	±3.41	0.22	3.76	1.56	±1.07
Pb	Adult	0.00	0.13	0.03	±0.03	0.00	0.13	0.04	±0.03	0.00	0.06	0.02	±0.02
	Children	0.01	0.17	0.04	±0.03	0.01	0.17	0.04	±0.04	0.01	0.08	0.02	±0.02
Cr	Adult	0.00	3.34	0.59	±0.72	0.00	3.34	1.09	±0.89	0.00	1.51	0.46	±0.44
	Children	0.00	4.24	0.86	±0.91	0.00	4.24	1.39	±1.13	0.00	1.92	0.59	±0.56
Ni	Adult	0.14	14.71	2.22	±2.88	0.96	14.71	3.63	±4.09	0.14	3.84	1.32	±1.02
	Children	0.18	18.66	2.82	±3.65	1.22	18.66	4.61	±5.18	0.18	4.87	1.67	±1.29
Fe	Adult	0.80	10.20	4.16	±2.51	1.11	9.61	4.31	±2.63	0.80	7.64	3.84	±2.31
	Children	1.01	12.94	5.27	±3.19	1.41	12.20	5.46	±3.34	1.01	9.70	4.88	±2.93
Mn	Adult	0.80	10.90	4.91	±2.91	1.12	9.67	4.54	±2.89	0.80	7.69	3.87	±2.33
	Children	1.02	13.83	6.23	±3.69	1.42	12.27	5.75	±3.67	1.02	9.75	4.91	±2.95

Evaluation of carcinogenic health risk

The carcinogenic health risk of heavy metals consisting of "Cr, Ni, Cd, and Pb" present in drinking water samples were determined in the current investigation which described that the risk of cancer for Ni, Cd, and Pb was insignificant, with average cancer risk factors. The hazard quotients (HQ) for the heavy metals intakes by drinking contaminated water for three study sites was analyzed, calculated and are presented in Table 3. The HQ values for the three study sites were found to be maximum in children as compared to adults while the "Pb" values recorded the highest HQ for both children and adults in water drinking samples collected from Muzaffargarh (1.034 for adult and 1.312 for children, Table 3) . The values of HQ indices for the heavy metal intakes for both adults and children were in the order Pb >Cd> Ni> Cr. However, the Kot Addu (KA) study site trend was also mirror image of Muzaffargarh but magnitude of metals contamination was less than Muzaffargarh. The HQ values for the Kot Addu (KA) were significantly greater than 1 (HQ >1) and may indicate high carcinogenic risk to of the population of Kot Addu (KA), Muzaffargarh and Alipur.

The observed trend may not be unconnected with the high "Pb" and "Cd" producing waste industries in both the Southern and Central districts. The hazard quotients for the heavy metals intakes which were greater than 1 (HQ) signifies that the population would also experience non-cancer risks due to exposure to these heavy metals in drinking water.

Table 5. Chronic daily intake (CDI, mg/kg/day) in different drinking water samples collected from three study sites: Kot Addu (KA), Muzaffargarh and Alipur.

		Kot Addu (KA)				Muzaffargarh				Alipur			
		MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD
Cd	Adult	0.00003	0.00194	0.00034	±0.000214	0.000411	0.00194	0.000429	±0.0005	0.000286	0.000486	0.000200	±0.001
	Children	0.00004	0.00246	0.00043	±0.000471	0.002465	0.00246	0.000544	±0.00072	0.000286	0.000616	0.000254	±0.001
Pb	Adult	0.00010	0.00045	0.00011	±0.000109	0.000257	0.00026	0.000114	±0.0001	0.000429	0.000229	0.036247	±0.003
	Children	0.00018	0.00059	0.00026	±0.000122	0.000326	0.00032	0.000186	±0.0001	0.000486	0.000290	0.037261	±0.003
Cr	Adult	0.00021	0.00668	0.00134	±0.001429	0.004257	0.00425	0.001029	±0.001	0.000571	0.00302	0.000914	±0.000
	Children	0.00029	0.00848	0.00170	±0.001812	0.005401	0.00540	0.001305	±0.0016	0.001943	0.00384	0.001160	±0.001
Ni	Adult	0.00017	0.01751	0.00266	±0.003429	0.012714	0.01271	0.002200	±0.029	0.000171	0.00457	0.001571	±0.001
	Children	0.00022	0.02222	0.00337	±0.004350	0.016130	0.01613	0.002791	±0.003	0.000217	0.00580	0.001994	±0.001
Fe	Adult	0.00160	0.0204	0.00831	±0.005029	0.020400	0.02040	0.008657	±0.054	0.001600	0.015286	0.007686	±0.004
	Children	0.00226	0.0258	0.01055	±0.006380	1.213800	0.02588	0.010983	±0.006	0.002030	0.019392	0.009751	±0.005
Mn	Adult	0.00169	0.0218	0.00983	±0.005829	0.021800	0.02180	0.012457	±0.061	0.001600	0.015371	0.007743	±0.004
	Children	0.00289	0.0276	0.01247	±0.007394	1.297100	0.02765	0.015804	±0.007	0.002030	0.019501	0.009823	±0.001

The prime cancer health hazards are associated with Cr and Ni and are commonly occurs in the industrial zone, followed by commercial, residential or educational, and parks, which have comparable HQ values. Beside of these, chromium is extensively used to preserve metal surfaces and for construction materials. Other undetected heavy metals including Fe and Mn, or in somewhat high-pollution areas (For example as mining areas), in addition to the risks posed by other contaminants. A value of HQ < 1 implies no significant non-cancer risks; a value ≥ 1 implies significant non-cancer risks, which increase with the increasing value of HQ or HI.

Cancer risk (CR)

The evaluation of ingestion rate (IR) per unit time—one liter per day for children and 2.25 liters per day for adults—was used to compute the risk of cancer. Tables 3 and 4 present the carcinogenic risk data associated with drinking water contaminated with heavy metals. Table 4 shows the cancer risk (CR) associated with oral consumption of Cr, Cd, Ni, Fe, and Pb in the three research locations. The results showed that children were at a higher risk than adults (Table 4). The CR from Table 4 demonstrated that children had a higher cancer risk than adults and that Pb was a significant contributor to cancer risk from the three study locations of the water collected. The result also showed the maximum concentration daily intake of Pb by means of drinking water by children inhabitant of Muzaffargarh; minimum values for Pb were recorded in Alipur. The children inhabitant in Alipur takes higher concentration of heavy metals by drinking contaminated water than adult. Similar trends were recorded for Pb in Kot Addu (KA). The observed values of Pb in term of "CR" were slightly higher than the Pb values guided by WHO. The results (Table 5) described that the CDI values are considerably higher than the guided dose as suggested by WHO or other international agencies. Outcomes Table 5 showed that the adults' CDI for Cd was 0.000427 mg/kg/day and the children's CDI was 0.000526 mg/kg/day in the water samples taken from Muzaffargarh. Water samples from Kot Addu (KA) had the lowest CDI values, while Alipur had intermediate levels of Cd (0.000200 mg/kg/day for adults and 0.000254 mg/kg/day for children; Table 5). Adults using Muzaffargarh water had the highest CDI values for Pb (0.003624 mg/kg/day); children in Alipur had lower values (0.003726 mg/kg/day); and adults residing in Kot Addu (KA) had intermediate values (0.000186 mg/kg/day). Comparable patterns were also noted in children, with the Muzaffargarh group having highest CDI values of 0.000186 mg/Kg/day (Table 5).

Conclusion

By the consumption of metal contaminated food and water, human health is directly influenced. Surplus amount of heavy metals in drinking water indicates it is not suitable for consumption and not good for health. Higher proportion of various industrial and agricultural activities has been releasing the considerable amount of heavy metals in environment.

Saturation of hazardous and toxic metals elements in the groundwater results contamination of drinking water and soil and also causing serious diseases in the human body. Health risk assessment results shows that the non-carcinogenic risk HQ values were found within the permissible limit (<1), except for children, while carcinogenic risk CR values of all the observed parameters were lower than the maximum threshold CR value (1×10^{-4}). In the study area, there are few water purification plants installed by NGEO's. The treatment plants are installed at very few places and are not properly maintained. People fetch treated water in bottles for drinking. However, due to lack of information and ignorance, most people drink untreated raw water. Furthermore, no treatment plant is installed at water sampling locations. It is concluded that, there is a need for the implementation of efficient water treatment system especially for microbial quality before it reaches the consumer.

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