Desalination and Water Treatment
www.deswater.com
doi:10.5004/dwt.2019.24145

159 (2019) 327–337
August

Potentially toxic elements contamination in water and evaluation for risk assessment in the Rawalpindi, Pakistan

Said Akbar Khan[a], Nayab Abeer[a], Syed Zahid Hussain[a], Said Muhammad[b,c,*], Farheen Jawad[a], Tahseenullah Khan[a]

[a]*Department of Earth & Environmental Sciences, Bahria University, Islamabad 44320, Pakistan, email: saidakbar2008@yahoo.com (S.A. Khan), nayab.abeer@gmail.com (N. Abeer), syedzahid23@live.com (S.Z. Hussain), farheen.jawad@gmail.com (F. Jawad), sirifsaid@yahoo.com (T. Khan)*
[b]*Department of Earth Sciences, COMSATS University, Abbottabad 22060, Pakistan, Tel. +92-91 9221254-6, Fax +92-91 9221228, email: saidmuhammad1@gmail.com (S. Muhammad)*
[c]*National Center of Excellence in Geology, University of Peshawar 25000, Pakistan*

Received 29 March 2018; Accepted 20 March 2019

ABSTRACT

This study examined the groundwater and surface water quality for drinking and irrigation purposes in the Rawalpindi, Pakistan. For this purpose, samples were collected from groundwater (n = 30), surface water (River Soan, n = 27) and wastewater (n = 21). Each sample was analyzed for the physiochemical parameters and potentially toxic elements (PTE) concentrations. Results revealed that groundwater showed the lowest levels of physiochemical parameters and PTE contaminations, followed by the surface water (River Soan) and the highest in wastewater. The PTE contamination's levels in groundwater, River Soan and wastewater surpassed the national environmental quality standards (NEQs) set by Pakistan's environmental protection agency (Pak EPA). Groundwater (hand pump, bore well and tube well) sources were evaluated for the risk assessment of PTE consumption through drinking water. Among drinking water, the highest PTE contaminations were observed in hand pump water that led to higher average daily intake (ADI) (0.079 mg/kg-d) value for Zn and hazard quotient (HQ) value (11.7) for Cd. The HQ values of Cd were > 1 for all sources of drinking water. Higher HQ values of Cd could induce various acute and chronic health problems to exposed human population of study area.

Keywords: Drinking water; Average daily intake; Hazard quotient; Risk assessment; River Soan; Wastewater

1. Introduction

Drinking water is derived from various sources depending availability of groundwater (aquifers) and surface water (lakes, reservoirs and rivers) [1]. Drinking water contamination is a serious natural calamity and public health risk that originates from both anthropogenic (industrial and domestic discharge, wastewater treatment plants, mining and agriculture) and geogenic (weathering and erosion of bedrocks and ore deposits) sources [2–4]. Among these sources, the discharge of industrial wastewater significantly alters water quality characteristics and contributes to water contamination [5,6].

Water quality characteristics are considered as one of the major health-controlling factors and state of disease in the living organisms [7–10]. Water characteristics include physiochemical, biological parameters, and potentially toxic elements (PTE) which are more hazardous due to their poisonousness, non-degradable and bio-accumulative nature. The PTE includes essential elements and non-essential or toxic elements. Essential elements such as nickel (Ni), manganese (Mn), copper (Cu), chromium (Cr),

*Corresponding author.

iron (Fe) and zinc (Zn) are required in a specific amount for normal function of living beings, while their higher concentration could induce harmful effects [11,12]. Toxic elements include lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg) are hazardous for living beings even in minute concentration [13,14]. The harmful effects of these PTE are headache, abdominal pain, vomiting, irritability, hypertension, nausea, kidney, liver and intellectual problems, mental retardation, anemia, nerve damages and problem, heart problem, teratogenesis and carcinogenesis [15].

Human exposures to PTE mainly occur through the oral ingestion of contaminated water [1,16] and food [17]. Determined PTE concentrations in drinking water were used to calculate potential health risk assessment including exposure risk through average daily dose (ADD) and hazard quotient (HQ).

Regular monitoring of water quality offer supportive information of an area health [18]. Therefore, water quality were regularly focused by various studies from both developing and developed countries, e.g. Bangladesh [19], and United States of America [20]. The problem of water contamination is more severe in developing countries due to high population growth rate and low investment on treatment facility. Like other developing countries in neighbor, Pakistan is also facing serious water problem in mega cities [21,22]. For this purposes, the quality and associated health risk [23–28], and pattern [29] of water in Rawalpindi District has been focused by environmental studies. However, these studies had limitations of samples and source either groundwater or surface water in the study area. Groundwater quality showed significant variation with depth [16]. Therefore, this study was aimed to present a complete and detail picture of quality investigation of surface water, groundwater variation with depth and wastewater. Furthermore, the PTE concentrations through drinking water (groundwater) consumption were evaluated for the potential risk assessment and surface water (River Soan) for the sodium adsorption ratio to highlight its significance for irrigation utilization.

2. Materials and methods

2.1. Study area

The study area is comprised in the Rawalpindi District, located in between 33°32'30''–33°34'30'' N latitudes and 73°5'30''–73°10'30'' E longitudes (Fig. 1). River Soan is one the most important River that originates from small village Bun in the foothills of Patriata, Murree. River Soan feed to Simblee Dam (drinking water reservoir of Islamabad) and drain much of Pothohar region. River Soan joined by the Ling stream and Nala Lai near Sihala and Swaan camp, respectively. River Soan is almost 250 km long and joins the Indus River near Kalabagh. River Soan and tributaries feed to local groundwater aquifers and used for irrigation in the Pothohar region. The study area has four seasons with lowest (–3.9°C) winter temperature in January and highest (46.1°C) summer temperature in June with average monsoon rainfall of 790.8 mm.

2.2. Water sampling

Drinking water (n = 30), River Soan (n = 27), wastewater (n = 21) samples having 3–5 replicate were collected from each selected site in April 2016 (Fig. 1). The main and typical drinking water sources; bore well, hand pump and tube

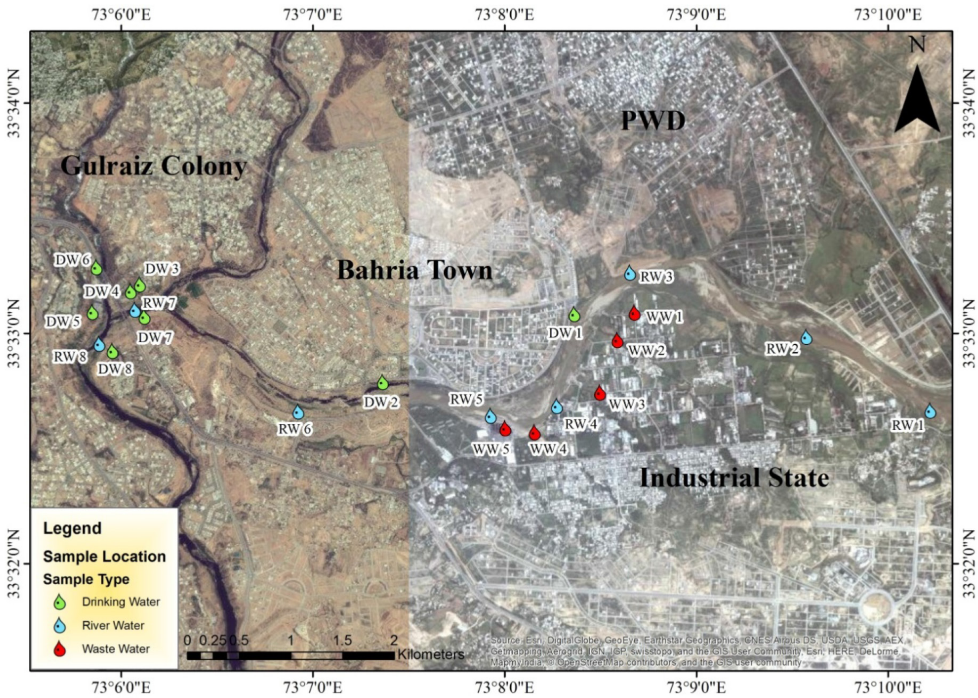

Fig. 1. Sampling location map of the study area.

well were allowed to flow for 5 min before sample collection. Hand pump water occur at depth 25–45 ft, bore well 90–130 ft and tube well 375–600 ft. River Soan water samples were collected at one feet depth and two feet distance from banks facing opposite to flow direction. Wastewater samples were collected from the effluent stream along each industry.

Basic parameters, including pH, total dissolved salts (TDS) and electrical conductivity (EC) measured on-site using the CONSORT C6030 instrument. During sampling, water (1 L each) was collected in two cleaned transparent low-density polyethylene (LDPE) bottles, pre-washed with 10% nitric acid (HNO_3) and deionized (DI). Water in one of two collected bottles from each sampling point was acidified with HNO_3 for preservation. Acidification of sample will reduce microbial activity, precipitation and sorption of PTE to container walls. Each sample was properly marked and transported to the laboratory and stored in dark at below 4°C.

2.3. Chemical analyses, precision and accuracy

Next day, the total suspended solids (TSS) was measured in non-acidified water samples using the filtration and drying method of Whatman filter paper # 42, while the sulfate, chloride (Cl) by the titration methods [30,31]. Filtered and acidified water was used for determination of calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and PTE including Zn, Mn, Ni, Cu, Cr, Fe and Cd by atomic absorption spectrophotometer (AAS, Perkin Elmer, AAS-PEA-700). Each parameter was measured in triplicate under standard optimum conditions of AAS and having r > 0.999 (Supplementary information, SI Table 1). For quality assurance of data, analytical grade reagents and the glassware and new plastic wares were washed with 10% HNO_3 and DI water. The atomic absorption spectrometer results were confirmed with standards of known concentrations of each element with interval of every 10 samples. Results reproducibility and recoveries were observed at 98 ± 10 and 95 ± 8 confidence level, respectively. For result interpretation, the mean values were used.

2.4. Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) is one of the most important parameters for determination of irrigation water quality. The values of SAR were calculated using the equation adopted from the [32]:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \tag{1}$$

2.5. Health risk assessment

Water sources, including hand pump, bore well and tube well are used for drinking and other domestic purposes. Primary health information such as age, gender, literacy rate, income level, water consumption, source and storage was collected during the field. Health information such water consumption and body weight together with PTE contamination was used for health risk assessment.

2.6. Average daily intake (ADI) index

For PTE exposure, the oral intakes through consumption of contaminated drinking water and food are the major pathway as compared to dermal contact and inhalation and can account for more than 90% of human exposure. The ADI value for water consumption was calculated according to the adapted equation [33]:

$$CDI = C \times \frac{DI}{BW} \tag{2}$$

where C, DI and BW represent the concentration of PTE through water consumption (mg/L), average daily water consumption rate (2 L/day) and body weight of individual (72 kg), respectively [21].

2.7. Hazard quotient (HQ) index

Non-carcinogenic risk (HQ) values for through water consumption were calculated from following adopted equation [33]:

$$HQ = \frac{CDI}{RfD} \tag{3}$$

where, according to USEPA database, the oral toxicity reference dose values (RfD) are Cd (5.0E−04 mg/kg-d), Cr (1.5 mg/kg-d), Cu (3.7E−02 mg/kg-d), Mn (1.4E−01 mg/kg-d), Ni (2.0E−02 mg/kg-d), Pb (3.6E−02 mg/kg-d) and Zn (3.0E−01 mg/kg-d) [33]. The exposed population is assumed to be safe when HQ < 1 [21].

2.8. Statistical analysis

Software such as Sigma plot 12.5 used for the arithmetic mean, standard deviation, range and data graphical presentation, statistical analyses such as one-way ANOVA and correlation using SPSS 25 (SPSS Inc., Chi-cago, IL, USA).

3. Results and discussion

3.1. Water quality characteristics

Drinking water showed the highest values for EC followed by TDS and TSS in basic parameters, Cl and Ca in anions and cations, while the lowest for K (Fig. 2a). Among PTE, the highest (2.83 mg/L) concentration was observed for Zn followed by Cu in hand pump water and the lowest (0.02 mg/L) for Cd in tube well water (Fig. 2b). Hand pump water showed the highest concentrations of water quality characteristics. Higher concentrations of these parameters and PTE in hand pump water could be attributed to higher levels of contaminants in wastewater discharged into River Soan water in the study area. Hand pumps water stay close to surface with shallow depth; therefore, the percolation/leaching resulted in enrichment of contamination in water sources. Higher contamination in shallow water (hand pump) of the study was in support of previous study on drinking water in Sadkal, Fateh Jang, Pakistan by Khan et al. [16]. Water quality characteristics including EC, TDS, Ca, Zn and Cu in hand pump only and PTE in all drinking water sources surpassed the national environmental quality

Table 1
Water quality characteristics of this study and previous reported studies on River Soan and Rawalpindi

Location	Source	No	pH	EC	TSS	TDS	SO_4	NO_3	PO_4	Cl	Na	K	Ca	Mg	Zn	Cr	Cu	Pb	Ni	Mn	Fe	Cd	Co	Sr	Coliform	References
Rawalpindi	Wastewater	21	7.5	1.6	594	1066	203			15.1	201	12.7	188	6.0	4.5	1.2	1.4	1.4	0.7	1.4	1.0	0.3				This study
	River Soan	27	6.9	1.1	374	755	105			16.7	54.3	11.2	57.8	5.9	2.2	1.5	1.6	1.8	1.0	2.1	2.8	1.2				This study
	Tube well	12	7.0	0.8	460	560	70.5			84.8	44.5	4.1	45.8	6.0	2.83	0.19	2.23	0.08	0.20	0.60	0.32	0.21				This study
	Hand pump	8	7.1	0.9	360	610	65.8			121	46.7	4.4	60.8	5.7	1.86	0.04	1.20	0.07	0.11	0.91	0.77	0.03				This study
	Bore well	10	7.1	1.3	325	895	99.8			79.8	50.4	4.6	67.1	3.6	1.53	0.98	0.78	0.08	0.07	0.67	0.95	0.15				This study
Chakwal	River Soan	8									62.1	7.56	11.6	10.4										0.23		[24]
Potwar	River Soan	8	8.2	0.63		379	25	2.75	0.45			3.55													212	[25]
Haripur	Khanpur Lake	50									6.46		20.4	10.6	0.02	0.05	0.01	0.22		0.01	0.05	0.02	0.11	0.74		[27]
Rawalpindi	Simly Lake	50									14.9		19.0	10.3	0.03	0.08	0.02	0.20		0.01	0.06	0.02	0.16	0.16		
Rawalpindi/Isb	Drinking water		7.3			911	46.2	0.34	0.02	23.3	103	7.26	92.8	13.6	0.01		0.04	0.17			0.02		0.01			[45]
	River Swan		6.9	0.75		495																				[46]

No denote Number of water samples collected in the study, EC were measured in mS/cm, E. coli in colonies/100 ml and all other water quality characteristic in mg/L

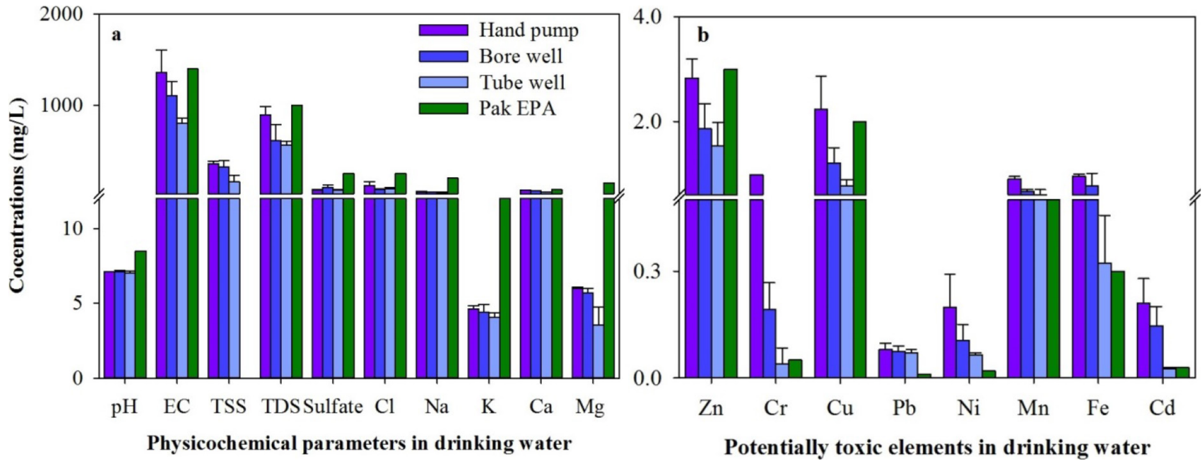

Fig. 2. Physicochemical parameters and potentially toxic elements in drinking water along the study area, *mean unit less and **μS/cm.

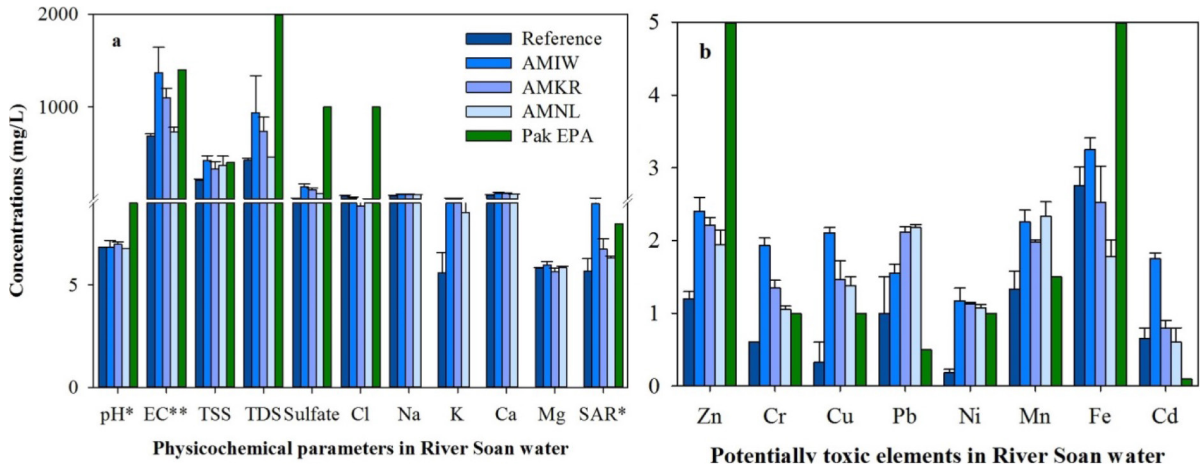

Fig. 3. Physicochemical parameters and potentially toxic elements in River Soan along the study area, reference means background water i.e. before mixing of contaminants in the area, AMIW after mixing of industrial wastewaters, AMKR after mixing of Korang River and AMNL after mixing of Nala Lai stream, *mean unit less and **μS/cm.

standards (NEQs) set by the Pakistan Environmental protection agency (Pak EPA). The water quality characteristics were observed higher than previously reported studies on River Soan and surrounding as reported in Table 1.

In the study area, majority of PTE surpassed their respective NEQs values. Various studies demonstrated that higher concentrations of PTE could induce the chronic and acute toxicity. Toxic effects include vomiting, irritation, abdominal pain, dehydration, drowsiness, lethargy, electrolytic imbalance, nausea, damage to capillaries, lack of muscular coordination, shock and coma, renal failure, inhibition of the synthesis of hemoglobin, joints, reproductive systems, cardiovascular system, skin allergies and lung fibrosis, which further cause lung cancer [21,34–37]. Various studies observed that majority of PTE were ingested through consumption of contaminated food and water [17,38].

River Soan water showed the highest (1366 μS/cm) values of EC followed by TDS and TSS for basic parameters, Cl and Ca for anions and cations, while the lowest for Mg (Fig. 3a). Water quality characteristics of River Soan were the lowest for the upstream reference point and highest after mixing with industrial effluents. This increase trend was due to the mixing of highly enriched contaminants' waste waters. Then the water showed a decreasing pattern for physiochemical parameters and PTE with downstream (3ab). One reason for decrease of physiochemical parameters and PTE was mixing of River Korang and Nala Lai. Another possible reason that PTE could be deposited or accumulated on riverbed sediments along with water flows. All selected physiochemical parameters of the study area were observed within the NEQs of water set by the Pak EPA; however, PTE except Zn and Fe surpassed their respective limits. Higher contamination levels in River Soan could be attributed to local industrial and domestic wastewater without pre-treatment discharge. These higher contaminations in water could induce various toxicological effects on the aquatic ecosystem [39,40]. River Soan showed higher levels of contamination for the majority of PTE than groundwater of the study area. Higher contaminations of surface water as compared to groundwater were consistent with the result of Gul et al. [41] for surface and sub-surface water.

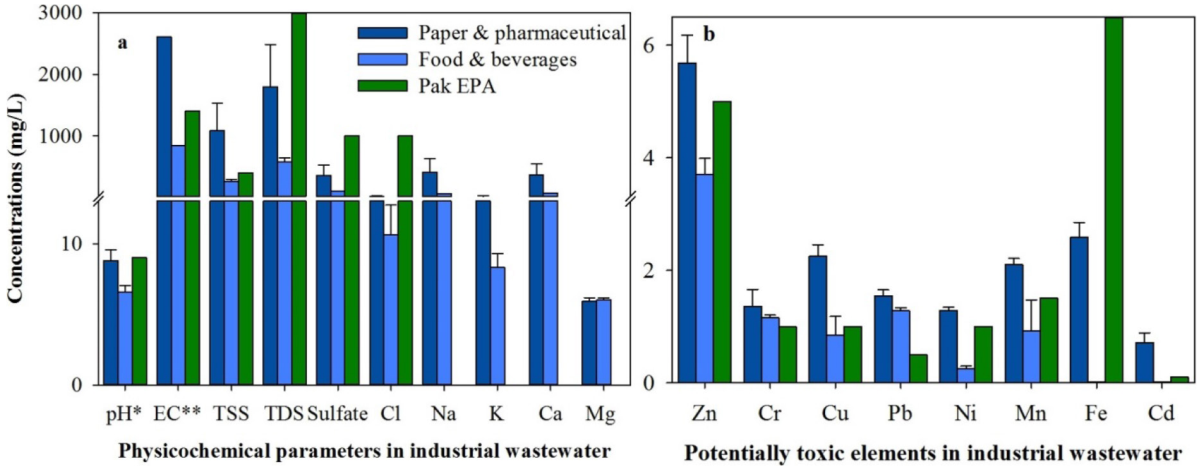

Fig. 4. Physicochemical parameters and potentially toxic elements in wastewater along the study area, *mean unit less and **µS/cm.

Table 2
Health risk assessment through drinking water (groundwater) consumption in the study area

PTE	Hand pump (n = 8)		Bore well (n = 10)		Tube well (n = 12)	
	ADD[a]	HQ[b]	ADD	HQ	ADD	HQ
Zn	0.079 ± 0.010	0.26 ± 0.03	0.052 ± 0.013	0.17 ± 0.04	0.043 ± 0.012	0.14 ± 0.04
Cr	0.027 ± <0.001	0.02 ± <0.01	0.005 ± 0.002	0.01 ± <0.01	<0.01 ± <0.01	<0.01 ± <0.01
Cu	0.062 ± 0.018	0.17 ± 0.05	0.033 ± 0.008	0.09 ± 0.02	0.022 ± 0.003	0.06 ± 0.01
Pb	0.002 ± <0.001	0.06 ± 0.01	0.002 ± <0.001	0.06 ± 0.01	0.002 ± <0.001	0.05 ± 0.01
Ni	0.005 ± 0.003	0.27 ± 0.13	0.003 ± 0.001	0.15 ± 0.06	0.002 ± <0.001	0.09 ± 0.01
Mn	0.025 ± 0.001	0.18 ± 0.01	0.019 ± 0.001	0.13 ± 0.01	0.017 ± 0.003	0.12 ± 0.02
Fe	0.026 ± 0.001		0.021 ± 0.007		0.009 ± 0.004	
Cd	0.006 ± 0.002	11.7 ± 3.82	0.004 ± 0.002	8.06 ± 3.06	0.001 ± <0.001	1.39 ± 0.28

[a]Average daily intake (mg/kg-d)

[b]Hazard quotient

The concentrations of physiochemical parameters' and PTE of waste waters summarized (Fig. 4ab). Selected physiochemical parameters' values were observed within the NEQs set by the Pak EPA, except that of pH and TSS values (Fig. 4a). These higher values of pH and TSS may attribute to paper and marble industries. Effluents of paper and marble industries showed brown and milky white colors, respectively. This high suspended load and enriched carbonates of effluents resulted in higher TSS and pH. Among PTE, Zn showed the highest (5.69 mg/L) concentrations and lowest (0.01 mg/L) for Cd, while rest in between these two extremes (Fig. 4b). The majority of PTE concentrations, including Zn, Cr, Cu, Pb, Ni, Mn and Cd in waste waters surpassed the NEQs of waste waters set by the Pak EPA. Results revealed that concentrations of physiochemical parameters and PTE in waste waters collected from the effluents of paper, and pharmaceutical industries were multi fold higher than that of food industries.

3.2. Sodium adsorption ratio

River Soan water is commonly used for irrigation in Rawalpindi and adjacent area along riverbanks. Therefore, the SAR was calculated for the River Soan water from the concentrations of Na, Ca and Mg. The SAR values of the study were observed within the maximum recommended of irrigation water quality guidelines set by [42], except AMIW site. The quality of irrigation water with high level of Na concentrations are of great concern due to its effects on the soil. The Na could be adsorbed and attached to soil particles making it hard, compact, that resist to watering penetration. Other elements, including Ca and Mg counters the effects of Na. River Soan water in terms of SAR along the downstream making it is suitable for irrigation of agriculture fields [43].

3.3. Risk assessment

Oral ingestion of the PTE through contaminated drinking water consumption is the major (90%) pathway of human exposure. High concentrations of PTE in the drinking water led to their higher intake. The highest (0.079 mg/kg-d) consumption of Zn occurred in hand pump drinking water and the lowest for Cr and Cd (<0.001 mg/kg-d) in the tube well water (Table 2). General tends among drinking water sources; the highest PTE consumption occurred

Table 3
One-way ANOVA comparison of water characteristics in the study area

Parameters		Sum of Squares	Degree of freedom	Mean Square	Factor	Significance
pH	Between groups	1.18	4	0.30	0.32	0.86
	Within groups	14.4	16	0.90		
	Total	15.6	20			
EC	Between groups	1.46	4	0.36	0.33	0.86
	Within groups	17.7	16	1.11		
	Total	19.2	20			
TSS	Between groups	169461	4	42365	0.31	0.87
	Within groups	220372	16	137733		
	Total	2373181	20			
TDS	Between groups	671947	4	167987	0.32	0.86
	Within groups	8429520	16	526845		
	Total	9101467	20			
SO4	Between groups	51825	4	12956	0.74	0.58
	Within groups	282153	16	17635		
	Total	333978	20			
Cl	Between groups	30230	4	7557	8.16	0.00
	Within groups	14811	16	926		
	Total	45041	20			
Na	Between groups	86785	4	21696	0.80	0.54
	Within groups	432014	16	27001		
	Total	518798	20			
K	Between groups	301	4	75.2	1.50	0.25
	Within groups	801	16	50.0		
	Total	1102	20			
Ca	Between groups	67131	4	16783	0.89	0.49
	Within groups	302933	16	18933		
	Total	370064	20			
Mg	Between groups	10.2	4	2.54	3.90	0.02
	Within groups	10.4	16	0.65		
	Total	20.6	20			
Zn	Between groups	22.1	4	5.52	9.55	0.00
	Within groups	9.25	16	0.58		
	Total	31.3	20			
Cr	Between groups	7.47	4	1.87	11.84	0.00
	Within groups	2.52	16	0.16		
	Total	9.99	20			
Cu	Between groups	3.59	4	0.89	1.56	0.23
	Within groups	9.18	16	0.57		
	Total	12.8	20			
Pb	Between groups	11.5	4	2.86	44.20	0.00
	Within groups	1.04	16	0.07		
	Total	12.5	20			
Ni	Between groups	2.57	4	0.64	3.85	0.02
	Within groups	2.68	16	0.17		
	Total	5.25	20			
Mn	Between groups	8.91	4	2.23	7.93	0.00
	Within groups	4.49	16	0.28		
	Total	13.4	20			
Fe	Between groups	26.8	4	6.69	10.58	0.00
	Within groups	10.1	16	0.63		
	Total	36.9	20			
Cd	Between groups	6.95	4	1.74	10.17	0.00
	Within groups	2.73	16	0.17		
	Total	9.68	20			

The mean difference is significant at a level of 0.05; Bold values are significant.

Table 4
Pearson correlation of water quality characteristics in the study area

	pH	EC	TSS	TDS	SO4	Cl	Na	K	Ca	Mg	Zn	Cr	Cu	Pb	Ni	Mn	Fe	Cd
pH	1.000	0.503	0.747	0.507	0.669	0.052	0.775	0.401	0.783	0.151	0.449	–0.056	0.237	0.062	0.279	0.001	0.114	–0.051
EC		1.000	0.786	1.000	0.910	0.002	0.766	0.911	0.693	–0.107	0.226	0.102	0.164	0.178	0.127	0.165	0.260	0.073
TSS			1.000	0.787	0.914	–0.068	0.931	0.709	0.900	0.109	0.334	–0.032	0.195	0.142	0.310	0.173	0.157	0.042
TDS				1.000	0.912	0.006	0.767	0.910	0.694	–0.106	0.231	0.102	0.175	0.172	0.129	0.163	0.255	0.072
SO_4					1.000	–0.127	0.941	0.857	0.904	0.045	0.400	0.166	0.215	0.267	0.307	0.232	0.216	0.085
Cl						1.000	–0.097	–0.284	–0.099	–0.237	–0.199	–0.688	0.000	–0.747	–0.603	–0.529	–0.400	–0.483
Na							1.000	0.711	0.989	0.145	0.435	0.029	0.131	0.208	0.290	0.157	0.124	–0.032
K								1.000	0.641	0.123	0.288	0.356	0.201	0.499	0.382	0.418	0.464	0.302
Ca									1.000	0.114	0.457	0.039	0.114	0.210	0.322	0.164	0.114	–0.043
Mg										1.000	0.313	0.062	0.239	0.294	0.245	0.217	0.071	0.203
Zn											1.000	0.182	0.368	0.255	0.365	0.105	–0.049	–0.090
Cr												1.000	0.205	0.735	0.738	0.698	0.706	0.786
Cu													1.000	0.050	0.454	0.218	0.248	0.358
Pb														1.000	0.742	0.779	0.664	0.600
Ni															1.000	0.810	0.729	0.718
Mn																1.000	0.803	0.769
Fe																	1.000	0.875
Cd																		1.000

Bold correlation is significant at the 0.05 level (2-tailed).
Italic correlation is significant at the 0.01 level (2-tailed).

through hand pump and the lowest through the tube well. Higher intake of PTE occurred through hand pump water were attributed to their higher contamination levels.

Hazard quotient values were the highest (11.667) in hand pump water for Cd and the lowest for Cr (0.001) in tube well water. Higher HQ values for Cd were attributing to its higher toxicity and low RfD values. Chronic risks of PTE were dependent on the toxicity, RfD values and consumption rate [17]. Higher intake of PTE in hand pump water resulted in their higher chronic risk (HQ) values. Results of higher risk of PTE consumption through shallow drinking water were consistent and in support of previous study [41] on drinking water in Mardan, Pakistan.

The oral intake of PTE through contaminated drinking water consumption can account as a major human exposure pathway [16]. In the field survey, we observed respondent with various health problems, including headache, vomiting, diarrhea, dehydration, abdominal pain, fatigue, sleeping disorder, depression, hypotension, hypertension, nausea, hepatitis-A, B, C, kidney, liver and heart problems, and cancer. It has been reported by the PCRWR that drinking contaminated water, and poor sanitation could attribute to 80% of human health diseases and occupies 50% of hospital beds [44]. Therefore, drinking water quality monitoring needs special attention for treatment to provide safe water in the study area.

3.4. Statistical analyses

Statistical comparison of water quality characteristics such as Cl, Mg, Zn, Cr, Pb, Ni, Fe, Mn and Cd in various water sources within the study area showed significant variation ($p < 0.05$) which revealed the sources of contamination greatly varied to the mean pollution level (Table 3). The wastewater may be contributing to high contamination levels in the area and resultantly in contamination of River Soan and shallow groundwater (hand pump). Pearson correlation of water quality characteristics was presented in Table 4. Results showed that many of the water quality characteristics had observed with strong significant correlations. Significant correlations of water quality characteristics include pairs of pH with TSS, SO_4, Na and Ca, Pb with Ni, Mn, Fe and Cd. Strong correlation of pH with TSS and Ca linked with marble industry. Results showed that natural geochemical associated of most water quality characteristics were disrupted. Therefore, the enrichment of contamination resulted from wastewater of industries and domestic in the study area.

4. Conclusions

This study concluded that industrial waste waters are highly contaminated with certain physiochemical parameters and PTE. Results revealed that physiochemical parameters such as pH, TSS, and all selected PTE had surpassed the NEQS set by Pak EPA for wastewater discharge. Wastewater discharge led to the contamination of River Soan. Waste waters and River Soan waters cause leaching or percolation of PTE to groundwater and lead to contamination. The hand pumps are shallow and receive higher levels of contamination as compared to bore well and tube well. Higher contamination levels of hand pump led to higher intake of PTE and resulted in higher potential health risk. Among PTE, the highest HQ values were observed for the Cd through hand pump drinking water consumption that had surpassed the threshold limit. Therefore, this study strongly recommends stopping the use of hand pump water for drinking and other domestic purposes and suggests water treatment of other drinking water sources for PTE.

Acknowledgements

We acknowledge the financial support of Higher Education Commission (HEC) Islamabad, Pakistan.

Conflict of Interest

We all authors declared that there no conflict of interest.

References

[1] J.A. Baig, T.G. Kazi, M.B. Arain, H.I. Afridi, G.A. Kandhro, R.A. Sarfraz, M.K. Jamal, A.Q. Shah, Evaluation of arsenic and other physico-chemical parameters of surface and ground water of Jamshoro, Pakistan, J. Hazard. Mater., 166 (2009) 662–669.

[2] S. Khan, R. Rauf, S. Muhammad, M. Qasim, I. Din, Arsenic and heavy metals health risk assessment through drinking water consumption in the Peshawar District, Pakistan, Hum. Ecol. Risk Assess., 22 (2016) 581–596.

[3] W. Brack, V. Dulio, M. Ågerstrand, I. Allan, R. Altenburger, M. Brinkmann, D. Bunke, R.M. Burgess, I. Cousins, B.I. Escher, Towards the review of the European Union Water Framework Directive: Recommendations for more efficient assessment and management of chemical contamination in European surface water resources, Sci. Total Environ., 576 (2017) 720–737.

[4] M.A. Sabir, S. Muhammad, M. Umar, M. Farooq, Fardiullah, A. Naz, Water quality assessment for drinking and irrigation purposes in upper indus basin, northern Pakistan, Fresen Environ. Bull., 26 (2017) 4180–4186.

[5] M. Kumar, A. Ramanathan, R. Tripathi, S. Farswan, D. Kumar, P. Bhattacharya, A study of trace element contamination using multivariate statistical techniques and health risk assessment in groundwater of Chhaprola Industrial Area, Gautam Buddha Nagar, Uttar Pradesh, India, Chemosphere, 166 (2017) 135–145.

[6] P. Patel, N.J. Raju, B.S.R. Reddy, U. Suresh, D. Sankar, T. Reddy, Heavy metal contamination in river water and sediments of the Swarnamukhi River Basin, India: risk assessment and environmental implications, Environ. Geochem. Health, 40 (2018) 609–623.

[7] T. Kazi, M. Arain, M.K. Jamali, N. Jalbani, H. Afridi, R. Sarfraz, J. Baig, A.Q. Shah, Assessment of water quality of polluted lake using multivariate statistical techniques: A case study, Ecotoxicol. Environ. Saf., 72 (2009) 301–309.

[8] H. Chappells, L. Parker, C.V. Fernandez, C. Conrad, J. Drage, G. O'Toole, N. Campbell, T.J. Dummer, Arsenic in private drinking water wells: an assessment of jurisdictional regulations and guidelines for risk remediation in North America, J. Water Health, 12 (2014) 372–392.

[9] S.P. Luby, M. Rahman, B.F. Arnold, L. Unicomb, S. Ashraf, P.J. Winch, C.P. Stewart, F. Begum, F. Hussain, J. Benjamin-Chung, Effects of water quality, sanitation, hand washing, and nutritional interventions on diarrhoea and child growth in rural Bangladesh: a cluster randomised controlled trial, Lancet Glob. Health, 6 (2018) 302–315.

[10] U. Rehman, S. Khan, S. Muhammad, Associations of potentially toxic elements (PTEs) in drinking water and human biomarkers: a case study from five districts of Pakistan, Environ. Sci. Pollut. Res., 25 (2018) 27912–27923.

[11] U. Saddique, S. Muhammad, M. Tariq, H. Zhang, M. Arif, I.A.K. Jadoon, N.U. Khattak, Potentially toxic elements in soil of the Khyber Pakhtunkhwa province and Tribal areas, Pakistan: evaluation for human and ecological risk assessment, Environ. Geochem. Health, 40 (2018) 2177–2190.
[12] Z. Ullah, A. Naz, U. Saddique, A. Khan, W. Shah, S. Muhammad, Potentially toxic element concentrations and human health risk assessment of food crops in Bajaur Agency, Pakistan, Environ. Earth Sci., 76 (2017) 482.
[13] M. Ishtiaq, N. Jehan, S.A. Khan, S. Muhammad, U. Saddique, B. Iftikhar, Zahidullah, Potential harmful elements in coal dust and human health risk assessment near the mining areas in Cherat, Pakistan, Environ. Sci. Pollut. Res., 25 (2018) 14666–14673.
[14] A. Riaz, S. Khan, S. Muhammad, C. Liu, M.T. Shah, M. Tariq, Mercury contamination in selected foodstuffs and potential health risk assessment along the artisanal gold mining, Gilgit-Baltistan, Pakistan, Environ. Geochem. Health, 40 (2018) 625–635.
[15] M. Moynihan, Role of Diet in Heavy Metal Exposure and Toxicity during Prenatal and Peripubertal Periods, (2016).
[16] S.A.K. Khan, H.K. Khan, M. Ishtiaq, U. Saddique, S. Muhammad, M. Farooq, Shallow water proved higher levels of potentially harmful elements and human health risk along the Sadkal oil exploration and production, Desal. Water Treat., 114 (2018) 146–154.
[17] M.U. Khan, R.N. Malik, S. Muhammad, Human health risk from heavy metal via food crops consumption with wastewater irrigation practices in Pakistan, Chemosphere, 93 (2013) 2230–2238.
[18] M. Rode, U. Suhr, Uncertainties in selected river water quality data, Hydrol. Earth Syst. Sci., 11 (2007) 863–874.
[19] M.M. Rahman, M. Asaduzzaman, R. Naidu, Consumption of arsenic and other elements from vegetables and drinking water from an arsenic-contaminated area of Bangladesh, J. Hazard. Mater., 262 (2013) 1056–1063.
[20] T.J. Sorg, A.S. Chen, L. Wang, Arsenic species in drinking water wells in the USA with high arsenic concentrations, Water Res., 48 (2014) 156–169.
[21] S. Muhammad, M.T. Shah, S. Khan, Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan, Microchem. J., 98 (2011) 334–343.
[22] M. Daud, M. Nafees, S. Ali, M. Rizwan, R.A. Bajwa, M.B. Shakoor, M.U. Arshad, S.A.S. Chatha, F. Deeba, W. Murad, Drinking water quality status and contamination in Pakistan, BioMed. Res. Int., 2017 (2017).
[23] R. Kausar, Z. Ahmad, Determination of toxic inorganic elements pollution in ground waters of Kahuta Industrial Triangle Islamabad, Pakistan using inductively coupled plasma mass spectrometry, Environ. Monit. Assess., 157 (2009) 347.
[24] F. Iqbal, A. Muhammad, A. Salam, Y. Kohkar, Studies on relationship between season and inorganic elements of river Soan at Dhoak Pathan Bridge (Chakwal), Pakistan, Pakistan, J. Biol. Sci., 7 (2004) 93–95.
[25] A. Jalil, K. Khan, Preliminary appraisal of physio-chemical and bacteriological water contaminations in Rawalpindi/Islamabad catchment of Soan river, Potwar plateau (Punjab), Pakistan, Punjab Univ. J. Zool., 27 (2012) 39–44.
[26] J. Iqbal, M.H. Shah, Water quality evaluation, health risk assessment and multivariate apportionment of selected elements from Simly Lake, Pakistan, Water Sci. Technol.: Water Supp., 12 (2012) 588–594.
[27] J. Iqbal, M.H. Shah, Health risk assessment of metals in surface water from freshwater source lakes, Pakistan, Hum. Ecol. Risk Assess., 19 (2013) 1530–1543.
[28] S. Nazeer, M.Z. Hashmi, R.N. Malik, Heavy metals distribution, risk assessment and water quality characterization by water quality index of the River Soan, Pakistan, Ecol. Indic., 43 (2014) 262–270.
[29] A. Butt, R. Shabbir, S.S. Ahmad, N. Aziz, Land use change mapping and analysis using remote sensing and GIS: A case study of Simly watershed, Islamabad, Pakistan, Egypt J. Remote Sens. Space Sci., 18 (2015) 251–259.
[30] M.L. Srivastava, Environmental Chemistry. 81-88658-11-1. Shree Publisher and Distributor; New Delhi, (2004) pp. 119–120.
[31] S. Muhammad, M.T. Shah, S. Khan, Arsenic health risk assessment in drinking water and source apportionment using multivariate statistical techniques in Kohistan region, northern Pakistan, Food Chem. Toxicol., 48 (2010) 2855–2864.
[32] S.C. Nishanthiny, M. Thushyanthy, T. Barathithasan, S. Saravanan, Irrigation water quality based on hydro chemical analysis, Jaffna, Sri Lanka, American-Eurasian J. Agric. Environ. Sci., 7 (2010) 100–102.
[33] USEPA, US Enviornmental Protection Agency, Guidance for Performing Aggregate Exposure and Risk Assessments, Office of Pesticide Programs, Washington, DC., 1999.
[34] T.E. Tuormaa, Chromium, selenium and copper and other trace minerals in health and reproduction, J. Orthomol. Med., 15 (2000) 145–156.
[35] J. Fu, Q. Zhou, J. Liu, W. Liu, T. Wang, Q. Zhang, G. Jiang, High levels of heavy metals in rice (Oryzasativa L.) from a typical E-waste recycling area in southeast China and its potential risk to human health, Chemosphere, 71 (2008) 1269–1275.
[36] M. Ogwuegbu, W. Muhanga, Investigation of lead concentration in the blood of people in the Copper belt Province of Zambia, J. Environ., 1 (2005) 66–75.
[37] A. Åkesson, T. Lundh, M. Vahter, P. Bjellerup, J. Lidfeldt, C. Nerbrand, G. Samsioe, U. Strömberg, S. Skerfving, Tubular and glomerular kidney effects in Swedish women with low environmental cadmium exposure, Environ. Health Perspect., (2005) 1627–1631.
[38] S.K. Egan, P.M. Bolger, C.D. Carrington, Update of US FDA's total diet study food list and diets, J. Expo. Sci. Environ. Epidemiol., 17 (2007) 573–582.
[39] E. Avigliano, N.F. Schenone, A.V. Volpedo, W. Goessler, A.F. Cirelli, Heavy metals and trace elements in muscle of silverside (Odontesthes bonariensis) and water from different environments (Argentina): aquatic pollution and consumption effect approach, Sci. Total Environ., 506 (2015) 102–108.
[40] R. Merciai, H. Guasch, A. Kumar, S. Sabater, E. García-Berthou, Trace metal concentration and fish size: Variation among fish species in a Mediterranean river, Ecotoxicol. Environ. Saf., 107 (2014) 154–161.
[41] N. Gul, M. Shah, S. Khan, N. Khattak, S. Muhammad, Arsenic and heavy metals contamination, risk assessment and their source in drinking water of the Mardan district, Khyber Pakhtunkhwa, Pakistan, J. Water Health., 13 (2015) 1073–1084.
[42] NSWCC/IWQG-Pak, National surface water classification criteria and irrigation water quality guidelines for Pakistan Pub WWF-Pakistan. Ferozpur Road Lahore-54600, Pakistan, (2007).
[43] S. Nagarajah, V. Abeykoon, B. Emerson, S. Yogalingam, Water quality of some wells in Jaffna and Kilinochchi with special reference to nitrate pollution [Sri Lanka], Trop. Agric. (Sri Lanka), (1988).
[44] A. Azizullah, M.N.K. Khattak, P. Richter, D.-P. Häder, Water pollution in Pakistan and its impact on public health—a review, Environ. Int., 37 (2011) 479–497.
[45] S. Mehmood, A. Ahmad, A. Ahmed, N. Khalid, T. Javed, Drinking water quality in capital city of Pakistan, Sci. Rep., 2 (2013) 637.
[46] I. Perveen, M.A. Raza, S. Sehar, I. Naz, B. Young, S. Ahmed, Heavy metal contamination in water, soil, and milk of the industrial area adjacent to Swan River, Islamabad, Pakistan, Hum. Ecol. Risk Assess., 23 (2017) 1564–1572.

Supplementary information

Table SI
Instrumental analytical condition for PTE analyses

Metal	Air (L/min)	Acetylene (L/min)	Slit width (nm)	Wavelength (nm)	Slit width (nm)	Lamp current (Ma)	Limit of detection (mg/L)
K	17.0	2.0	0.7	766.5	0.7	12	0.030
Na	17.0	2.0	0.2	589.0	0.2	8	0.003
Ca	17.0	2.0	0.7	422.7	0.7	10	0.075
Mg	17.0	2.0	0.7	285.2	0.7	6	0.015
Mn	17.0	2.0	0.2	279.5	0.2	20	0.002
Fe	17.0	2.3	0.2	288.3	0.2	30	0.008
Cd	17.0	2.0	0.7	228.8	0.7	4	0.001
Pb	17.0	2.0	0.7	283.3	0.7	30	0.015
Zn	17.0	2.0	0.7	213.9	0.7	15	0.002
Cr	17.0	2.5	0.7	357.9	0.7	25	0.003
Ni	17.0	2.0	0.2	232.0	0.2	25	0.006
Co	17.0	2.0	0.2	240.7	0.2	30	0.009
Cu	17.0	2.0	0.7	324.8	0.7	15	0.002