

*Original Research*

# Health Risk Surveillance of Arsenic in Wastewater, Groundwater, and Agricultural Land along Hudaira Drain, Pakistan Using GIS Techniques

Ambreena Javaid<sup>1,2\*</sup>, Sajid Rashid Ahmad<sup>2</sup>, Abdul Qadir<sup>2</sup>

<sup>1</sup>Kinnaird College for Women, Lahore, Pakistan

<sup>2</sup>College of Earth and Environmental Science, University of the Punjab, Lahore, Pakistan.

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## Abstract

The present study focuses on the health risk assessment and spatial distribution of arsenic in Hudaira Drain and its adjoining areas using GIS techniques. For this purpose, surface water, groundwater, and soil samples were collected from the nine transects across the drain. The results of the present study indicated that two of the examined transects were situated in a high arsenic concentration zone and this area was dominated by industrial activities. A strong correlation at 95% confidence level exists among drain water, ground water, and soil. Furthermore, Hazard quotient (HQ) was calculated and results indicated that about 75% of children and 50% of adults may be affected by arsenic through drinking of groundwater. The presence of arsenic in groundwater, which is a major source of drinking water in this area, may cause excess lifetime cancer risk (ELCR)  $> 10^{-4}$  in 44.4% of the resident human population. There is an urgent need to focus on the arsenic contamination issue in this area in order to protect the groundwater, surface water, and soil resources from arsenic contamination for better human health.

**Keywords:** groundwater, hazard quotient, non-carcinogenic, excess lifetime cancer risk

## Introduction

A major source of toxic elements is the industrial and municipal wastewater that contaminates soil and groundwater. These toxic metals (As, Cd, Cr, Pb, Hg, etc.) ultimately enter the human food chain mainly through drinking water and contaminated food [1].

The crops become polluted due to soil pollution, ultimately putting the adverse effects of metals on human food [2-4]. This intensity of adverse effects is aggravated if non-essential metals are consumed. The non-essential metals are responsible for mutagenesis and teratogenesis, and disrupt the metabolic integrity of the human body [5].

Arsenic is categorized as a non-essential metal found in low concentrations within the environment. Arsenic is present in the earth's crust and is exposed to biological

\*e-mail: ambreena.mubashir@gmail.com

systems through weathering, mining, and excavation [6]. The de-absorption of arsenic from hydroxides of manganese, iron, and aluminum; oxidation of arsenic-carrying sulfides and reductive dissolution of arsenic-bearing iron hydroxides are the major natural source of arsenic in drinking water [7, 8]. In the environment, arsenic is activated due to the combination of various natural processes like weathering, biological measures, volcanic eruptions, and anthropogenic activities [9]. Arsenic combines with other elements and forms compounds of organic and inorganic arsenic. Inorganic arsenic is found in compounds with oxygen, sodium, potassium, copper, chlorine, iron, and sulphur. The organic form of arsenic is formed by the combination of carbon and hydrogen with arsenic in animals and plants. The food that carries organic arsenic is quickly absorbed into the body. Inorganic arsenic is more toxic and can have severe and chronic effects. It is accumulated in the body and becomes more poisonous due to continuous exposure. Arsenic is a carcinogen even at very low levels of exposure, with no possible useful metabolic functions for human beings [10, 11].

Exposure to arsenic-polluted drinking water causes skin, liver, kidney, and lung cancer [12]. Moreover, chronic intake of inorganic arsenic causes skin lesions, including changes in pigmentation – principally on the keratosis of the palm of hands, extremities, and trunk, and soles of feet [13-16]. At the end of the second millennium, in Asia only, water containing arsenic has affected more than 100 million people [17, 18]. Apart from anthropogenic sources, geogenic sources are also one of the major reasons for the arsenic-affected human population [19, 20].

Quantitative risk and exposure analysis have the ability to determine the impartial view of the present status, if variables like chronic daily intake, intake

factor, average body weight, time exposed, frequency, and duration for an entire lifetime are considered. The most affected countries by arsenic from groundwater resources are Bangladesh, Nepal, various Indian states, Pakistan, Cambodia, Myanmar, Vietnam, Lao People's Democratic Republic, China, and Vietnam [17, 21]. In Pakistan, China, and Cambodia, the risk levels have been calculated on the basis of drinking water polluted with arsenic in relevance to chronic exposure. After the arsenic disaster in Bangladesh and other neighboring countries, the government of Pakistan has initiated an assessment of drinking water with the help of UNICEF, which includes the development of various plans to determine and control the arsenic threat to drinking water [22].

A few studies on arsenic pollution in groundwater and its sources have been carried out in Pakistan [23-30]. Arsenic is a burning issue nowadays in Pakistan, but no comprehensive literature about arsenic contamination is available. However, some reports related to arsenic contamination have been documented from various parts of Pakistan. The present study has been carried out to highlight the spatial distribution of arsenic in drain water, groundwater, and soil in order to find its possible risk. This is a first-time effort to highlight arsenic in groundwater, soil, and drain water of Lahore with the help of GIS to identify the arsenic hotspots and sources of arsenic within the vicinity of Lahore.

## Materials and Methods

### Study Area

Hudaira Drain is a 98.6 km-long trans-boundary drain that starts from Indian Punjab. It enters Pakistan

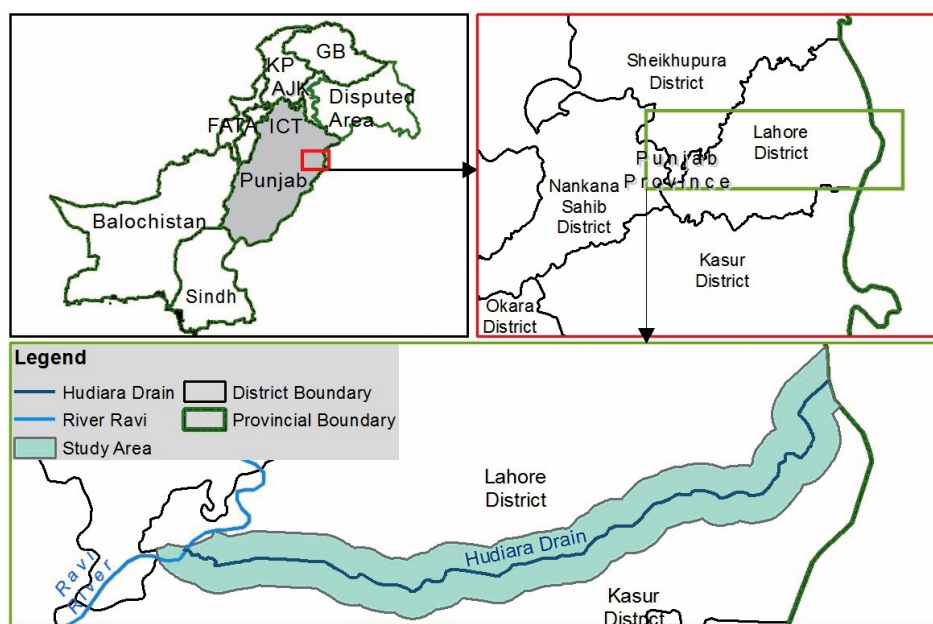


Fig. 1. Map of study area.

Table 1. Sample summary.

Sampling Sites	Source of Samples	Location /Coordinates		Soil type
		X	Y	
Transect 1	DW1, SD1	74.5940	31.4758	Silt loam
	GLP1	74.5896	31.4824	
	GRP1	74.5958	31.4700	
	GLE1, SBLE1	74.5789	31.4878	Loam
	GRE1, SBRE1	74.5978	31.4646	Loam
Transect 2	DW2, SD2	74.5569	31.4441	Silt loam
	GLP2	74.5554	31.4492	
	GRP2	74.5555	31.4384	
	GLE2, SBLE2	74.5522	31.4529	Loam
	GRE2, SBRE2	74.5533	31.4334	Silt loam
Transect 3	DW3, SD3	74.4988	31.4426	Loam
	GLP3	74.4973	31.4471	
	GRP3	74.4970	31.4376	
	GLE3, SBLE3	74.4934	31.4520	Silt loam
	GRE3, SBRE3	74.4948	31.4331	Silt loam
Transect 4	DW4, SD4	74.4451	31.4216	Silt loam
	GLP4	74.4437	31.4261	
	GRP4	74.4434	31.4171	
	GLE4, SBLE4	74.4573	31.4366	Loam
	GRE4, SBRE4	74.4425	31.4104	Loam
Transect 5	DW5, SD5	74.3925	31.3999	Silt loam
	GLP5	74.3908	31.4044	
	GRP5	74.3906	31.3954	
	GLE5, SBLE5	74.3860	31.4087	Loam
	GRE5, SBRE5	74.3878	31.3908	Silt loam

near the village of Lallo after traversing 44.2 km through India and falls into the Ravi River in Pakistan [31]. The location of the drain in Pakistan is 31.4 (31°23'42"N) latitude and 74.13 (74°8'1"E) longitude (Fig. 1). In this region, a chain of aquifers is found which are limited in number. Most of these aquifers are not in geologic contact with surficial aquifers [32]. These aquifers are unconfined in nature [33]. This area receives an average 650 mm rainfall; out of 650 mm, 65% rain falls during the southwestern monsoon (June to September) and 20% of rain falls during the northeastern monsoon. The remaining 15% of rain falls during winter. The drain flows over alluvial deposits of the Ravi. Due to the discharge of untreated industrial effluents and sewage, this rainstorm water stream is converted into a polluted wastewater drain [34-37]. Untreated industrial effluents of roughly

Transect 6	DW6, SD6	74.3335	31.3905	Silt loam
	GLP6	74.3524	31.3950	
	GRP6	74.3315	31.3862	
	GLE6, SBLE6	74.3268	31.4005	Silt loam
	GRE6, SBRE6	74.3495	31.3791	Silt loam
Transect 7	DW7, SD7	74.2803	31.3790	Silt loam
	GLP7	74.2793	31.3846	
	GRP7	74.2778	31.3751	
	GLE7, SBLE7	74.2717	31.3912	Silt loam
Transect 8	GRE7, SBRE7	74.2738	31.3719	Silt loam
	DW8, SD8	74.2235	31.3933	Loam
	GLP8	74.2222	31.3991	
	GRP8	74.2207	31.3894	
Transect 9	GLE8, SBLE8	74.2328	31.3989	Loam
	GRE8, SBRE8	74.2160	31.3865	Silt loam
	DW9, SD9	74.1622	31.4000	Loam
	GLP9	74.1605	31.4044	
	GRP9	74.1593	31.3951	
	GLE9, SBLE9	74.1518	31.4075	Loam
	GRE9, SBRE9	74.1542	31.3895	Silt loam

Where:

DW = Drain water samples

GRP = Groundwater samples on right side of drain at half km

GLP = Groundwater samples on left side of drain at half km

GRE = Groundwater samples on right side of drain at one km

GLE = Groundwater samples on left side of drain at one km

SD = Soil samples on drain

SBRE = Soil samples on right side of drain at one km

SBLE = Soil samples on left side of drain at one

120 different industries are discharged in this drain. 178 cusecs/5.04m<sup>3</sup> per second of untreated industrial effluent and sewage waste are discharged annually in this drain [38]. There are four tributaries of Hudaira Drain: Minhala Drain, Charrar Drain, Ferozepur Road Drain, and Sattu Katla Drain. Sattu Katla is the largest tributary of Hudaira Drain of the above four. There are two other drains discharging into Sattu Katla: the Link Sattu Katla Drain and College Road Drain [39].

### Field Survey

An exclusive field survey was conducted for the sampling of drain water, groundwater, and soil from 31 March to 11 April 2015 (pre-monsoon), followed by another survey commencing from 23 to 31 October 2015 (post-monsoon) for drain water and groundwater only. Pre-monsoon and post-monsoon values were

analyzed to get the mean value used in this study. Soil samples were not collected again in post monsoon season because the properties of soil do not change so frequently. These samples were tested and then mapped through different GIS techniques. Finally, the results were analyzed to assess the spatial concentration of arsenic level in the study area. The arsenic standard units for drain water, groundwater, and soil are 1000 ppb or  $\mu\text{g/L}$  (NEQS), 10ppb or  $\mu\text{g/L}$  (WHO), and should not exceed 3.9 mg/kg (FAO).

### Sampling Techniques

The decision of sampling sites was carried out on the basis of heterogeneity of anthropogenic and natural factors. In this regard, a comprehensive preliminary survey was conducted, and information related to the study area was also collected. Discussions related to properties of soil and water with different experts like environmentalists, government, and non-government concerned persons led to the decision for buffer zones and sample intervals. The locations of the samples were

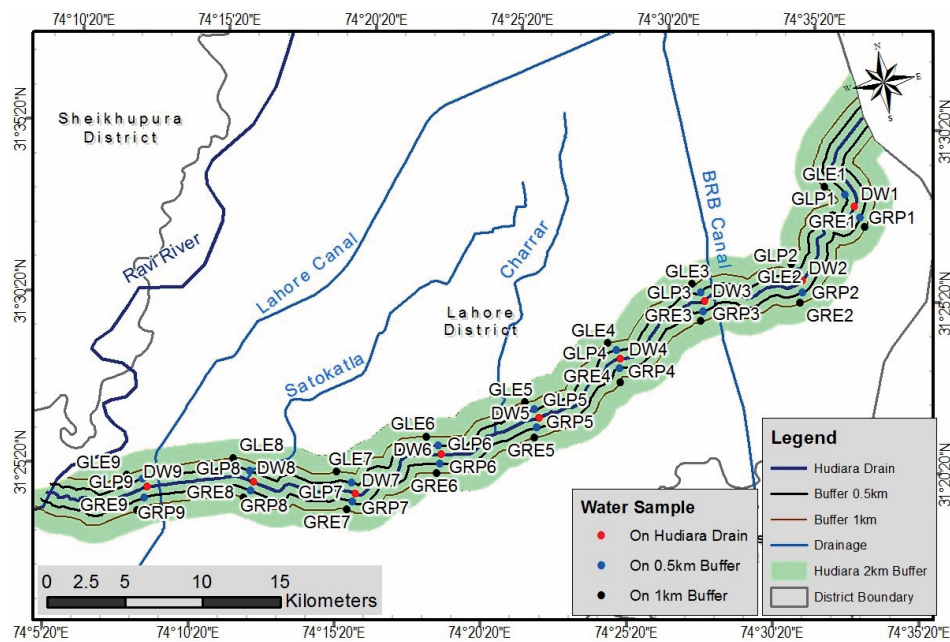


Fig. 2. Sample sites for drain water and groundwater.

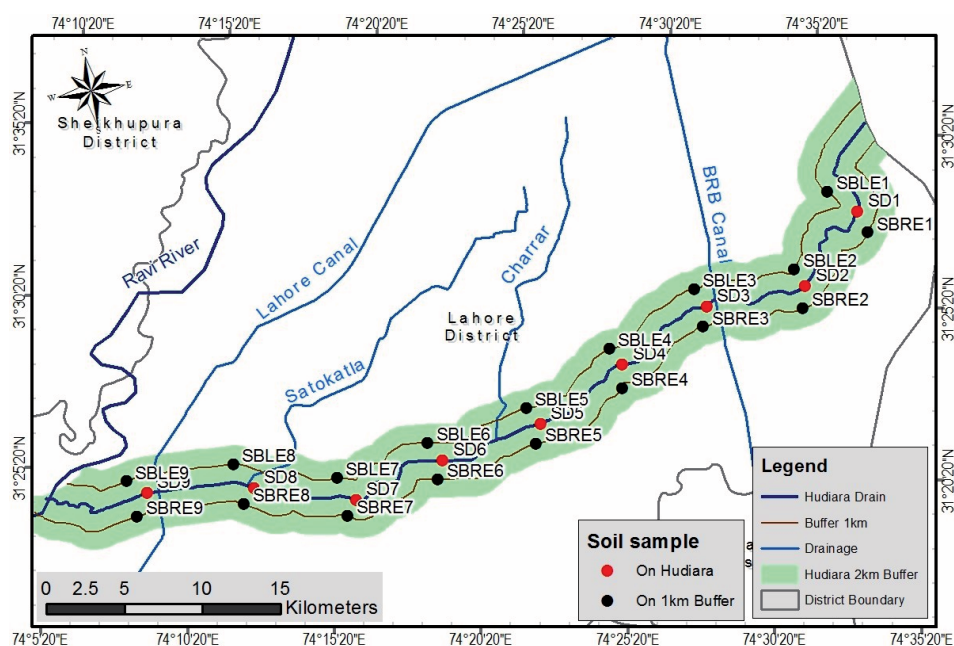


Fig. 3. Sample sites for soil.



identified or traced with the help of GARMIN eTrex 30 GPS. A systematic sampling technique was used to mark the sampling sites (Table 1). Two buffer zones were selected at 0.5 km and 1 km on both sides from the main Hudaira Drain. Samples from the drain were taken every 3 km. 20 drain water samples were collected from the main Hudaira Drain through grab sampling procedure.

Water samples were taken from 0.5 km buffer zone and 1 km buffer zone on both sides of the main Hudaira drain at a distance of 6 km along the drain. A total of 36 water samples were collected from both sides of the drain. For the collection of tap water, the mouth of the tap was heated for 1-2 minutes and then water was allowed to run for 5 minutes. For microbiological analysis, plastic bottles of 200 ml capacity were used to collect the samples of water. In the microbiological analysis, only the absence or presence of *E. Coli* was checked. These samples were kept in an icebox and brought to the laboratory within the recommended time period. Tap water was also collected in 0.5 L plastic sampling bottles. Proper code numbers were labeled on all bottles before analysis in the laboratory. Samples were immediately preserved by adding 2 ml/L concentrated nitric acid ( $\text{HNO}_3$ ) as per APHA-AWWA-WEF [40]. Different analyses were conducted on the samples in 2015.

Soil sampling was carried out at a distance of one km buffer zone on both sides of the drain and along the drain. The consecutive interval between the soil samples was 6 km. 27 soil samples were collected: 9 along the drain and 18 from the one km buffer on both sides of the drain. The auger method was used for soil sampling at one km buffer zone. The auger method along with composite soil sampling method was done to get the soil samples alongside the drain. For the purpose of analysis, samples were kept in airtight polythene bags. Each sample bag was labeled carefully according to the sample code. Each polythene bag contained about 1.5 kilograms of soil. Before chemical and physical analysis, soil samples were sieved through a 2 mm sieve. These sieved samples were later kept in polythene bags for various chemical and physical analyses.

Thirty-six groundwater samples were selected for arsenic testing from 0.5 km and 1 km buffer on both sides of the drain, 9 drain samples were selected from the main drain and 27 soil samples were selected from along the Hudaira Drain and 1 km buffer from the drain on the basis of systematic random sampling, as shown in Figs 2 and 3. Arsenic samples were analyzed through atomic absorption spectrometry (AAS). Finally, statistical analysis, which includes descriptive statistics, scatter plots, and box plots was done using STATISTICA 10 software.

For a non-carcinogenic approach, the chronic daily intakes (CDI) for adults and children were calculated using Equations I and II:

$$CDI_{\text{water-nc-ing}} = \frac{[C_{\text{g-water}} \times EF_{\text{resw}} \times ED_{\text{resw}} \times IRW_{\text{resw}}]}{[365 \times ED_{\text{resw}} \times BW_{\text{reswa}}]} \text{ For Adults} \quad \text{I}$$

$$CDI_{\text{water-nc-ing}} = \frac{[C_{\text{g-water}} \times EF_{\text{reswc}} \times ED_{\text{reswc}} \times IRW_{\text{reswc}}]}{[365 \times ED_{\text{reswc}} \times BW_{\text{reswc}}]} \text{ For Children} \quad \text{II}$$

For carcinogenic cases, equations III and IV were used to compute the age-adjusted CDI

$$CDI_{\text{water-ca-ing}} = [C_{\text{g-water}} \times IFW_{\text{resw-adj}}] / AT_{\text{reswc}} \quad \text{III}$$

... where:

$$IFW_{\text{resw-adj}} = \frac{[ED_{\text{reswc}} \times EF_{\text{reswc}} \times IRW_{\text{reswc}}] / BW_{\text{reswc}}}{+ [(ED_{\text{resw}} - ED_{\text{reswc}}) \times IRW_{\text{reswa}}] / BW_{\text{reswa}}} \quad \text{IV}$$

Excess lifetime cancer risk (ELCR) and the significant hazard quotient (HQ) were calculated using equations V and VI, respectively:

$$ELCR = CDI_{\text{water-ca-ing}} \times SF_{\text{oral}} \quad \text{V}$$

$$HQ = CDI_{\text{water-nc-ing}} / RfD \quad \text{VI}$$

Table 2 shows the input variables for exposure assessment, risk, and hazard analysis.

### Spatial Generalization of Samples through GIS

In the initial phase, groundwater, soil, and drain water parameters (location/sampling sites and arsenic concentration) were entered in MS Excel database format because Excel can be easily transported to the GIS database for further analysis. A shape file of the sampling location was prepared by importing the database file prepared in Excel. Once the data were imported as a point layer, spatial distribution maps of the attribute information were created using spatial interpolation techniques (IDW). Interpolation is a method of converting point data to surface data. Interpolation is the process used to calculate the values of locations that do not have sample points. It is based on the rule of spatial autocorrelation in which measurement is done on the degree of relationship between near and far-away objects, i.e., where data are not known, the interpolation method is used.

In this research we used the inverse distance weighted (IDW) interpolation method to produce distribution maps on a spatial basis for different parameters. IDW interpolation implements the assumption that things that are close to one another are more alike than those that are farther apart. In this study, arsenic concentration in groundwater, drain water, and soil was categorized as low, moderate, and high in order to identify the hotspot areas. The soil values range between 15.89-39.14  $\mu\text{g/L}$  (0.0391-0.0159 mg/kg) and were within the FAO limits. The hotspot areas identified were based on the obtained data to estimate the future scenario. Soil values were categorized into a relative low group (15-22  $\mu\text{g/L}$ ), moderate group (23-31  $\mu\text{g/L}$ ), and high group (above 31  $\mu\text{g/L}$ ). For drain water, the values ranged from 4.36 to 22.40 ppb and were within the NEQS standards, whereas for groundwater the values ranged from 2.75 to

Table 2. Input Parameters for CDI, ELCR, and HQ [46].

Parameter	Abbreviation	Unit	Value
Chronic daily intake (water-non-carcinogenic-ingestion)	CDI <sub>water-nc-ing</sub>	mg/kg-day	
Concentration	C <sub>g-water</sub>	mg/L	
Adjusted intake factor	IFW <sub>resw-adj</sub>	L/kg	380
Average time- noncarcinogenic	A <sub>Iresw</sub>	Day	10950
Exposure duration – adult	ED <sub>reswa</sub>	Year	30
Exposure frequency – child	EF <sub>reswc</sub>	day/year	350
Water intake rate – child	IRW <sub>reswc</sub>	L/day	1
Body weight – child	BW <sub>reswc</sub>	Kg	15
Exposure duration – resident	ED <sub>resw</sub>	Year	30
Exposure duration – child	ED <sub>reswc</sub>	Year	6
Exposure frequency	EF <sub>reswa</sub>	Day/year	350
Water intake rate – adult	IRW <sub>reswa</sub>	L/day	2
Body weight – adult	BW <sub>reswa</sub>	Kg	70
Average time- carcinogenic	AT <sub>reswc</sub>	Day	25550
Chronic daily intake (water-carcinogenic-ingestion)	CDI <sub>water-ca-ing</sub>	mg/kg-day	
Oral slope factor	SF <sub>oral</sub>	(mg/kg-day) <sup>-1</sup>	1.5
Reference dose	R <sub>Fd</sub>	mg/kg-day	3.00E-04

22.35 µg/L and some were higher than WHO standards. For the study, drain water and groundwater were categorized as low group (up to 10 µg/L), moderate group (11-18 µg/L), and high group (above 18 µg/L).

## Results and Discussion

Total arsenic concentrations in soil, drain water, and groundwater from different sites were analyzed. The descriptive statistics for arsenic results are shown in Table 3. Through IDW interpolation technique, it was observed that transects 1, 2, 3 and 9 belong to low arsenic group as shown in Fig. 4. Along the drain, the mean value of arsenic for soil ranges from 21.61 to 29.27 µg/L (0.02161 to 0.02927 mg/kg) and along the

one km buffer the mean arsenic value ranges from 15.89 to 21.56 µg/L (0.01589 to 0.02156 mg/kg). For drain water and groundwater, transects 1, 2, and 3 belong to the low arsenic group (Fig. 5). In drain water, the mean arsenic value ranged from 4.36 to 5.35 µg/L and for groundwater it ranged from 2.75 to 5.33 µg/L. These were the sites surrounding the area from where the drain enters Pakistan from India. Most of this area is comprised of agricultural land with scattered settlements.

Transects 4, 5, and 8 belong to the moderate arsenic group (Fig. 4). Along the drain, the mean value of arsenic for soil ranged from 28.53 to 29.77 µg/L (0.02853 to 0.02977 mg/kg) and along the one km buffer the mean arsenic value ranged from 21.29 to 25.72 µg/L (0.02129 to 0.02572 mg/kg). For drain water and groundwater, transects 4, 5, 8, and 9 belong to the moderate arsenic group (Fig. 5). In drain water the mean arsenic value ranged from 11.32 to 17.65 µg/L and for groundwater it ranged from 6.25 to 17.85 µg/L. These were the sites that have agriculture on one side and industries on the other. Industries found in this group were mostly comprised of textiles (yarn and garments), food, and a few related to chemicals.

Transects 6 and 7 belong to high arsenic group (Fig. 4). Along the drain, the mean value of arsenic for soil ranged from 36.41 to 39.14 µg/L (0.03614 to 0.03914 mg/kg) and along the one km buffer the mean arsenic value ranged from 28.46 to 31.82 µg/L (0.02846 to 0.03182 mg/kg). For drain water and groundwater, transects 6 and 7 belong to the high arsenic group as

Table 3. Descriptive statistics for arsenic.

Descriptive statistics	Drainwater	Groundwater	Soil
Mean	13.36	10.75	25.00
Median	16.89	10.75	23.43
Std. Deviation	7.07	5.94	5.94
Range	18.04	19.60	23.3
Minimum	4.36	2.75	15.9
Maximum	22.40	22.35	39.1

shown in Fig. 5. For drain water, the mean arsenic value ranged from 20.39 to 22.40  $\mu\text{g/L}$  and for groundwater it ranged from 10 to 22.35  $\mu\text{g/L}$ . This was the main industrial region and industries found here are mainly for chemicals, dyeing units, motor vehicle parts, and food. The motor vehicle industries use metallic arsenic in alloying with lead because lead batteries are strengthened by adding arsenic. It is also used in the processing of pigments, textiles, etc. Charar

Drain and Sattu Katla Drain also join Hudaira Drain in this section (Fig. 1). Sattu Katla is highly polluted because it comes from the Quaid-i-Azam industrial area in the township. Recent studies have also shown an increased level of arsenic [23, 24] in different areas of Pakistan. If this groundwater with high arsenic will be used continuously for irrigation, then the arsenic concentration in the soil will exceed the permissible limit.

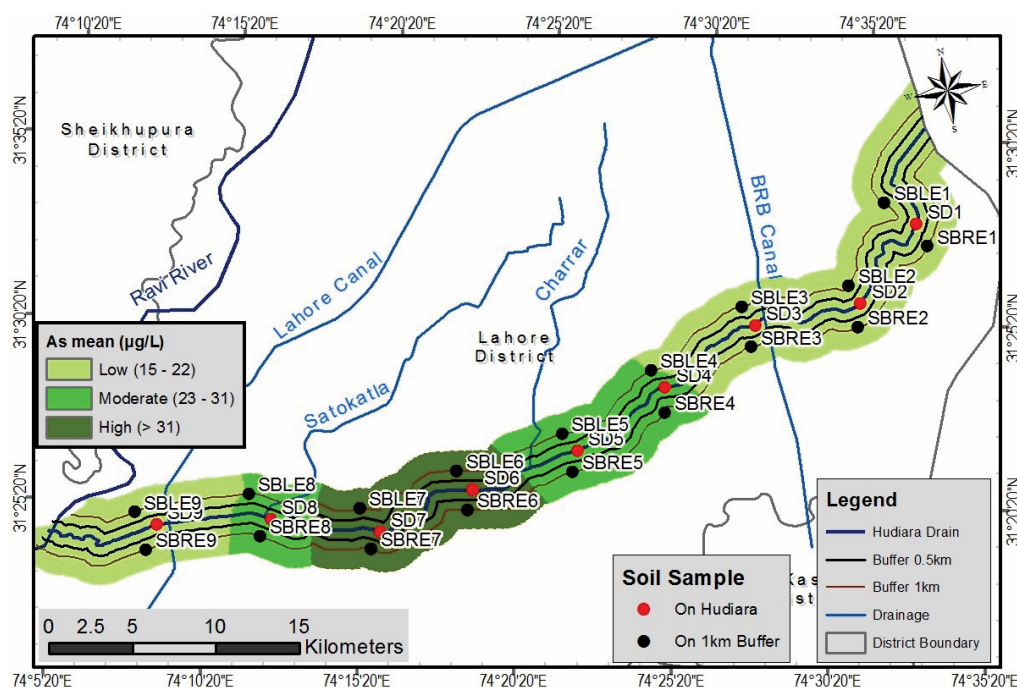


Fig. 4. Interpolation of mean arsenic value for soil samples.

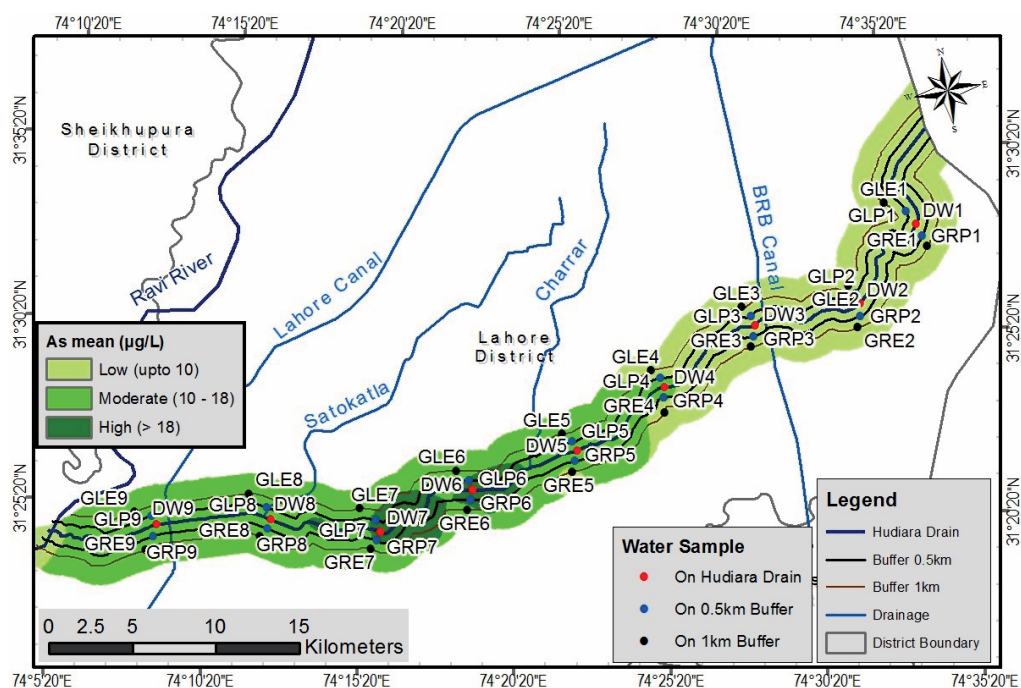


Fig. 5. Interpolation of mean arsenic value for drain water and groundwater samples.

Statistically, Pearson's correlation was applied to drain water (surface water) and groundwater data (Fig. 6). All the p values were taken at 95% confidence level in the study. There is a very strong correlation of 87.7% ( $r = 0.8774$ ) between drain water (surface water) and groundwater with p value of 0.0001, which is highly significant. There is a strong correlation of 74.8% ( $r = 0.7489$ ) between drain water (surface water) and soil samples on the extremes (one km buffer) with p value of 0.0001, which is highly significant as shown in Fig. 7. Fig. 8 shows the correlation between soil samples on the drain and soil samples on the extremes (one km buffer). There is a strong correlation of 86.4% ( $r = 0.8645$ ) between soil samples on the drain and soil samples on the extremes (one km buffer) with p value of 0.0001, which is highly significant. Fig. 9 shows the box plot for mean arsenic values of sample sites. Keeping in

view the values of arsenic in groundwater samples, the impact of arsenic on human beings was determined. It is considered that oral intake is the only source of exposure. Possible risk and threats were determined in view of the carcinogenic and non-carcinogenic effects of arsenic. Risks of lifetime cancer through oral intake of arsenic in groundwater samples were estimated by Equation 4. Evaluation of non-carcinogenic threats due to arsenic-laced drinking water was determined by comparing the chronic daily intake of non-carcinogenic with oral reference doses of arsenic. It was observed that due to the high value of HQ, the possibility of threats of the non-carcinogenic due to arsenic poisoning in the area was high. Intake threat possibility is extensively used to identify relevant non-carcinogenic threats as compared to other possible routes of arsenic intake. In different sample sites, quantitative risks and hazards due to arsenic poisoning are shown in Table 4.

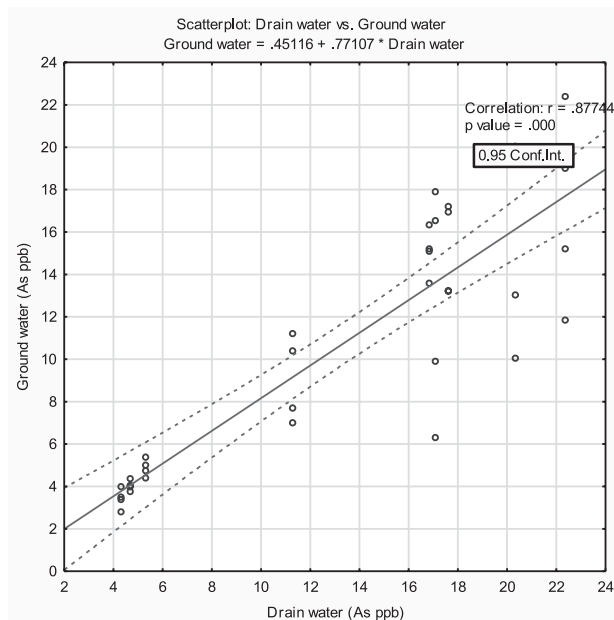


Fig. 6. Scatter plot of drain water and groundwater.

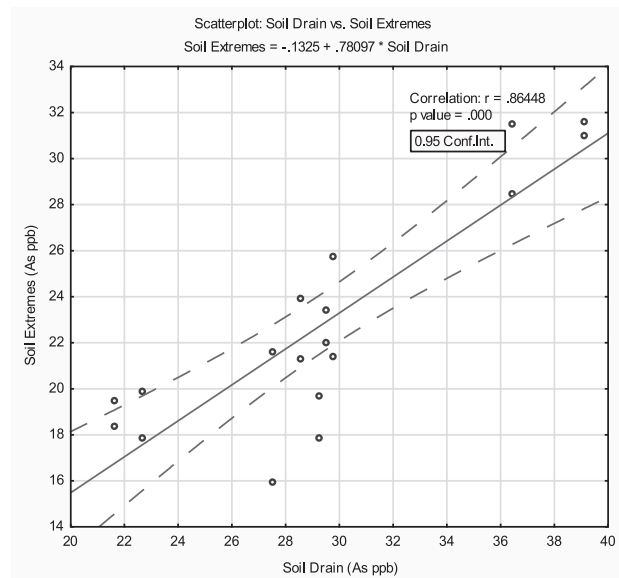


Fig. 8. Scatterplot between soil drain and soil extremes.

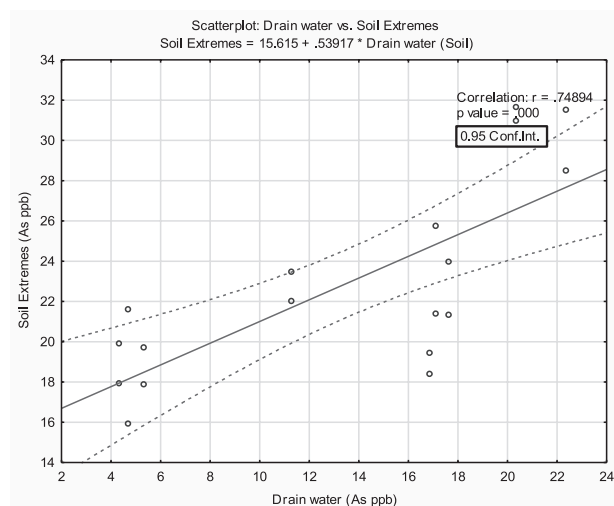


Fig. 7. Scatter plot between drain water and soil.

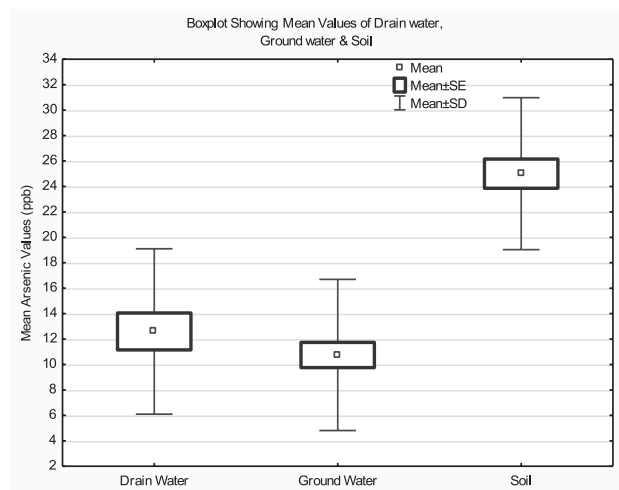


Fig. 9. Boxplot for mean arsenic of sample sites.



Table 4. Arsenic concentrations and relevant risk and hazard levels in sample sites.

Sites	CDI (Adult) (mg /kg/day)	CDI (Child) (mg/kg/day)	Child Ingestion Hazard Quotient(HQ)	Adult Ingestion Hazard Quotient(HQ)	ELCR
GRP1	9.2E-05	2.1E-4	0.7	0.3	2.8E-05
GRP2	1.2E-04	2.8E-4	0.9	0.4	3.6E-05
GRP3	1.5E-04	3.4E-4	1.1	0.5	4.4E-05
GRP4	3.1E-04	7.1E-4	2.4	1.0	9.2E-05
GRP5	4.9E-04	1.1E-3	3.8	1.6	1.5E-04
GRP6	6.1E-04	1.4E-3	4.8	2.0	1.8E-04
GRP7	5.5E-04	1.3E-3	4.3	1.8	1.6E-04
GRP8	4.6E-04	1.1E-3	3.6	1.5	1.4E-04
GRP9	4.2E-04	9.7E-4	3.2	1.4	1.3E-04
GLP1	1.1E-04	2.5E-4	0.8	0.4	3.3E-05
GLP2	1.1E-04	2.5E-4	0.8	0.4	3.9E-05
GLP3	1.3E-04	3.0E-4	1.0	0.4	8.5E-05
GLP4	2.8E-04	6.6E-4	2.2	0.9	1.4E-04
GLP5	4.5E-04	1.1E-3	3.5	1.5	1.6E-04
GLP6	5.2E-04	1.2E-3	4.0	1.7	1.7E-04
GLP7	5.5E-04	1.3E-3	4.3	1.8	1.4E-04
GLP8	4.7E-04	1.1E-3	3.7	1.6	1.3E-04
GLP9	4.5E-04	1.0E-3	3.5	1.5	2.3E-05
GRE1	7.5E-05	1.8E-4	0.6	0.3	3.3E-05
GRE2	1.1E-04	2.6E-4	0.9	0.4	4.1E-05
GRE3	1.4E-04	3.2E-4	1.0	0.5	5.7E-05
GRE4	1.9E-04	4.4E-4	1.5	0.6	5.2E-05
GRE5	1.7E-04	4.0E-4	1.3	0.6	1.3E-04
GRE6	4.2E-04	9.7E-4	3.2	1.4	8.3E-05
GRE7	2.7E-04	6.4E-4	2.1	0.9	1.1E-04
GRE8	3.6E-04	8.4E-4	2.8	1.2	1.1E-04
GRE9	3.7E-04	8.7E-4	2.9	1.2	2.9E-05
GLE1	9.5E-05	2.2E-4	0.7	0.3	3.1E-05
GLE2	1.0E-04	2.4E-4	0.8	0.3	3.6E-05
GLE3	1.1E-04	2.8E-4	0.9	0.4	6.3E-05
GLE4	2.1E-04	4.9E-4	1.6	0.7	8.1E-05
GLE5	2.7E-04	6.3E-4	2.1	0.9	9.7E-05
GLE6	3.2E-04	7.5E-4	2.5	1.1	1.1E-04
GLE7	3.6E-04	8.3E-4	2.8	1.2	1.1E-04
GLE8	3.6E-04	8.4E-4	2.8	1.2	1.2E-04
GLE9	4.1E-04	9.6E-04	3.2	1.4	2.8E-05

HQ < 1 = Safe      HQ > 1 = Unsafe      ELCR 1.0E-06 to 1.0E-04 = Acceptable.      ELCR > 1.0E-04 = High Risk

Where

GRP = Groundwater samples on right side of drain at half km

GLP = Groundwater samples on left side of drain at half km

GRE = Groundwater samples on right side of drain at one km

GLE = Groundwater samples on left side of drain at one km

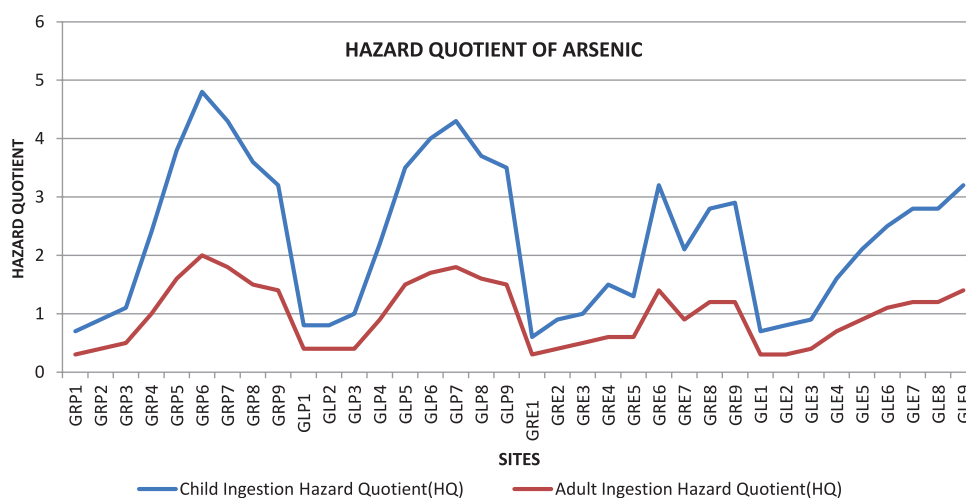


Fig. 10. Line graph for hazard quotient of arsenic for sample sites.

The highest and lowest arsenic concentrations were reported at GRP6 and GRE1, with 22.35  $\mu\text{g/L}$  and 2.75  $\mu\text{g/L}$ , respectively. The highest value of 22.35  $\mu\text{g/L}$  seems to be very high while comparing with the highest values of arsenic in groundwater in Xiangjiang watershed in south-central China, which is 21.2  $\mu\text{g/L}$  [41]. The inorganic form of As is more dangerous than the organic one, whereas inorganic As(III) is nearly 60 times more dangerous than As(V) [42]. The continuous intake of groundwater with high As (V) for a long period would eventually cause hazards to human health because it is reduced to arsenite, which is more complicated to eliminate from supplies of drinking water than arsenate [43, 44].

The spatial distribution of age-adjusted ELCR and hazard levels among 36 sites of the study area are shown in Table 4, which shows that 50% of the adults have HQ value greater than 1, meaning that they are unsafe and are more prone to non- carcinogenic threats due to arsenic. For child HQ >1, 75% of the children in the study area are more prone to the severity of non- carcinogenic threats due to arsenic in groundwater. Fig. 10 also shows the HQ levels for adults and children. The range of carcinogenic risks acceptable or tolerable by [45] was 1.0E-06 to 1.0E-04.

Values of the risk of cancer varied from highest 1.8E-04 at GRP6 to 2.3E-05 at GRE1. This study revealed that if only drinking water intake is considered, then even 44.4% of individuals have excess lifetime cancer risk >  $10^{-4}$ , showing high-risk. Hence, it is seen that nearly half of the individuals have a high risk of ELCR only through drinking water.

### Conclusion

It is concluded from the present study that 52% of groundwater samples have arsenic value above the WHO-recommended limits. P-value indicates that there is a strong relationship between drain water, groundwater,

and soil. The health risk assessment values 50% for HQ (ADULT) and 75% for HQ (CHILD) were found to be above unity, indicating significant risk via the ingestion route. In the samples of groundwater from the study area, the carcinogenic risk was found to be associated with the slightly elevated values of arsenic. Such drinking water sources have the potential to pose carcinogenic and non-carcinogenic effects on the local people of the study area. Therefore, the decision regarding substitution of current drinking water with safe and clean water must be taken as early as possible. This study can be used for future drinking water quality monitoring and planning in order to help save local people from the carcinogenic effects of arsenic.

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### Conflict of Interest

The authors declare that there are no conflicts of interest.

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