Determination of Arsenic and Health Risk Assessment in the Ground Water of Sindh, Pakistan

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ABSTRACT

As (Arsenic) is one of the lethal element present at the various locations of the world, putting human beings in danger by polluting the water. Arsenic Kit and atomic absorption spectrometer were used to determine As in ground water of Sindh province, Pakistan. Twenty-Four (24) districts both on the left and right bank of RI (River Indus) were analyzed. It was observed from the results that highest As concentration 200 ppb (parts per billion) i.e. above the WHO (World Health Organization) limit (10 ppb) was observed in Sakrand, district Shaheed Benazirabad followed by Hala, Matairi, TMK (Tando Mohammad Khan) and Nasarpur regions. It was further found that ground water of regions on the left bank of RIwas more contaminated than the right bank. Contour map was created using OriginPro and coordinate systems to highlight the elevated arsenic in the studied area. HRA (Health Risk Assessment) of these areas was carried out to calculate EDI (Estimated Daily Intake), TQH (Target Hazard Quotient) and CR (Cancer Risk). 45% of the total ground water samples analyzed were above the permissible limit for As in water and mostly these are located on the left bank of RI.

The local wells in Sindh have never been tested for metal concentration former to use. These results provide baselines for researchers, NGO's (Non-Governmental Organizations) and government to apply arsenic treatment technologies in those areas.

Key Words: Arsenic, Groundwater, River Indus, Sindh, Atomic Absorption Spectrometer, Health Risk Assessment.

1. INTRODUCTION

As is a hazardous element which is present in ground water in the form of As(III) and As(V). Its presence in the earth's crust is 0.00021%. Illness characteristic of long-term arsenic exposure comes in the form of skin cancer, bladder cancer, inactivation of an enzyme system in the body, black foot disease, and obesity [1-3]. As contact can also cause other health consequences such as gastrointestinal irritation, diabetes, less number of white and red blood cells, hypertension, blood vessels rupture and abnormal heart beats [4]. Baig

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et. al. [3] performed a study of Gambat town, Sindh and found people suffering from chest infections, pain in the whole body, cramps in legs due to As contamination in water.

Naturally occurring arsenic is known to trickle from contaminated soils. Thus, contact of the general population with arsenic is mainly through the ingestion of groundwater, which comes across As-bearing soils and minerals. Pakistan is suffering from the toxic effects of arsenic as other countries such as Bangladesh, India, Thailand, Taiwan, China, Japan, USA, Canada, Hungary and Ghana [5].

The high level of As species in ground water is due to the dissolution of As compounds coming from the Himalayas through RI and settled down throughout the years and then introduced into ground water by geothermal, hydrological and biochemical factors [6]. In Pakistan, a number of people consume ground water for their drinking, domestic purposes as clean river water is not accessible to them. As toxicity is mostly found in ground water and transported to human beings by ingestion, vegetables, crops, fruits and fishes. The authors in a research showed that the Mancharlake near town Sehwan, Sindh was contaminated with arsenic and the daily intake of As by people is 241-390 µg As/4L [5].

The present study was designed to investigate As in drinking water of Sindh province on both left and right banks of RI.

2. MATERIALS AND METHOD

2.1 Materials

Ground water samples were collected from various areas of Sindh Province, Pakistan and analyzed in a water quality laboratory, Department of Chemical Engineering, Mehran University of Engineering & Technology, Jamshoro, Pakistan. All sample bottles (well-stoppered polyethylene plastic) were rinsed with clean water, then filled completely with sample water and tagged properly with a location. Analysis of water samples was performed by using the Arsenic test Kit (Merck, Germany) and AAS (Atomic Absorption Spectrometer). The arsenic kit is a mobile analytical tool that is used in the field to check the arsenic in water. AAS was used to analyze 106 ground water samples, whereas kit method was applied to test 214 ground water samples.

Analytical grade chemicals were used throughout the research work. Distilled water was used during the experiments to prepare all the solutions. Distilled water was prepared in a water quality laboratory by Distilled water machine (Model No. BMS-4CE, Spain). All the glass wares were kept overnight in 5M HNO_3 and then rinsed with deionized water before use. Stock solutions of concentration 1000 ppb As(III) were prepared by mixing arsenic standard solution of 100 mg/L As(III) (Inorganic Venture Company, USA) with distilled water. The stock solutions were used to prepare fresh experimental solutions as per need in clean plastic bottles and were kept away from light to avoid any change in chemical properties [7-9]. For the confirmation of reproducibility, the tests were replicated and the mean values were taken.

2.2 Methods

2.2.1 Arsenic Kit method

Water samples were analyzed by Arsenic kit (Merck, Germany) by using a calorimetric method with test strips. The arsenic kit reaction bottle was filled to the mark with 60 ml sample water and the analysis was carried out as recommended by the kit manufacturer.

2.2.2 Atomic Absorption Spectrometer

Arsenic was analyzed in water samples by AAS (A Analyst 700, Perkin Elmer, USA), at a wavelength of

193.7 nm, by the MHS-15 (Mercury Hydride System) technique. The energy source was the single-element hollow cathode lamp of arsenic working at 7.5 mA. The AAS was attached to a computer and WinLab32 software used to receive and process analytical data. The solution of 1% potassium hydroxide (KOH) was prepared. Then 3% sodium borohydride ($NaBH_4$) was prepared in 1% KOH solution on Stirrer (Wisd, MSH-20, Korea). The chemicals were weighed using weighing balance (Adventurer, AR 3130, OHAUS, USA). 1.5% HCl (Hydrochloric Acid) was prepared by appropriate dilution of HCl (37%). The arsenic standards were prepared to calibrate the AAS. Then the ASS was used to analyze water samples and the results were obtained by Winlab 32.

2.2.3 Technique to Assess Human Health Risk

The HRA of the left bank of RI areas is studied by calculating EDI, THQ and CR. EDI is calculated by using the following equation;

$$EDI = Cm \times \frac{Dw}{Bw} \quad (1)$$

Where Cm denotes metal concentration (µg/L) in water, Dw is the daily average intake of water (Lit/day, taken as 2 Lit/day), and Bw is the body average weight (kg, taken as 72 kg) [10].

The THQ was obtained by applying the following relationship;

$$THQ = \frac{EDI}{RfD} \quad (2)$$

Where the oral toxicity reference doseRfD (µg/kg-day) value for arsenic is (3.00E-01) [11].

Following relationship was used to calculate CR;

$$CR = EDI \times CSF \quad (3)$$

In Equation (3) CSF (µg/kg-day) is Cancer Slope Factor and its value for As is 1.5E+03 (µg/kg-day) [12-13].

3. RESULTS AND DISCUSSION

3.1 Arsenic kit Method

The As kit is a portable and easy tool method used to analyze As of 24 districts of Sindh Province. Out of 214 ground water samples, 182 were from localities on the left bank and 32 samples from the right bank of RI. All the sample areas were assigned codes as shown in Table 1.

The results of localities on the left bank are reported in **Table 1**. About 40% of the samples were exceeding the WHO safe limit for As in water, i.e. 10 ppb. The higher As levels were observed in ground water samples of Hala i.e. 10-180 ppb. The other areas with higher As concentrations were Sakrand, Matairi, Nasarpur, Pano Aqil and TMK.

The reasons for higher concentrations in the left bank of RI are the geological presence due to the deposition over the years from the Himalayas, thick population, intense farming, and the areas from where RI passed during the Holocene period such as Tando Allahyar and TMK from where the As ranges from 10-500 ppb [6].

Fig. 1 demonstrates the sample from the right bank of RI. The Dadu district samples showed higher As levels ranging between 0-60 ppb which is inconsistent with the earlier report of As in scalp and hair of children of Dadu district [14]. Apart from the natural deposition of arsenic in ground water other factors for As pollution are coal burning at brick industries, power plants in Jamshoro district [15]. Samples of Jamshoro and Kashmore ranged within permissible limit of 10 ppb.

TABLE 1. GROUND WATER SAMPLE CODES ASSIGNED TO LOCATIONS OF SINDH, PAKISTAN AND ARSENIC KIT RESULTS

Code	Location	As(ppb)	Code	Location	As(ppb)
BD1	Hand Pump, NabiBuxBhurgri, Badin	0	ST3	Abbasi Village, Sekhat	40
BD2	MuhammadNizamiMalhan, Matli, Badin	0	TM1	Village SaeedPur, Bulri Shah Karim, TMK	3
BD3	NabiBuxBhurgri, Badin	0	TM2	Water Pond, Sajawal Road, TMK	0
BD4	NizamaniOtaq, Matli, Badin	0	TA1	Mosque, Village Talpur, TandoAllahyar	25
BD4	Village Malhan, Matli, Badin	0	TA2	Village Talpur, TandoAllahyar	0
DK1	Ghulab Shah Colony, Dharki	0	SR1	Old Sukkur	0
DK2	Imam Bargah, Dharki	5	TM10	SafeenaShifa, TMK	30
DP1	DaburiWell Water, Diplo	0	TM11	SaqibTalpur, TMK	5
DP2	DileepSaqiHome, Diplo	0	TM12	Tube Well Water (City), TMK	50
DP3	RafiqLangho, Diplo	0	TM13	Village Gaja Mori, TMK	0
DP4	SaqiParo, Diplo	0	TM14	Village GhulamHussainTalpur, TMK	50
GK2	Hand Pump, Yaro Lund, MirpurMathelo, Ghotki	5	TM3	Bus Stop Near Ayobia Hotel, TMK	60
GK3	Motor Water, Yaro Lund, MirpurMathelo, Ghotki	0	TM4	Gaja Mori, Sajawal Road, TMK	0
HD1	House No. 137, Latifabad, Hyderabad	0	TM5	Govt: Girls High School, TMK	40
HD2	House No. 97, Latifabad, Hyderabad	0	TM6	Govt: Girls School, TMK	5
HD3	Hussainabad, Police Colony, Hyderabad	0	TM7	MadarsahJamiatmadinah, TMK	20
HD6	Latifabad, Hyderabad	0	TM8	Majid Ali, Mir Mohalla, TMK	6
HD7	Miyani Road, Hyderabad	0	TM9	SaeedPur, TalukaBulri Shah Karim, TMK	100
HD8	MohsinMemon, Citizen's Colony, Hyderabad	5	TB1	14 KM from GuniChowk, TandoBago	10
HD9	New Wahdat Colony, Hyderabad	10	TJ2	RazaSaeed, Tando Jam	15
IK1	Govt: RO Plant, IslamKot	0	TT2	Warial Khan Khoso, Jhirk, Thatta	0
IK2	Private RO Plant, IslamKot	0	UK3	AkriPithoro, Umerkot	10
IK3	Village BhabinoBhell, UC SonalBhoh, Thar	0	HL1	Abdul Aziz, KadhMohalla, Hala	30
IK4	Coal Gasification Site, IslamKot, Thar	0	HL10	DargahMakhdomNoh,SalineWater, Pump 2, Hala	40
KD1	Mohammad Din, Kandiaro	0	HL11	DargahMakhdom Noh,Sweet Water, Pump 1, Hala	60
JD7	Liaquat, Ward-2, Jhuddo	0	HL12	DawoodMemonHome, KanarMohalla, Hala	50
KP10	Naib Ali, Tarkowado, Khairpur Mir's	0	HL13	Dr. AR Memon Home, Hala	35
KP13	TarkoWado, Khaipur Mir's	0	HL14	Envious Girls Public School, KadhMohalla, Hala	50
KP14	Tube Well, TalukaNaro, Khairpur	0	HL15	Faiz Mohammad, Hala New	45
KP16	Village Allah Dino Khuhro,Gambat,Khairpur	45	HL16	Fareed Ahmed Home, PirFazalColony, Hala	180
KP18	Wandh, Khairpur Mir's	10	HL17	Fazal, Hala New	7
KGM1	Jamesabad, KotGhulam Mohammad	0	HL18	Govt: Girls High School, KadhMohalla, Hala	5
KP3	HadiBuxLeghari, ThariMirwah, Khairpur	5	HL19	Haji Anwar, Kaka Mohalla, Hala	40
KP4	Hand pump, TalukaNaro, Khairpur	5	HL2	Aftab Ansari, Hala	25
KP6	Jadowahan, Gambat, Khairpur	25	HL20	Haji Faiz Mohammad Home, SiraiMohalla, Hala	50
KP8	Latif colony, Kairpur Mir's	5	HL21	Haji QamarudinHome, Kanar Mohall, Hala	55
MT16	HazoorBux Shop, Khyber Stop, Matairi	30	HL22	Imam Bargah, Hala	40
MH1	Mithi	0	HL23	Imdad Rajput, MohajirChowk, Hala	25
MH2	RO Water, Mithi	0	HL24	JealArbabHome, ArbabMohalla, Hala	70
MT10	Macon-Washy, Matairi	0	HL25	Khair Mohammad, PiniladhoColony, Hala	30
MT11	MatairiCity	80	HL26	Khokhar Fridge Shop, BrohiMohalla, Hala	10
MT12	Matairi City, DargahPardehiPir	100	HL27	MuhammadUsmanHome, PiniLadho Colony, Hala	50
MT13	Matairi Sugar Mills Officers Mess, Matairi	110	HL28	MuhammadUsmanHome, PirFazal Colony, Hala	100
MT14	Matairi Sugar Mills RO Plant, Matairi	120	HL29	MuhammadYousuf, TalibMola Road, Hala	40
MT15	Matairi Sugar Mills Supervisor mess, Matairi	25	HL3	Ahmed KhalkaniHome, Kaka Mohalla, Hala	50
MT16	MianpotaMohalla, Matairi	0	HL30	Mohammad Hussain, Kaka Mohalla, Hala	25
MT17	Mir Hassan Mohalla, Matairi	5	HL31	Mohammad Usman, MohajirChowk, Hala	20
MT18	Sekhat, Matairi	50	HL32	Mohammad, Hala New	25
MT19	ShameerJiWari, Matairi	0	HL33	Mosque, Hala New	50
MT2	AbasPir, Highway Road, Matairi	0	HL34	Naseer, Kaka Mohalla, Hala	30
MT20	Village BachalDetho, Near Matairi Sugar Mills	100	HL35	Near Girls College, Hala	25
MT21	Village Bhambra, Matairi	0	HL36	Near Imam Bargah, Hala	40
MT22	Village Shah Alam Shah Wasi, Matairi	40	HL37	Old Hala	10
MT23	Village Vighio, Matairi	0	HL38	Prof. Nafees Ahmed, KashigarMohalla, Hala	40

Code	Location	As(ppb)	Code	Location	As(ppb)
MT3	BurkatPota, Matairi	0	HL39	Raja Fahad Home, Hala	90
MT4	Canteen, Matairi Sugar Mills	0	HL4	Al Shifa Medical center,KadhMohalla, Hala	50
MT5	Graveyard, Matairi	30	HL40	Raja FahadQureshi Agricultural Farm,Hala	90
MT9	Khyber, Matairi	0	HL41	Rehan home,KashigarMohalla, Hala	70
NF3	Darpa, Tharushah, NausheroFeroz	0	HL42	SaeedMemon, Hala New	50
NF4	KhudaBuxKalhoro, NausheroFeroz	10	HL43	SarfarazQureshi, Mujawar colony, Hala	10
NF6	Tharushah, NausheroFeroz	0	HL44	Shamsudin Book Store, Kanar, Hala	10
NF7	Village Allah Bachayo, NausheroFeroz	3	HL45	Soomar Shah, Hala	90
UK9	Pump Water, Umerkot	5	HL46	Sweet Shop, Hala	13
NK1	Naukot	0	HL47	TahirYasirHome, TalibMola Road, Hala	150
NP10	Ward-6, Nasarpur	15	HL48	TalibMola Colony, Hala	100
NP2	ArainMohallah, Nasarpur	13	HL49	Tariq Road, Hala	40
NP3	Bus Stop, Nasarpur	80	HL5	Alamgir, Kaka Mohalla, Hala	50
NP7	SikanderAlmaniHome, Nasarpur	40	HL50	Tariq, Hala	20
NP9	Ward-4, Nasarpur	35	HL51	Tariq, Hala New	50
NF1	ImdadHome Halani, NausheroFeroz	60	HL52	Zameer, KanarMohalla, Hala	45
NF2	SajadHome Halani,NausheroFeroz	25	HL6	Al-Hafeez Pathology, Hala	40
NS3	Aslam, ShaheedBenazirabad	0	HL7	Allah Bux, ShahnawazMohalla, Hala	10
NS4	Habib College, ShaheedBenazirabad	50	HL8	Arbani Street, Hala	50
NS1	Habib Sugar Mills ShaheedBenazirabad	0	HL9	Cloth Factory, PiniladhoColony, Hala	40
PA10	Village Bhelar, PanoAqil	35	DD1	AB Jamali, Johi, Dadu	0
NS2	Railway station ShaheedBenazirabad	0	DD4	JohiCity, Pump 2, Dadu	0
PA5	Basheerabad,PanoAqil	90	DD11	Water Well, JohiCity, Dadu	0
PA6	Dhandi, PanoAqil	0	DD8	Village Allah Dad, Johi, Dadu	5
PA8	ManderGali, PanoAqil	10	DD2	JohiCity Pump 1, Dadu	10
PA9	Shahi Bazar, PanoAqil	2	DD7	Sample Pump 3, JohiCity, Dadu	10
PA1	Village Sanghi, PanoAqil	5	DD3	JohiCity, Dadu	60
PA2	Village Sultan Pur, PanoAqil	30	JC1	AKColony Jacobabad	0
RH2	Village Abello, Rohri	0	JC2	PaichohaVillage, Jacobabad	0
ST1	Village Abbasi, Sekhat	80	JC3	Village Pandhi, Jacobabad	0
SK1	Seed Plant, MajeedKeerio, Sakrand	35	JS2	SajadAbbasi, Phatak, Jamshoro	0
SK2	Wasomal Stop, MajeedKeerio, Sakrand	0	JS3	Syed YaseenHome, SUECH Society, Jamshoro	0
ST2	Village Abbasi, Sekhat	50	JS4	Village Nawab Khan Khoso, Jamshoro	0
SP1	Society, Shahdadpur	4	JS6	ZABhatti Home, SUECHS, Jamshoro	0
SK10	Jan Mohammad House,, Sakrand	0	JS1	OwaisBhatti, Phatak, Jamshoro	10
SK11	KhadimHussainLakho, MajeedKeerio, Sakrand	5	KH1	Haris, Upper Gizri, Clifton, Karachi	0
SK12	Mosque, MajeedKeerio, Sakrand	0	KM1	Hindu Colony, Kashmore	0
SK13	MunawarJamali House, MajeedKeerio, Sakrand	10	KM3	Town, Kashmore	0
SK14	Murtaza Agricultural Farm 1, Sakrand	5	KM4	Village MohdHashim, Kashmore	0
SK15	Murtaza Agricultural Farm 2, Sakrand	5	KM2	Guddu, Kashmore	10
SK16	Qasim Ansari House, MajeedKeerio, Sakrand	0	KT1	Market Kotri	0
SK17	RazzaqKhokhar, MajeedKeerio, Sakrand	8	KT2	Pathan Colony, Kotri	0
SK18	School Road, MajeedKeerio, Sakrand	0	LR4	Hand Pump, Larkana	0
SL1	RasoolBuxTheboHome, Sajawal	0	LR9	Ratodero, Larkana	2
SK3	Animal Hospital, MajeedKeerio, Sakrand	5	LR1	Ali SherKhokhar, Larkana	5
SK4	Anwar, Sakrand	0	LR3	Dhamrah, Larkana	5
SK5	AwaisMugheri home, MajeedKeerio, Sakrand	25	SH3	Akbar Brohi, Shahdadkot	0
SK6	DargahWater, MajeedKerio, Sakrand	10	SH4	Masan Mohalla, Shahdadkot	0
SK7	Drip No. 1 Water, MajeedKerio, Sakrand	3	SH5	Saifullah Colony, Shahdadkot	0
SK8	Godown,MajeedKeerio, Sakrand	50	SH1	Shahdadkot	0
SK9	Gulshan-e-Imdad, MajeedKeerio, Sakrand	0	SH2	Tanwary Branch, Shahdadkot	0
SR3	Jamia Mosque, Bander Road, Sukkur	80	SR2	NizamdinBhatti, GarhiYaseen, Shikarpur	5
SG2	Public Handpump, Sarhari, Sanghar	0			

3.2 Atomic Absorption Spectrometry

AAS was used to analyze the samples from the left bank of RI and the results are shown in Fig. 2. The Fig. 2 is showing minimum and maximum As concentrations of the studied areas. Eighty-three (83) ground water samples were obtained from various locations of left bank RI. The highest As concentration observed was 204 ppb at Godown, Majeed Keerio in Sakrand, district Shaheed Benazirabad. It was observed that 85% of the studied areas had arsenic above WHO limit, i.e. 10 ppb, whereas, 43% of the analyzed areas reported the level of arsenic above the Pakistan-EPA standard i.e. 50 ppb.

3.3 Comparison of As Kit and AAS

The As kit and AAS results are quite similar as shown by percent standard deviation (% SD (±)) in Table 2. The As kit and AAS (% SD) results are comparable with a research work conducted on As detection of ground water at district Rahim Yar Khan, Punjab, Pakistan in which (4-25 % SD) was observed between kit and AAS results [16].

3.4 Contour Mapping

In Fig. 3 Contour plot of As concentration (ppb) in ground water is shown by the map of Sindh province,

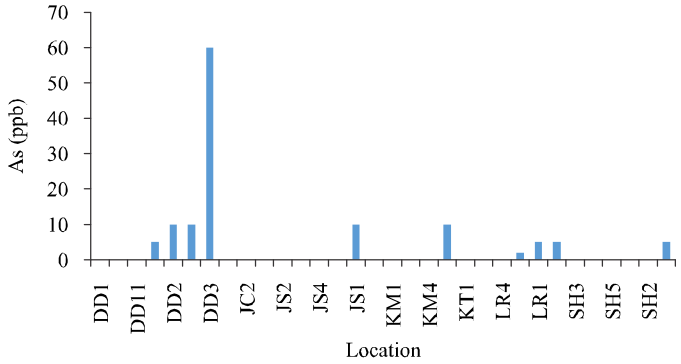

FIG. 1. SAMPLES ANALYZED FROM THE AREAS OF THE RIGHT BANK OF RIVER INDUS THROUGH ARSENIC KIT METHOD

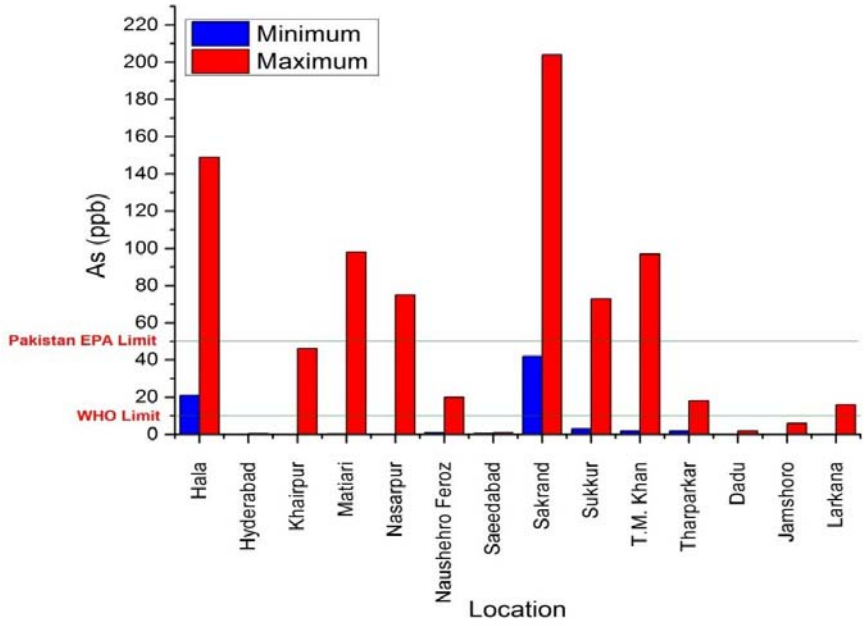

FIG. 2. ARSENIC IN SINDH SHOWING MINIMUM AND MAXIMUM CONCENTRATIONS WITH (WHO) AND (PAKISTAN- EPA LIMITS)

Pakistan. The contour map was made by using sample locations (coordinates) on google maps and OriginPro 9 software. The black dots are showing the sampling locations at various regions of Sindh province. The cross-sectional lines show the non-sampling areas in the map. The As concentration is presented in the map by various colors according to the As ranges shown along with the contour map. It is evident from the Fig. 3 that As was found in higher concentrations on the left bank of RI. The red color highlights the highest As levels at the location MajeedKeerio, SakrandTaluka, district Shaheed Benazirabad. The other higher As contaminations are displayed by orange, yellow, green and cyan colors at Hala, Matairi, TMK and Nasarpur. The authors discussed the ground water samples As (ppb) in district Rahim Yar Khan, Punjab, Pakistan with the help of contour diagrams. They found As levels from 8-118 ppb in ground water of district Rahim Yar

TABLE 2. COMPARISON OF ARSENIC CONCENTRATION ANALYZED WITH KIT METHOD AND ATOMIC ABSORPTION SPECTROMETER

Sample Code	As (ppb) Kit Method	As (ppb) with AAS	% Standard Deviation (±)
HL4	50	37	9.192
HL10	40	23	12.020
HL11	60	39	14.849
HL12	50	34	11.313
HL14	50	38	8.485
HL20	50	70	14.142
HL21	55	40	10.606
HL22	40	40	0
HL24	70	43	19.091
HL27	50	36	9.899
HL28	100	96	2.828
HL41	70	51	13.435
KP6	25	25	0
KP16	46	45	0.707
MT11	30	16	9.899
MT12	80	53	19.091
MT14	110	98	8.485
MT17	5	3	1.414
NP2	40	44	2.828
NP3	35	35	0
NP7	60	57	2.121
NP10	80	75	3.535
NF9	15	18	2.121
NF10	13	20	4.949
PA5	30	20	7.071
PA12	90	73	12.020
SK5	35	42	4.949
SR3	25	20	3.535
TM6	5	9	2.828
TM7	100	97	2.121
TM9	15	2	9.192
TM10	50	70	14.142
LR1	5	1	2.828

Khan, which is located on the left bank of RI [16]. Another study conducted in the Shorabhaji region, northwest of Iran shows the arsenic contents of 1000 ppb. The authors used geochemical contour mapping to determine As and other elements and found As in both metallic and non-metallic forms [17].

3.5 Contamination Index (C_d)

It is a method to evaluate and anticipate the regions characterized by irregular or toxic contents of elements. This shows the extent of contamination by taking into consideration the number of parameters crossing the upper allowable levels of hazardous elements and concentrations above these levels. The equation of calculating C_d is as follows [18]:

$$C_d = \sum_{i=1}^{n} C_{fi} \quad (4)$$

Where,

$$C_{fi} = {C_{Ai}}/{C_{Ni}} - 1$$

C_{fi} is the contamination factor for i^{th} component, C_{Ai} is the analytical value of i^{th} component, and C_{Ni} is the upper allowable concentration of i^{th} component.

In this study, C_d is studied for As. Contamination index for ground water was in the range between 0-19. 61.5% of the samples were below the permissible limit of WHO guidelines. The ground water on the basis of C_d values may be arranged into four categories; 8.94% of ground water contained $C_d < 1$ showed low contamination, 12.85% were in the range $1 < C_d < 3$ expressing intermediate contamination, 13.97% were within $3 < C_d < 10$ and 2.79% samples resulted in $C_d > 10$ demonstrating the very high contamination. The ground water samples on the left bank

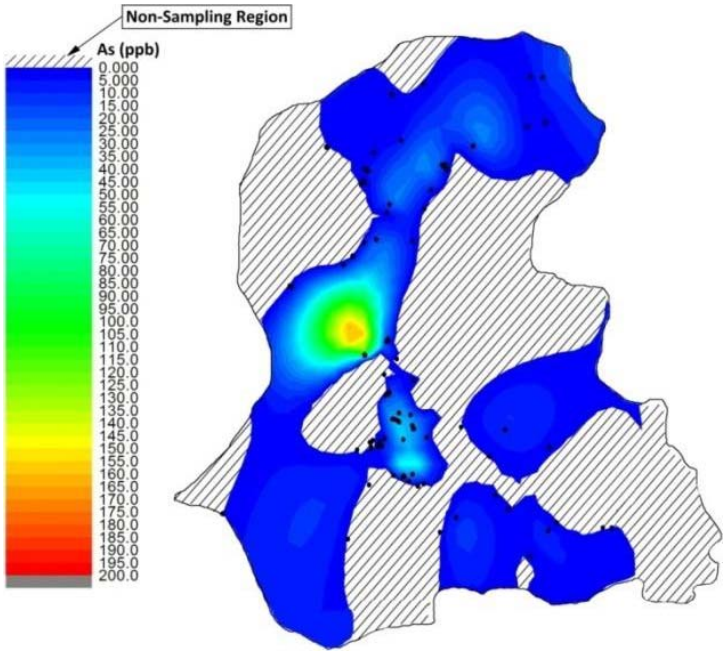

FIG. 3. CONTOUR PLOT OF ARSENIC CONCENTRATION (PPB) FROM GROUND WATER IN SINDH PROVINCE, PAKISTAN AT SELECTED SAMPLING LOCATIONS (BLACK DOTS SHOW SAMPLING LOCATIONS, CROSS- SECTIONAL LINES SHOW THE REGIONS FROM WHERE SAMPLES WERE NOT COLLECTED)

TABLE 3. HEALTH RISK ASSESSMENT THROUGH GROUND WATER CONSUMPTION OF REGIONS LOCATED ON LEFT BANK OF RIVER INDUS IN SINDH PROVINCE

No.	Location Code	Location	As Contamination (?g/L)	EDI (?g/kg-day)	THQ	CR
1.	HL3	Hala	21	0.583	1.94E+00	8.75E+02
2.	HL10		23	0.638	2.13E+00	9.58E+02
3.	HL12		34	0.944	3.15E+00	1.42E+03
4.	HL27		36	1	3.33E+00	1.50E+03
5.	HL40		36	1	3.33E+00	1.50E+03
6.	HL4		37	1.027	3.43E+00	1.54E+03
7.	HL14		38	1.055	3.52E+00	1.58E+03
8.	HL11		39	1.083	3.61E+00	1.63E+03
9.	HL21		40	1.111	3.70E+00	1.67E+03
10.	HL22		40	1.111	3.70E+00	1.67E+03
11.	HL24		43	1.194	3.98E+00	1.79E+03
12.	HL41		51	1.416	4.72E+00	2.13E+03
13.	HL20		70	1.944	6.48E+00	2.92E+03
14.	HL28		96	2.666	8.89E+00	4.00E+03
15.	HL47		101	2.805	9.35E+00	4.21E+03
16.	HL16		149	4.138	1.38E+01	6.21E+03
17.	KP6	Khairpur	25	0.694	2.31E+00	1.04E+03
18.	KP16		46	1.277	4.26E+00	1.92E+03
19.	MT8	Matiari	11	0.305	1.02E+00	4.58E+02
20.	MT11		16	0.444	1.48E+00	6.67E+02
21.	MT12		53	1.472	4.91E+00	2.21E+03
22.	MT13		67	1.861	6.20E+00	2.79E+03
23.	MT15		75	2.083	6.94E+00	3.13E+03
24.	MT14		98	2.722	9.07E+00	4.08E+03
25.	NP3	Nasarpur	35	0.972	3.24E+00	1.46E+03
26.	NP2		44	1.222	4.07E+00	1.83E+03
27.	NP9		56	1.555	5.19E+00	2.33E+03
28.	NP7		57	1.583	5.28E+00	2.38E+03
29.	NP6		66	1.833	6.11E+00	2.75E+03
30.	NP10		75	2.083	6.94E+00	3.13E+03
31.	NF4	Naushahro Feroz	18	0.5	1.67E+00	7.50E+02
32.	NF3		20	0.555	1.85E+00	8.33E+02
33.	PA7	Pano Aqil	11	0.305	1.02E+00	4.58E+02
34.	PA5		20	0.555	1.85E+00	8.33E+02
35.	PA3		27	0.75	2.50E+00	1.13E+03
36.	PA4		37	1.027	3.43E+00	1.54E+03
37.	PA1		73	2.027	6.76E+00	3.04E+03
38.	SK5	Sakrand	42	1.166	3.89E+00	1.75E+03
39.	SK2		195	5.416	1.81E+01	8.13E+03
40.	SK8		204	5.666	1.89E+01	8.50E+03
41.	ST1	Sekhat	18	0.5	1.67E+00	7.50E+02
42.	ST1		49	1.361	4.54E+00	2.04E+03
43.	SK3		20	0.555	1.85E+00	8.33E+02
44.	TM14	Tando Muhammad Khan	27	0.75	2.50E+00	1.13E+03
45.	TM10		70	1.944	6.48E+00	2.92E+03
46.	TM7		97	2.694	8.98E+00	4.04E+03
47.	TP3	Tharparkar	18	0.5	1.67E+00	7.50E+02
Average			53.702	1.492	4.972	2237.589
Minimum			11	0.305	1.018	458.333
Maximum			204	5.667	18.889	8500
Safe Values			10 (µg/L) (WHO Guideline)	-	1	1 in 10^{-6}

of RI have elevated C_d values because of the higher contents of As in ground water. Mahar et. al. [16] also reported that riverine areas of district Rahim Yar Khan, which is located on the border of Sindh and Punjab provinces, Pakistan were contaminated with As and other impurities.

3.6 Health Risk Assessment

The HRA of the left bank RI was performed because it was found more contaminated than the right bank in this study. The people of the studied area consume ground water for their drinking, household and farming purposes. The residents of these areas cannot afford mineral water, therefore, they utilize ground water for their daily use. The estimated daily intake EDI (µg/kg-day) for As is given in Table 3.

EDI values ranged from 0.305-5.667 (µg/kg-day) for As. The highest EDI value of 5.66 (µg/kg-day) was observed in the sample of Sakrand district showing the elevated threat level of As contamination to the local people. The higher EDI values of As can be because of municipal waste, leaching of waste materials in the groundwater, use of excess fertilizers and pesticides by farmers.

The THQ indices were calculated to get a health risk assessment. THQ index for As in potable water was in the range from 1.018-18.889. The results show that the THQ is crossing the safe limits, i.e. (THQ should be less than 1) posing a high health risk to the inhabitants of examined areas. Around, 90% population of the left bank RI is utilizing ground water for their domestic and drinking purposes, hence at high health risk because of As contamination which is "carcinogenic to human beings".

As is the single available element in the periodic table for which there is a cancer slope factor.CR was calculated in the ground water as shown in Table 3. The CR values ranged from 458.333-8500 with an average value of 2237.589 in the ground water of examined region exhibiting elevated risk. It is reported that CR value 1 in 10^6 is significantly considered [12,19]. The results of this study show that the ground water exhibits high risk in the studied areas of Sindh province when compared to USEPA (2010) guidelines. The cancer risk assessment results of this work show the elevated health risk in the observed areas of Sindh.

4. CONCLUSION

The kit method was used to analyze the 214 ground water samples from the both sides of RI. Then AAS technique was applied to analyze 83 samples from the left bank of RI. The high THQ and CR values for As indicated, that higher intake of As in ground water may pose chronic toxicity and carcinogenic risk to the local inhabitants.

Our results suggest that the ground water from the left bank of RI areas i.e. Sakrand, Hala, Matiari, TMK, Nasarpur and Sukkur is not safe for drinking without proper treatment.

Hence drinking water quality and continuous assessment should be conducted at regular intervals to check the quality of drinking water.

As kit and atomic absorption spectrometer results are quite similar with 0.707-19 % SD. The contour plot of As concentration (ppb) in ground water is shown by the map of Sindh and it is observed that the higher levels of arsenic are present on the left bank of RI. Contamination index was calculated for ground water of Sindh and found in the range between 0-19.

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