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ARSENIC CONTAMINATION OF GROUNDWATER IN DADU DISTRICT, SINDH PROVINCE, SOUTHERN PAKISTAN

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Abstract: In this study Arsenic concentration of groundwater samples collected from Dadu District, Sindh Province, Southern Pakistan is presented. About 30 water samples were collected for analysis of As, Fe and other physico chemical parameters. Arsenic in the study area varies form 0-500 µg/l (mean 114 µg/l) while Fe ranges from 1.2 to 22 µg/l (mean 10.6 µg/l), TDS in 23 out of 30 of samples is higher than the permissible limits set forth by World Health Organisation for drinking water. Similarly, As in 23 out of 30 samples shows concentration above the 10 µg/l limit, set forth internationally for drinking water. Groundwater in the study area is characterized as slightly alkaline, slightly-moderately saline and anoxic. Such chemical properties in addition to higher concentration of Fe in the groundwater of the study area may be responsible for the higher concentration of As in groundwater. All these conditions favor higher mobility and solubility of As in groundwater.

Introduction

Arsenic contamination of drinking water has become an important subject of study for environmental scientists all over the world. The "Arsenic Problem" first came to light in the mid 1990s in Bangladesh, since then various regions of the world like Vietnam, India, China, Argentina, Chile, Mexico, Hungary and many parts of USA have been reported to have high levels of Arsenic in drinking water. Tens of millions of people all over the world are assumed to be at risk from Arsenic contamination of groundwater, used for drinking (Jessen, 2009). Arsenic is a known carcinogen, causes Arsenicosis (Sampsons et al., 2008), skin, lung, bladder, Kidney cancers and acute myocardial infarction (Yaun et al., 2007). Other adverse health effects due to chronic exposure of Arsenic contamination are Black foot disease and coronal heart diseases (Tseng, 1977).

Arsenic is ubiquitous in nature and is found in air, water, soil and even in biological systems. More than 30000 tons of Arsenic is extracted annually in elemental form for use in industries. Pesticides manufacturing these days amount for 50% consumption of the total Arsenic produced worldwide. However, it is the geogenic sources of Arsenic which remained the main concern for researchers over the past two decades, when it comes to Arsenic contamination of the groundwater all over the world. The amount of Arsenic in the lithosphere is believed to be 4.01 x 10^{16} Kg, based on the concentration in rocks and minerals (Matschullat, 2000). The natural levels of Arsenic in soils may vary from region to region owing to the heterogeneity of the pedosphere caused by local soil forming factors, especially soil parent material and climate. Allard (1995) suggested that the natural background levels of Arsenic in groundwater may vary form 0.5-0.9 µg/l. On the other hand Driehaus (1994) cites the background levels of Arsenic in groundwater to lie in the range of 0.01-800 µg/l by including Arsenic concentration in the groundwater in the highly mineralized areas. Matschullat (2000) presented a detail review of Arsenic concentration in various environmental compartments in an attempt to delineate Global Biogeochemical Cycle for Arsenic. The extensive literature review shows that Arsenic concentration in groundwater may show greater variance based on regional geological conditions.

In Pakistan however, Arsenic contamination has remained under reported, with a few scholarly and non scholarly reports available. Most of the work in non scholarly sector was carried out by United Nations Development Program (2001) in various districts of Pakistan. Review of scientific papers on the subject have reported Arsenic contamination in drinking water samples of northern, eastern and southern Punjab (Nickson et al, 2005). Arsenic contamination in

drinking water samples obtained from hand pump and tap water is also reported from Karachi City (Rahman, 1996 & 1997). Muhammad et al (2010) in a recent study conducted in a mineralized (Jijal) area have shown that only 2 % of the samples obtained from drinking water sources i.e. surface and groundwater were contaminated with arsenic. Keeping in view the growing concern of Arsenic contamination of drinking water sources and the resultant health risks faced by local population, studies shall be conducted on smaller scales, rather on regional levels.

This study was conducted in order to ascertain Arsenic contamination of groundwater in Dadu district of Sindh province, Pakistan and resultant health risks faced by local population. An attempt was also made to characterize the Arsenic enrichment based on water chemistry in one of its two major sources i.e. geogenic and anthropogenic.

Study Area

Dadu district lies in the North West of Sindh province in between latitude 26° 19 60 N and longitude 67° 34 60 E, with total population of 1,688,811 individuals. The total area of the district is 19,079 sq kilometers divided into seven talukas. The population density in the area is 88.6 persons per square kilometer as compared to the population density of the whole country which is 214.3 persons/km^2 (DCR, 1998). The area is characterized by hot and arid climate with very low precipitation and less humidity. The mean annual rainfall in the study area may range from 120 to 150 mm. Agricultural activities in the area mostly depend upon the scanty rainfall in the monsoon season. Rainfall is the main source of groundwater recharge in the study area, however in the centre of the district Indus may also serve as a source of recharge for aquifers. The aquifers in the study area are alluvial in nature formed mainly by the fluvial deposits of the Indus River. The depth to groundwater table is reportedly 110 meters and the height of the water table is reported to be 23.8 meters. Topographically the northern and southern parts of the district are dominated by the Indus plain and in the west by flat topped hills (Brohi, 2009). Two major surface water sources are the Indus River and the Manchar Lake which lies in the South Western part of the area (Fig. 1).

Materials and Methods

Water Sampling

Two types of water samples were collected in clean polyethylene bottles. One for the analysis of physicochemical parameters in 1.5 liter bottles and for the analysis of Fe in 500 ml bottles. The samples collected for the analysis of Fe were acidified in the field using HNO_3 (APHA, 1998). A total of 30 samples were collected randomly from tubewells and borewells, either privately owned or installed by the irrigation department. The tube wells were flushed for 20 minutes before sampling in order to get a representative sample of the groundwater.

Analysis of Water Samples

Water quality parameters like pH, EC, TDS, Turbidity and DO were analyzed on the spot by using handheld portable meters (Hannah, 2000). Fe was determined using atomic absorption spectrometry at the PCRWR. Arsenic was determined using Hach EZ Arsenic test kit®.

Statistical Analysis

For statistical analysis of the data computer software packages like Minitab 13 and Statistica 11 were used. Correlation analysis among the parameters was also carried out, however, only those significant to the discussion are reported.

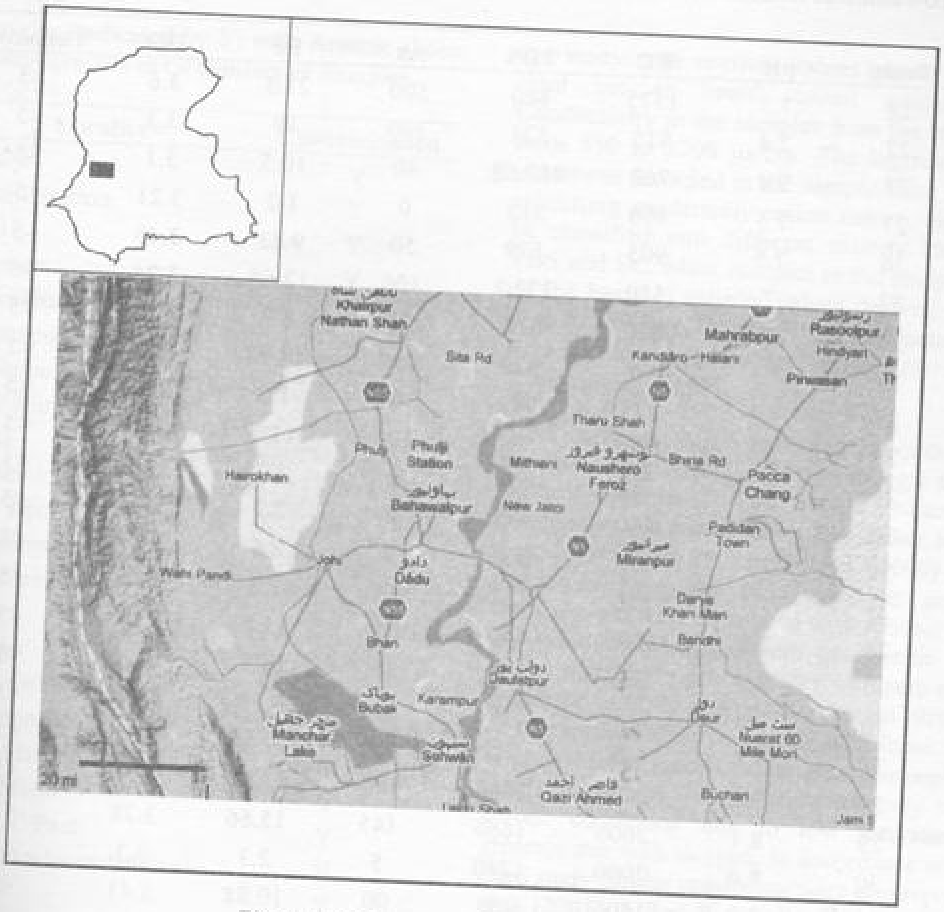

Fig. 1. Location map of the study area.

Results and Discussions

Table 1 summarizes concentration of various parameters studied. Temperature in the groundwater samples in the study area ranges from 25-31°C. The lowest temperature was recorded at village Sitta, U.C. Paatt and the highest was recorded at Phulji station. Temperature is an important water quality parameter. The solubility of various solvents in water depends upon the differences in temperature. Gases tend to be soluble at lower temperatures in water; conversely other substances are soluble in water at higher temperatures. pH in the study area varies from 7 to 8.4 with highest pH value recorded at UC Kakar. The pH values in the study area indicate that ground water is slightly alkaline in nature. pH plays an important role in Arsenic mobility in aquifers and its speciation. Arsenic mobility in groundwater is largely influenced by two types of chemical processes: Adsorption and desorption reactions and Solid phase precipitation and dissolution (Hinkel and Polette, 1999). Dzomback and Morel (1990) have shown that arsenite and arsenate adsorption to aquifer materials decreases with the increase in pH mainly in between the range of 6 to 9. Similar pH dependence of Arsenic adsorption and desorption process is also suggested by other authors (Stumm and Morgan, 1996; Manning and Goldberg, 1997).

Turbidity in almost all the samples remained below the permissible limit of 5 NTU set by WHO guidelines for drinking water quality.

Table 1. Physico-chemical Characteristics of Groundwater Samples, Dadu District, Sindh,Pakistan.

S.No	Temp	pH	EC	TDS	As	Fe	DO	Turbidity	Sali
1	28	7.5	1375	880	500	21.5	3.6	<5	S
2	27	7.4	815	521	300	19	3.3	<5	S
3	27	7.4	762	487.68	40	10.5	3.1	<5	S
4	27	7.5	800	512	0	1.2	3.21	<5	S
5	26	7.5	905	579	50	9.83	3.45	<5	S
6	27	7	580	371.2	100	12.66	3.24	<5	N
7	26	7	820	524	20	8.7	3.54	<5	S
8	27	7.3	825	528	250	14.98	3.32	<5	[illegible]
9	27	7.4	923	590	0	1.2	3.56	<5	[illegible]
10	27	7.2	831	531	100	11.7	3.2	<5	
11	29	7.9	730	467	0	1.2	3.22	<5	
12	30	7.8	840	537	5	2.2	3.3	<5	
13	31	7.1	939	600	8	2.5	3.44	<5	
14	25	7.5	550	352	0	1.2	3.44	<5	
15	28	7.5	1000	640	35	11.8	3.56	<5	
16	30	7.5	1275	816	35	11.9	3.3	<5	
17	30	7.3	1250	800	10	6.78	3.31	<5	
18	31	7.8	826	529	40	10.68	3.21	<5	
19	29	7.8	2600	1664	100	13.69	3.25	<5	
[illegible]	29	8.1	2600	1666	145	15.66	3.28	<5	
21	30	8.4	2000	1280	5	2.3	3.3	<5	
22	30	7.9	1500	960	90	10.88	3.41	<5	
23	28	8.1	648	414	150	14.35	3.42	<5	
24	29	7.8	3200	2048	150	15	3.43	<5	
25	25	7.8	2020	1292	150	12	3.23	<5	
26	26	8.1	600	384	24	8.9	3.24	<5	
27	31	7.6	887	567.68	270	22	3.21	<5	
28	28	7.5	1375	880	500	22.3	3.23	<5	
29	27	7.4	815	521.6	300	10.6	3.24	<5	
30	27	7.4	762	487	60	11	3.2	<5	
Units	C°		µS/cm	mg/l	µg/l	µg/l	mg/l		
WHO (2004)				500	10	0.3	5		
Minimum	25	7	550	352	0	1.2	3.1		
Maximum	31	8.4	3200	2048	500	22.3	3.6		
Mean	28.1	7.6	1168.4	747.6	114.6	10.6	3.3		

Table 2. Localities (indicated by Y) with Arsenic above 10 micrograms/l in Groundwater Samples.

S. No	Locality	Contaminated
1	Phulji	Y
2	Phulji Station	Y
3	Johi	Y
4	Sehwan	Y
5	Hairokhan	Y
6	Karampur	Y
7	Daulatpur	Y
8	Qazi Ahmed	N
9	Dadu	Y
10	Mithiani	N
11	New Jatoi	Y
12	Mahrabpur	N
13	Kandiaro	N
14	Bhan	Y
15	Bubak	Y
16	Bhati Colony	Y
17	Old Moro Road	Y
18	Piaro Station	Y
19	Pipri Minor	Y
20	Sitta UC Paat	Y
21	UC Makhdoom Bilawal	Y
22	Kakar	Y
23	Hingora	Y
24	Chowdagi	Y
25	Miranpur	N
26	Buchari	N
27	Daur	Y
28	Darya Khan Mari	N
29	Bandhi	Y
30	Tharu Shah	Y

Total Dissolved Solids in the water samples from the study area range from 352 to 2048. The lowest TDS value is recorded at Sitta UC Paatt and the highest concentration of TDS comes from the sample obtained near Hingora village. The World Health Organization (WHO, 2004) has setup a permissible value of 500 mg/l TDS based on health safety purposes for groundwater. As shown in Table 1 about 23 samples in the study area register values above the permissible limit set as health based guideline. Electrical Conductivity in the samples from the study area ranges from 550 to 3200 µs/cm. The highest value of 3200 µs/cmwas recorded in the sample from Hingora village exhibiting moderately saline nature. Groundwater can be classified into different salinity classes based on TDS and EC. Most samples in the study area classified on the basis of salinity values derived from EC show slightly saline to Moderately Saline nature. Mobility of Arsenic in groundwater tends to increase with increasing salinity.

Dissolved oxygen concentration in the ground water samples ranged from 3.1 to 3.6 mg/l thus exhibiting anoxic conditions. The lowest concentration was recorded in the sample from Pir Shakar and the highest from Chowdagi. Nickson et al (2000) reported that appreciable amounts of Oxygen in groundwater of Ganges plain were correlated with Arsenic concentration of less than 50 µg/l where as Arsenic concentration higher than, 330 µg/l coincides with zero or low oxygen saturation in other parts of the Ganges plain. The results of this study are in accordance with those of Nickson et al (2000) further substantiating the assumption that high levels of Arsenic in groundwater may result due to anoxic conditions due to low saturation levels of groundwater with oxygen. In accordance with the above cited study similar conditions were also reported by Berg et al (2001) in Red River alluvial tract near the city of Hanoi in Vietnam.

Iron concentration in the groundwater samples varied from 1.2 to 22.3 µg/l. The lowest Fe concentration was recorded in the sample from UC Makhdoom Bilawal and the highest was recorded in the sample from Kakar. Fe is a commonly occurring metal in soils, rocks and minerals. Fe dissolves when groundwater comes in contact with these materials. WHO does not maintain any health based guideline for Fe however a permissible limit of 0.3 µg/l is suggested for aesthetic reasons. Fe concentration above this limit may cause metallic taste and staining of plumbing fixtures and cloths thereby reducing the usefulness of water. All the samples in the study area exceeded the permissible limit of 0.3 µg/l set by WHO. As is clear from the Table 1, groundwater in the study area shows Iron rich conditions. Fe dissolves rapidly in water especially when groundwater shows anoxic (oxygen

poor) conditions. Further, Fe plays a vital role in the mobility and solubility of Arsenic in groundwater. Higher Fe concentration in groundwater may enhance the mobility and solubility of Arsenic, resulting in higher concentrations (Bose and Sharma, 2002; Han et al., 2002).

Arsenic

Arsenic concentration in the study area shows greater degree of variation. Ranging from 0 to 500 µg/l. The health based guideline limit set forth for Arsenic in drinking water is 10 µg/l. About 7 samples in the study area show concentration below 10 µg/l while the rest of the samples (23) show concentration higher than the guideline value. As shown in the frequency distribution diagram (Fig 2) for Arsenic concentration in the samples from the study area about 50 % of the samples lie in the class of 0-50 µg/l, 2 samples in 50-100 µg/l, 7 samples in 100-150 µg/l, 2 samples each in the class 250-300 µg/l, 300-350 µg/l and 450-500 µg/l respectively. Furthermore, As and Fe show a very significant statistical correlation (0.815). Studies conducted globally in alluvial tracts and aquifers suggest that As and Fe are positively correlated in both groundwater and sediment samples (Ahmed et al 2003). Nickson et al., (2004) reported Arseni concentration above 10 µg/l and 50 µg/l in 21 and 2 samples out of 49 samples taken from urban and rura areas in Muzaffargarh Punjab respectively. He als reported that the Arsenic concentration in groundwate samples from urban areas were higher than the sample collected from rural areas. However, no suc distinction in Arsenic concentration based o population centers could be made here in this study Farooqi et al (2007) conducted research on Arseni concentration in groundwater in Lahore and Kasu areas and reported that Arsenic concentration varie from 32 to 1900 µg/l, with an average concentration o Arsenic in shallow groundwater being 235 µg/l. Thu Arsenic concentration in groundwater in Dadu Sind based on our finding are much lower than that reporte by Farooqi et al (2007) in Lahore and Kasur areas Furthermore, they found a significant impact of hig pH (7.3-8.7) on Arsenic concentration in groundwate which substantiates the pH levels (7.5-8.1) found i this study and its possible impact on increase concentration of Arsenic in the groundwater, a discussed earlier Arsenic concentration in groundwate increases with increased levels of alkalinity.

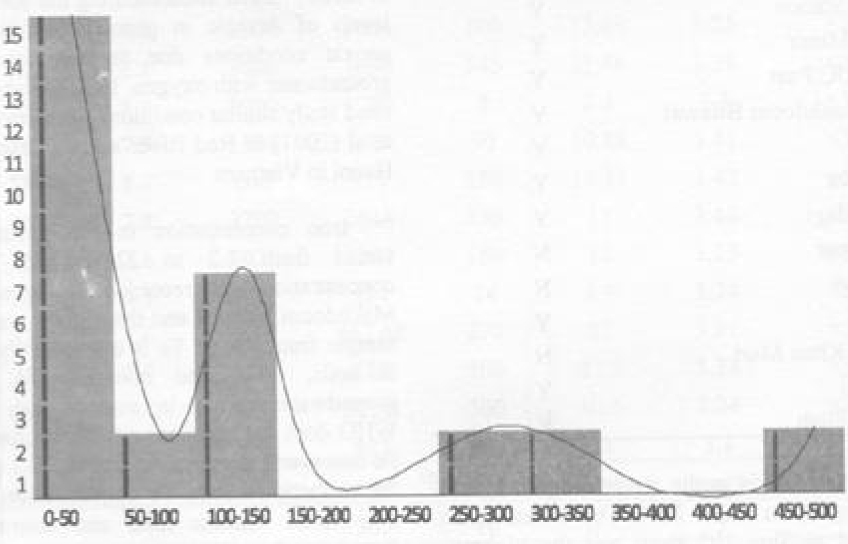

Fig. 2. Frequency Distribution of Arsenic Concentration in Groundwater Samples, Dadu District, Sindh, Pakista

However, by comparing the results of Arsenic in drinking water samples (0.08 ppb) as reported by Rahman et al (1997) from Karachi, the average Arsenic concentration of 114 µg/l in this study is much higher. Similarly, Jaleel et al (2001) reported that Arsenic and Mercury concentration were found to be nil during their investigations of the drinking water sources in east Karachi. The result from these studies further strengthens the assumption that groundwater Arsenic in Sindh region may by and large occur as a result of geogenic sources instead of anthropogenic ones. Arain et al (2008) investigated Arsenic concentration in surface water, sediments, soils and vegetables in Sehwan area of Sindh province which lies in close proximity to the area under the focus in this study. Their analysis showed that the local population in the study area is exposed to alarming levels of Arsenic in their environment via the food chain. They calculated the daily uptake of Arsenic for each adult individual in the area to be 343.3 µg/day. Similarly the levels of Arsenic in Dadu Sindh are much higher than those reported by Jhakhrani et al (2010) from Khairpur.

Studies also suggest that geogenic Arsenic contamination of groundwater is more profound in alluvial aquifers, all over the world (Nickson et al 1998; Bhattacharya et al., 2006; Korte 1991; Saunders et al 2005, Sonderegger 1998, Welch et al 2000).

Conclusions

Arsenic concentration in 23 out of 30 localities investigated in this study show levels above the permissible limit of 10 µg/l, thus posing a serious health risk to the local population in the area. Similarly, Fe concentration in all the samples and TDS in 23 samples show undesirable concentration. The alkaline, slightly saline and anoxic nature of groundwater is resulting in higher concentration of Arsenic in the area, as such conditions increase the mobility of Arsenic. The highly significant correlation between Arsenic and Iron may suggest the greater affinity of As towards Fe and similar geochemical sources. As, Fe play an important role in the mobility and solubility of Arsenic in groundwater aquifers the higher concentration of Fe may also be responsible for high levels of Arsenic in groundwater of Dadu district. From all the above factors it may be concluded that Arsenic contamination of groundwater in Dadu district, Sindh is mainly due to geogenic sources.

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