

Arsenic and F⁻ testing of groundwater is considered as an important activity because As and F⁻ are now recognized as the most serious inorganic contaminants in drinking water on a worldwide basis and due to its serious effects on human health (Smedley et al. 2002). Considering the adverse effects of As and F⁻ on human health and increasing incidences of As and F⁻ pollution in the world, Pakistan Council of Research in Water Resources (PCRWR) and United Nations Children's Fund (UNICEF) has jointly carried out preliminary investigative studies for initial detection which led to detailed monitoring. Major programs in this regard are as following:

1. Northern Punjab phase-I and II (1999–2000)
2. National survey for As (2001)
 - effort of UNICEF, LG&RD, PCSIR and
3. National Water Quality Monitoring Program (NWQMP 2001–2006)
4. Arsenic mitigation program (2002–2004)
 - Southern Punjab (2002–2003)-Phase-I and II
 - Central Sindh (2003–2004)-Phase-I

The data collected from the Phase-I (2001–2002) of NWQMP program revealed the presence of As above 50 ppb in some cities of Punjab particularly in Multan, Sheikhpura, Lahore, Kasur, Gujranwala and Bahawalpur. The situation of presence of As in groundwater of Southern Punjab has become clearer as the result of detailed testing by UNICEF and PCRWR. According to field data, 22.63 % samples had As concentration above the WHO guidelines of 10 ppb (Ahmad et al. 2004).

It was reported that As contamination exceeded 200 ppb in some districts of Sindh (Ahmad et al. 2004). The province of Sindh forms the Lower Indus basin with an area of 1, 40,915 km². The population of the province stands around the 40 million souls. In 2001, the Public Health Engineering Department (PHED), Government of Sindh in collaboration with the UNICEF, Sindh Karachi conducted drinking water quality survey in nine districts of Sindh in order to determine presence of As in drinking water. For this evaluation study five samples were taken from each Union Council of these districts. The survey found that out of nine (09) districts, five districts namely Khairpur, Dadu, Nawabshah, Nausheroferoz, and Thatta contained As in drinking water. Thirtyfive districts from all the four provinces monitored through an inter-organizational program.

Under the arid conditions in Pakistan, high F⁻ concentrations and high salinity appear to be more widespread water-related problems. Fluoride has also been reported from some areas of Pakistan; F⁻ is contained in most groundwater, however, concentrations are commonly <1 mg/L, with the highest concentration at 2.8 mg/L (www.pcrwr.gov.pk/Arsenic), but F⁻ testing is not done in detail as compared to the As testing, while on soil and sediment pollution no data is available (Fig. 2.1; Tables 2.1 and 2.2).

The main sources of drinking water in Pakistan come from ground or surface water which is being highly polluted by freeway disposal of agricultural,

industrial and domestic wastes into natural water bodies (Arain et al. 2009a, b). Studies by Farooqi et al. (2007a, b), Arain et al. (2009a, b), revealed high levels of As in different regions of the country. Government of Pakistan along with collaboration of UNICEF, conducted a study in 2004 in order to assess arsenic level in different parts of the country. From total of 144 districts, 35 were selected and 8,712 drinking water samples were collected. Most of the samples were found contaminated with As in a range of 0–500 µg/L and 9 % samples were found contaminated with >10 µg/L and 0.7 % with >50 µg/L (Fatmi et al. 2009).

2.1 Spatial Extent of Arsenic Contamination

For the very first time, Ashraf et al. (1991) conducted a study in 1990 for identification of different trace metals in three large water reservoirs of the country including Tarbela, Chashma and Lloyd. The order of elevated concentrations of As were Chashma > Tarbela, Lloyd with values of 750, 620 and 620 µg/L respectively. After that no published study was reported till 1997 on As contamination in water. Aziz (2005) in his review highlighted the results of unpublished report that groundwater sampling from

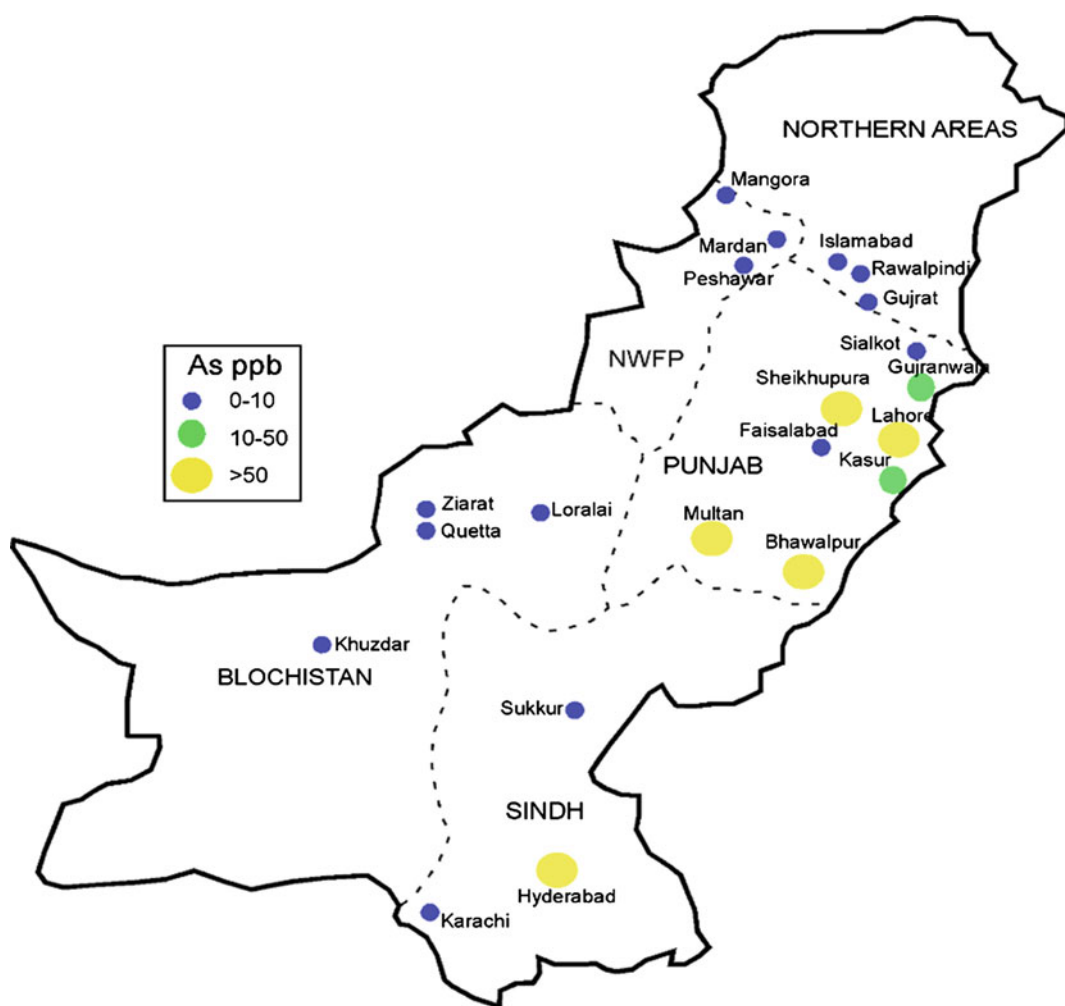


Fig. 2.1 Documented arsenic areas in Pakistan

Table 2.1 Results of the initial screening done by PCRWR and UNICEF

Province	Total area (km ²) ^a	Population ^a	Total districts ^a	Number of districts having wells contaminated with As ^b			
				<10	10–50	>50	Unknown
Punjab	205,345	73,621,000	36	6	13	14	3
Sindh	140,914	30,440,000	23	2	1	10	13
^c Balochistan	347,190	6,566,000	30	NS	NS	NS	NS
^c Khyber Pakhtunkhwa	74,521	17,744,000	24	NS	NS	NS	NS

^aSource Pakistan Bureau of Statistics, Government of Pakistan, 1998

^bSource Pakistan Council of Research in Water Resources, 2001

^cAccording to PCRWR, In Khyber Pakhtunkhwa, 156 samples were analyzed, out of which 0.3 % were found exceeded the WHO limits. Samples taken from Peshawar, Mangora and Mardan were found with As concentration less than 10 mg/L. In Balochistan, 71 samples were analyzed out of which 1.4 % exceeded the WHO limits and Ziarat, Quetta, Loralai and Khuzdar were the areas where As concentration were found less than 10 mg/L (PCRWR 2001)

NS No study conducted

Table 2.2 Arsenic and fluoride analysis of groundwater samples in selected cities of Pakistan from 2002 to 2006 by PCRWR

Province	City	Parameter	2002	2003	2004	2005	2006	Number of samples
			Percentage exceeding the WHO limit As (10 ppb) and F (1.5 mg/L)					
Punjab Province	Bahawalpur	As	72	68	76	80	88	767
		F	4	4	4	4	4	
		No. of samples	25	25	25	25	25	
	Faisal abad	As	—	—	—	—	—	
		F	7	8	8	15	15	
		No. of samples	14	13	13	13	13	
	Gujranwala	As	7	43	43	43	64	
		F	—	—	—	—	—	
		No. of samples	14	14	14	14	14	
	Gujrat	As	—	—	—	—	—	
		F	—	—	—	—	—	
		No. of samples	9	9	9	9	9	
	Kasur	As	30	40	80	90	100	
		F	30	20	20	20	20	
		No. of samples	10	10	10	10	10	
	Lahore	As	31	100	100	100	100	
		F	—	—	—	—	—	
		No. of samples	16	16	16	16	16	

(continued)

Table 2.2 (continued)

Province	City	Parameter	2002	2003	2004	2005	2006	Number of samples
			Percentage exceeding the WHO limit As (10 ppb) and F (1.5 mg/L)					
	Multan	As	75	94	88	94	94	
		F	—	—	—	—	—	
		No. of samples	16	16	16	16	16	
	Rawalpindi	As	—	—	—	—	—	
		F	—	—	—	—	—	
		No. of samples	15	14	15	15	15	
	Sarghodha	As			13	13	13	
		F			8	4	4	
		No. of samples			24	24	24	
	Shekupura	As	45	64	45	64	73	
		F						
		No. of samples	11	11	11	11	11	
	Sialkot	As		10	20	20	20	
		F	—	—	—	—	—	
		No. of samples	10	10	10	10	10	
KPK Province	Abbottabad	As	—	—	—	—	—	196
		F	—	—	—	—	—	
		No. of samples				11	11	
	Mangora	As	—	—	—	—	—	
		F	—	—	—	—	—	
		No. of samples	10	9	10	10	10	
	Mardan	As						
		F						
		No. of samples	12	12	12	12	12	
	Peshawar	As	—	—	—	—	—	
		F	—	—	—	—	—	
		No. of samples	13	13	13	13	13	

(continued)

Jhelum, Gujrat and Sargodha districts has shown exceeded As concentrations in some samples above the WHO guidelines. A study conducted by Rahman et al. (1997) reported relatively less concentrations (80 µg/L) of As in ground water samples from Karachi but this concentration was

still very high when compared to permissible limits (10 and 50 µg/L) of WHO. In 2000, a joint study by the Pakistan Council of Research in Water Resources (PCRWR) and United Nations Children Fund (UNICEF) was conducted and the issue of As was raised as a threat to drinking

Table 2.2 (continued)

Province	City	Parameter	2002	2003	2004	2005	2006	Number of samples
			Percentage exceeding the WHO limit As (10 ppb) and F (1.5 mg/L)					
Balochistan Province	Khuzdar	As	—	—	—	—	—	319
		F	—	—	—	—	—	
		No. of samples	8	8	11	9	11	
	Loralai	As	—	—	—	—	—	
		F	55	10	9	9	9	
		No. of samples	11	10	11	11	11	
	Quetta	As	—	—	—	—	—	
		F	42	31	24	22	24	
		No. of samples	38	35	34	32	34	
	Ziarat	As	—	—	—	—	—	
		F	—	—	—	—	—	
		No. of samples	8	7	10	10	10	
Sindh Province	Hyderabad	As	—	—	—	—	—	275
		F	—	—	—	—	—	
		No. of samples	15	15	15	15	15	
	Karachi	As	—	—	—	—	—	
		F	7	14	4	4	4	
		No. of samples	28	28	28	28	28	
	Sukkur	As	—	—	8	—	8	
		F	—	8	—	8	8	
		No. of samples	12	12	12	12	12	
								1,557

water in Pakistan. The results of monitoring program showed As contamination in many areas of Punjab and Sindh province (PCRWR 2004). Ahmad et al. (2004) reported that 16–36 % of population of Sindh is exposed to As contaminated water with over 10–50 µg/L.

A total of 49 groundwater samples were collected by Nickson et al. (2005) from Muzaffargarh, a district of southern Punjab, reported As contamination in 58 % samples with exceeded limits above 10 µg/L. Samples from 21 wells had As contamination level >50 µg/L and these wells were all found in urban areas while rest of wells containing less than 50 µg/L were found in

outside the urban areas. A study conducted by Farooqi et al. (2007a, b) in eastern part of the Punjab province reported high As concentrations in water. In first attempt, Kalalanwala and Kot Asadullah, two small villages of the area, were selected for assessment of As contamination in water. The results reported arsenic concentrations range from 32 to 1,900 µg/L in the analyzed groundwater samples. These values are alarming are far more than permissible limits of WHO. Higher As concentration was found in shallow groundwater samples. Another finding of this study was presence of As in rain water samples with a maximum value of 90 µg/L which

indicates the possible contribution of atmospheric pollutants to groundwater contamination (Farooqi et al. 2007a). Another study by the same author (Farooqi et al. 2007b) in the same area with sampling from different wells revealed high As contamination of groundwater. It was reported that from a total of 149 groundwater samples, 91 % were found contaminated with As concentration more than 10 µg/L. A positive correlation between As and pH was also observed. Overall, groundwater samples were found contaminated with arsenic in a range from 1 to 2,400 µg/L (Farooqi et al. 2007b).

Apart from groundwater, lake water is also heavily contaminated by As in Pakistan. Manchar lake is one of the major shallow water natural lake of Pakistan whose water is used for agriculture, fishing, drinking and domestic purposes. A study by Arain et al. (2008) reported high levels of As in this lake water ranged from 60.4 to 101.8 µg/L which is 6–10 times more than permissible limits of WHO. Another study by Arain et al. (2009a, b) conducted at the same site by taking 5 sampling sites of lake and 18 sampling sites of groundwater from the adjacent areas of Manchar lake showed high concentration of As levels. The As concentration in 1944 groundwater samples ranged between 23.3 and 96.3 µg/L which is unable for drinking purposes. The lake water was also found heavily polluted and ranged between 35 and 157 µg/L. A study at Jamshoro district which is located in southwest edge of the Sindh province reported varied As concentrations ranged between 13.0 and 106 µg/L in groundwater and 3.00–50.0 µg/L in surface waters (Baig et al. 2009). The As concentration in river water from Lahore was reported to be 2,400 µg/L (Farooqi et al. 2009) which is then used for irrigation and drinking purposes and may highly contaminate the adjacent soils where this water is used for agricultural purposes. Muhammad et al. (2010) analyzed surface and groundwater of Jijal-Dubair, Besham and Alpuri of northern Kohistan areas for As concentration. The highest As concentration was reported in Dubair (16.69 µg/L) in surface waters. Overall, the As concentration in ground and surface waters of Dubair, Besham and Alpuri in µg/L

were <0.03 to 0.48 and 0.13 to 16.69, 0.05 to 1.11 and <0.03 to 0.45, 0.98 to 2.02 and <0.03 to 0.02 respectively. Except one value of Dubair in surface water, all other As concentrations were in the ranges allowed by WHO for safe drinking water.

2.2 Depth Dependent Contamination of Arsenic

Hydro geochemical investigation regarding As is very important in order to understand the release of As into groundwater aquifers. According to Farooqi et al. (2007a, b) flowing rate and direction of groundwater deeply affect the chemistry of groundwater and these are further dependent upon the geological profile of the area under consideration. In Pakistan, very rare work has been done in order to understand the relationship of deep aquifers and geological profile due to which As contamination of ground water has not been done. These studies were carried out in east Punjab by Farooqi et al. (2007a, b) but still the complete understanding of the geochemical behavior of As in geological profiles and underground water aquifers is unclear and demands further investigations. Farooqi et al. (2007a, b geo) describes the physico-chemical behavior of As in the area and reported high As concentrations in shallow depths. It is because that As mobilizes at high pH and EC which means that under alkaline conditions, As mobilizes from bound forms under oxidizing conditions (Smedley and Kinniburgh 2002). Furthermore, As releases to underground aquifers through oxidation of arsenic-bearing sulfide minerals or desorption of FeOOH adsorbing As at high pH and decrease of redox potential of the groundwater (Farooqi et al. 2007a, b geo). In east Punjab, As (V) was found to be the dominant As species and it mobilizes in alkaline conditions, otherwise it is adsorbed on Fe-oxyhydroxide/oxide at weakly acidic to neutral pH conditions. The study of Farooqi et al. (2007a, b geo) showed a negative correlation between As and Fe which indicates that FeOOH controls the As concentration in the studied groundwater. The deep aquifers >40 m depth was

found most polluted with As which is the indication of high pH and Na-HCO_3^- dominant type of As, indicating typical characteristics of groundwater chemistry in stagnant aquifers. Another study by Farooqi et al. (2009) in the same area indicated that wet and dry deposition of atmospheric pollutants cause As pollution in the local soil. It was reported that soil of east Punjab has low pH but it increases owing to extensive fertilizer application in the area which mobilizes the As adsorbed onto the soil particles. After mobilization, As is released into the water and infiltrate into the shallowest groundwater. Furthermore Farooqi et al. (2007a, b) reported that As contaminated groundwater contain NO_3^- as dominant species as compared to NH_4^+ , indicating the oxidizing condition for As (V) to become a dominant species form of As in the area (Table 2.3).

2.3 Population Exposed to Arsenic Contamination

Ground and surface water contamination of heavy metals through anthropogenic activities like large scale use of chemicals in agriculture and improper discharge industrial and municipal waste is attributed to major public health concern specially in developing countries like Pakistan where no proper waste management and treatment system is present (Haque et al. 2007). Arsenic is one of the most toxic heavy metal in context of human health globally and in the countries like India, Bangladesh, China and Nepal it has been reported as a major threat to health (Azizullah et al. 2011; Haque et al. 2007). Similar situation is present in Pakistan and according to a study conducted by Rahman et al. (1997) a large number of population in the

Table 2.3 Concentration of As in Pakistan coming from different sources ($\mu\text{g/L}$)

Location	Source	No. of samples (n)	As ($\mu\text{g/L}$)	Mean value	References
<i>Groundwater</i>					
Various spots in Karachi	Groundwater	–	–	80	Rahman et al. (1997)
Multan	Well water	3	60–1000	–	Nickson et al. (2005)
Muzaffargarh	Well water	46	0.0–400	–	Nickson et al. (2005)
Kalanwala, Punjab	Well water from residential area	24	32–1900	–	Farooqi et al. (2007a)
Manchar lake, Sindh	Hand pump water	1,944	23.3–96.3	60.2	Arain et al. (2009b)
Jijal-Dubair	Groundwater	10	0.13–16.69	6.07 ± 6.23	Muhammad et al. (2010)
Besham	Groundwater	15	<0.03 –0.45	0.14 ± 0.18	
Alpuri	Groundwater	12	<0.03 –0.02	0.01 ± 0.01	
Manchar lake adjacent areas	Groundwater	–	–	60.2 ± 12.5	
Jamshoro, Sindh	Groundwater	–	13–106	–	Baig et al. (2009)
Dera Ghazi Khan	Groundwater	–	0.37–29.30	–	Malana and Khosa (2011)
Lahore and Kasur districts, Punjab	Shallow groundwater	32		235	Farooqi et al. (2007a)
Lahore and Kasur districts, Punjab	Middle groundwater	17		45	Farooqi et al. (2007a)

(continued)

Table 2.3 (continued)

Location	Source	No. of samples (n)	As (µg/L)	Mean value	References
Lahore and Kasur districts, Punjab	Deep groundwater	3		60	Farooqi et al. (2007a)
<i>Surface water</i>					
Manchar Lake	Lake water	150	35–157	97.5 ± 28.5	Arain et al. (2009b)
Tarbela Reservoir	River water	–	–	0.620 ± 0.040	Ashraf et al. (1991)
Chashma Reservoir	River water	–	–	0.750 ± 0.146	Ashraf et al. (1991)
Lloyd	River water	–	–	0.620 ± 0.051	Ashraf et al. (1991)
River Ravi, Lahore	River water	5	0.32–1.8	–	Tariq et al. (1994)
River Chanab	River water	1	–	7	Nickson et al. (2005)
Manchar lake	Lake water	–	–	97.5 ± 28.5	Arain et al. (2009a)
Manchar lake		2,160	76.5–86.1	–	Kazi et al. (2009)
Besham	Surface water	9	0.05–1.11	0.71 ± 0.35	Muhammad et al. (2010)
Jamshoro, Sindh	Surface water	–	3.0–50.0	–	Baig et al. (2009)
Jijal-Dubair	Surface water	8	<0.03–0.48	0.24 ± 0.34	Muhammad et al. (2010)
Alpuri	Surface water	8	0.98–2.02	1.50 ± 0.73	Muhammad et al. (2010)
<i>Industrial wastewater</i>					
Peshawar Industrial Estate No. 1 Peshawar	Industrial discharge water	–	–	643	Rehman et al. (2008)
Gujranwala Industrial Estate No. 2	Industrial discharge water	–	–	475	
Hattar Industrial Estate Haripur	Industrial discharge water	–	–	942	

country is exposed to high doses of Arsenic and are under risk of various health problems and overexposure may cause a decrease in the production of red and white blood cells, gastrointestinal irritation, disruption of heart rhythm, blood vessels damage and may cause “pins and needles” sensation in hands and feet (Abernathy et al. 2003). Arsenic concentration of 80 µg/L was found in groundwater samples of Karachi (Rahman et al. 1997). Recently a study conducted in eastern Punjab reaching have reported

a high concentration in groundwater reaching 1,900 and 2,400 µg/L and 91 % of samples have exceeded the WHO standard limits of 10 µg/L (Farooqi et al. 2007a, b). population living close to large water channels like river, streams and canals have a higher risk of health related problems and in Pakistan and it has been reported that, the health burden in the skin lesions alongside the river Indus suggests that there is a strong link present between proximity of river and Arsenic contamination in ground water

(Fatmi et al. 2009; Shafiq et al. 2011). Nafees et al. (2011) reported that decrement in lung function is significantly related with chronic exposure to arsenic in drinking groundwater among population living around Indus river in district Kahirpur, Sindh. A study conducted by Masuda et al. (2010) reported a high concentration of Arsenic in the sediments of village of Kalalanwala, Punjab, Pakistan and this high concentration was attributed to various anthropogenic sources like industrial waste, or detrital chlorite. Arsenic concentration in drinking water and tobacco smoking was correlated with human health in the population living in the vicinity of Manchar lake, southern Sindh and it was revealed that high concentration of Arsenic in lake water (35.2–158 µg/L) and in local cigarette tobacco was attributed to respiratory effects among the population (Arain et al. 2009a, b). Industries play a major role in the increase in heavy metal contamination of groundwater and these heavy metals when enter into the food chain through agriculture or groundwater seepage, have potential to cause some serious health issue (Rehman et al. 2008). Pathway of arsenic may also be related to occupational exposure especially those people working in various industries and a study in the industrial estates of Gujranwala, Peshawar and Hattar have shown a significant increase in the arsenic concentration (0.942 mg/L) in the groundwater and ultimately affecting the health of the population exposed to it (Rehman et al. 2008). Southern Punjab has also been reported under the influence of arsenic contamination and a study conducted by Nickson et al. (2005) reported a high concentration of arsenic in the urban areas of District Muzaffargarh however, the concentration in the rural areas was found within permissible limits and this low arsenic level was attributed less pollution level in the rural areas. In conclusion, ground and surface water of most areas especially urban and industrial areas are under the high influence of Arsenic contamination and population exposed to this contamination has serious threats to their health. Therefore mitigation measures must be taken to minimize the burden of arsenic exposure and

must be considered a priority and included in the water policies. Millions of people that reside along the banks of river Indus, principally in Punjab and Sindh provinces in Pakistan are exposed to high level of arsenic and should be a major target for mitigation.

2.4 Epidemiological Investigation of Arsenic in Pakistan

Arsenic concentration is found to be high in different areas of Pakistan in ground and surface water which is used for drinking and irrigation purposes. By the use of As contaminated water, public health is severely affected in the country (Shah et al. 2009). Rare epidemiological investigations have been carried out regarding arsenic in the country. Although exposure to even low quantities of arsenic is dangerous and can cause severe diseases and need epidemiological investigations by public health officials and professionals but unfortunately there is less awareness regarding this serious issue. Kazi et al. (2009) conducted epidemiological investigation in Sindh to reveal the health effects of arsenic. Their findings showed that 61–73 % population suffered from chronic arsenic toxicity residing on the bank of Manchar lake. Melanosis and keratosis were the commonly found diseases owing to arsenic toxicity. A strong correlation was also observed in drinking water and patients samples (hair and blood samples of exposed skin) in terms of arsenic concentration which indicated that As contaminated drinking water is the source of such diseases. Other health problems like anemia, respiratory effects, muscles cramps and gastrointestinal effects were also observed in the patients. All these diseases were found in those effected persons who had high As intake in their diet or drinking water. The people consuming less As contaminated water were found free from such problems discussed above. At the same area, but with different sampling location, Arain et al. (2009a, b) conducted a study in Bobak village near Manchar lake and found that

Table 2.4 Diseases reported in Pakistan due to high As contamination

Water source	Disease	City/area	References
Ground water	Skin lesions	District Khairpur	Fatmi et al. (2009)
Drinking water	Respiratory diseases	Southern Sindh	Arain et al. (2009a, b)
Drinking water	Lungs function decrement	District Khairpur	Nafees et al. (2011)
Ground and surface water	Cancer risk	Kohistan region	Muhammad et al. (2010)

30–40 % of people were suffering from skin lesions and rough skin with black dots possibly due to exposure of high arsenic concentrations. Malik et al. (2009) recognized drinking water as one of the major source of arsenic intake by humans. The authors also describes that detection of arsenic in drinking water is a difficult process because of involvement of complex analytical techniques and without its proper detection, one cannot find its presence in water because even at high As concentrations in drinking water, it does not accompanied any change in taste, odor or visible appearance of drinking water (Table 2.4).

2.5 Sources and Causes of As Contamination in Pakistan

Natural and anthropogenic are the main sources of water contamination (Arain et al. 2009a, b) including industrial, municipal and domestic disposal in water systems (Ahmad et al. 2004). Intensive agricultural system also causes arsenic pollution through runoff containing organic and inorganic arsenic fertilizers. Similarly industrial activities contribute a lot in arsenic pollution. According to Sial et al. (2006), there are total 6,634 registered industries in Pakistan, out of which, 1,228 are considered highly polluting. The waste effluent of these industries contains high organic loads and toxic metals including arsenic (Rehman et al. 2008) conducted a study to assess arsenic concentrations in industrial discharges. Their results clearly indicated high arsenic containing discharge from major industries of the country. The maximum concentration of As was found in Hattar Industrial Estate samples with a mean

concentration of 942 µg/L. Among agricultural sources, Arain et al. (2009a, b) pointed out that extensive application of inorganic As herbicides, insecticides, and fungicides would be the source of As pollution. Farooqi et al. (2007a, b) also pointed out that pesticides in the form of calcium arsenate, arsenic acid, lead arsenate and sodium arsenate are the major contributor of As in local water bodies. Another source from agriculture is the use of arsenic fertilizers such as di ammonium phosphate (DAP) which contains water soluble As (Farooqi et al. 2007a, b). It is estimated that DAP contains 5–10 mg/kg with an average of 7.4 mg/kg which may seep down to underground waters and cause contamination (Baig et al. 2009). Furthermore, the problem is extended when As containing fertilizers are not properly utilized by crops and agricultural runoff of As during flooding and monsoon season also increases. Another main route of water pollution is from air deposition of As mainly from coal burning and brick kilns (Baig et al. 2009; Farooqi et al. 2009). It is supported by the study of Farooqi et al. (2007a, b) who reported high As concentration in rain water which clearly indicates the atmospheric pollution of As. According to Shah et al. (2009) ore mining and processing, dye manufacturing, tanneries, thermal power plants, pesticides, herbicides and insecticides are the major As pollution sources in the country. Domestic and municipal wastes also contain high arsenic levels which are directly discharged into drains or thrown openly in fields in many areas of the country. These drains when discharge into the lake or river bodies cause high As pollution such as reported by (Shah et al. 2009), according to whom As pollution in Manchar lake is possibly due to local drains receiving high domestic and municipal wastes.

Table 2.5 Arsenic polluted countries in South Asia with affected population and the reason/mechanism of pollution

Country	Year of discovery	Population affected by As	Max. range of Pollution	Mechanism/reason of pollution
Bangladesh	1993	35,000,000	0.052–4.727	Over-exploitation of groundwater (pyrite oxidation) or arsenic released under reducing condition
India	1978	11,000,000	0.05–3.7	Over-exploitation of groundwater (pyrite oxidation)
China	1953	5,600,000	^a	Use of coal as fuel
Pakistan	2000	2, 000,000 ^b	0.05–2.4	Oxidation of arsenic bearing minerals ^c

^aNot exactly known^bNot exactly known^cProbable source not exactly known

Source Akram (1997), BGS (1999), SOES-DCH (2000) and Farooqi et al. (2007b)

2.6 Co-occurrence of F with As

Fluoride occurs naturally in soil, water, plants, animals and humans in trace quantities. It is an essential element for human health and both its deficiency and overexposure lead to different severities like bone deformities and dental fluorosis. In Pakistan, a large variation in fluoride concentration has been observed in drinking water (Azizullah et al. 2011). The high concentrations of fluoride that are observed in various studies is due to leaching from fluoride-bearing minerals (Naseem et al. 2010; Shah and Danishwar 2003), industrial wastes (Siddique et al. 2006), agricultural fertilizers and combustion of coal which release fluoride into the air which later reaches the soil with rain (Farooqi et al. 2007a, b).

Previous researches suggest that some areas are characterized by high levels of As along with F. Highly F⁻ and As contaminated groundwaters appear in Waran Pira Wara, Kalalanwala, and Kot Asad Ullah (Masuda et al. 2010), and surrounding areas (Farooqi et al. 2009). There seems no appreciable trend of Arsenic concentration with respect to concentration of other physicochemical parameters except for small correlation between arsenic concentration and pH, EC, nitrate, chloride, total hardness and sodium does exist (Malana and Khosa 2011). In some areas the distribution of areas with high F⁻

concentrations is characterized by sites having high levels of As, however, As and F fail to show any positive correlation suggesting that the two may have different sources but similar polluting paths (Farooqi et al. 2009) (Table 2.5).

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