Research Article Open Access

Analytical Study of Drinking Water Quality Sources of Dighri Sub-division of Sindh, Pakistan

Amjad Hussain Memon[1, a,*], Gul Muneer Lund[1,2, a], Naseem Aslam Channa[1],Muhammad Younis[3], Sajjad Ali Shah[4], Fahim Buriro[1]

[1]Institute of Biochemistry, University of Sindh, Jamshoro, Sindh, Pakistan.
[2]School of Life Sciences, Northeast Normal University, Changchun130024, P.R China.
[3]The Key Laboratory of Development Genes and Human Diseases, Institute of Life Sciences, Southeast University, Sipailou 2, Nanjing, 210096, P.R China
[4] Department of Fresh Water Biology and Fisheries, University of Sindh, Jamshoro, Sindh, Pakistan.

Article History
Received
March 13, 2016

Published Online
August 05, 2016

Keywords:
Drinking Water,
Dighri,
Sindh,
Physicochemical,
Microbial,
Water Quality.

Abstract: Water contamination is one of the serious problems to human health, particularly in Sindh province of Pakistan. The present research work carried out to analyze physical, chemical and microbiological parameters of drinking water collected from different sources of taluka Dighri, district Mirpurkhas, Sindh, Pakistan. In total 200 water samples were collected from branches, hand-pump, open well and water supply schemes of more than 100 villages of three Union Councils (UC), including UC Sofaan Shah, UC Tando Jan Muhammad, UC Mir Khuda Bux in Dighri Taluka**.** Previously, no work has been reported related to this area. The results of this study showed that drinking water sources readily available to the residents of Dighri taluka were not fit in accordance with the standards of World Health Organization (WHO). Turbidity observed in order of ground water>water canals>open wells. Electric conductance (EC) and total dissolved solids/salts (TDS) observed beyond WHO limits, and pH level fluctuated between 7.4 to 8.2 showed slight saline nature of drinking water sources. One-third of all water samples were contaminated with *Escherichia coli* colonies. The level of arsenic in drinking water sources of Soofan Shah UC found 10 times higher than the WHO permissible range, and Health Quotient (HQ) chronic observed more than upper threshold limit reflects seriousness of the contamination level, and its health impacts on local residents.

[a] Both authors contributed equally

***Corresponding authors:** Amjad Hussain Memon: ahmemon05@gmail.com

Cite this article as: Memon, A.H., G.M. Lund, N.A. Channa, M. Younis, S.A. Shah and F. Buriro. 2016.**Analytical Study of Drinking Water Quality Sources of Dighri Sub-division of Sindh, Pakistan.** *Journal of Environmental & Agricultural Sciences*. 8: 38-44.

1. Introduction

Contamination of drinking water is one of the most severe environmental problems in the world. Water quality is a major concern for people because it is directly associated with human well-being. It is affected by natural and human (anthropogenic) influences such as domestic, industrial activities and agricultural run-off (Simeonov et al., 2003;Paul et al., 2015). Pakistan stands 80th among 122 nations regarding quality of drinking water (Azizullah et al., 2011). The microbiological and physicochemical characteristics determine the quality of drinking water (Shah et al., 2007; Garg et al., 1990), which are the main factors responsible alone or in combination for several public health issues. The pH, temperature, total dissolved solids/salts (TDS), turbidity, alkalinity, dissolved oxygen are important physicochemical characteristics that affect the quality of water (Nduka et al., 2008). Each water quality parameter interacts with and influences other parameters. The major source of microbial contamination is microbes from human or animal excreta, which mix with drinking water by contamination of ground water from wastewater, landfills, or wastewater treatment stations, causing serious health problems (Gasana et al., 2002; Al-Khatib et al., 2003). In Pakistan bacterial contamination has been considered major drinking water problem (PCRWR, 2004).

Arsenic is a toxic carcinogenic element commonly found in contaminated water (WHO, 1981). It is recognized as a big threat to public health in several countries including Bangladesh, China, India, Myanmar, Nepal and Vietnam (Islam-Ul-Haque et al., 2007). The consumptionof arsenic contaminated drinking water may cause reduction in both white and red blood corpuscles production, , disrupt the cardiac rhythm, damage blood vessels and paraesthesia in hands and feet (Abernathy et al., 2003). Long-term arsenic exposure from drinking water can cause black foot disease (BFD), cardiovascular disease, hyperkeratosis, leuko-melanosis, melanosis, neuropathy (Caussy, 2005), urinary bladder cancer, lung cancer and skin cancer(IARC, 2004; Khan et al., 2009) as well as arsenic-induced skin lesions (Fatmi et al., 2009).

Elevated level of Arsenic and physicochemical characteristics in surface and ground water has been previously reported in China (Xie et al., 2009), India (Gupta et al., 2009), and Bangladesh (Halim et al., 2009). Elevated Arsenic concentration in water sources has been reported in different parts of the world like Argentina (1–9900 µg/L),Brazil (0.5-350 µg/L), China (0.05-850 µg/L), India(10–3200 µg/L), Mexico (8–620µg/L), USA (1–100,000 µg/L), Taiwan (10–1820 µg/L),and Bangladesh having 1–2500 µg/L (Nordstrom, 2002; Mandal and Suzuki, 2002; Chowdhury et al., 2000). In Bangladesh, more than 50% of the total population is consuming arsenic contaminated water and 35% out of 2022 water samples were contaminated with arsenic more than 50 µg/L and 8.4% samples reached up to 300 µg/L has been reported (Smith et al., 2000). In Pakistan, 20% population of Punjab is exposed to 10 µg/L level of arsenic contamination and 3% population above 50 µg/L. In Sindh province of Pakistan, 16 to 36% of population has been exposed to arsenic contaminated water (Ahmad, 2004). In a recent study, arsenic reaching 96 µg/L in groundwater and 157 µg/L in surface water (Manchar Lake, Sindh) has been documented (Arain et al., 2009). In the province of Sindh, arsenic level in ground water has reached up to 1100 µg/L above WHO limits of 10 µg/l (Islam-Ul-Haque et al., 2007), and 37% water samples positive for more than 50 µg/L of arsenic and 15% samples positive for very high level of 250 µg/L of arsenic in underground water of Matiari and Khairpur districts has been reported (Arain et al., 2007).

Access is to safe drinking water is the basic right of humans and also a basic need for good health. At taluka Dighri district Mirpurkhas, Sindh, Pakistan all communities are exposed to the effects of un-safe drinking water which may lead the residents towards numerous life-threatening diseases. The main objectives of the present study was to analyze physical, chemical and biological parameters of drinking water samples collected from Dighri tehsil, Mirpurkhas district, Sindh, Pakistan, and to assess health risk for exposure to arsenic via drinking water ingestion.

2. Materials and Methods

2.1. Sampling and Study site

Present study was conducted in taluka/tehsil/administrative subdivision Dighri, Mirpurkhas (Digri or Dhigri) of Sindh province of Pakistan. The Area of taluka Dighri is 1075 km²,situated at 25°9′ N (latitude) and 69°6′ E (longitude), population 0.2986 million. A total of 200 water samples were collected from different drinking water sources in the sterilized bottles. Water sources includes branches, hand-pump, open well and water supply schemes of more than 100 villages of three Union Councils (UC),including UC Sofaan Shah, UC Tando Jan Muhammad, UC Mir Khuda Buxin Dighri Taluka.

2.2. Methodology

Electric conductance (EC), total dissolved salts/solids (TDS) and pH were determined by conductivity meter Orion 115 (Orion, Inc, Boston, USA)and pH meter (Hanna Instruments, HI 8417, Italy), respectively. Turbidity measured by turbidity meter (Model: PC Chekit Lovibond, Germany), which shows clearness of water. A portable water testing kit (DelAgua Kit) was used to check the contamination of water by the detection of *Escherichia coli*. Briefly, each water sample of 100 ml passed through a filtration membrane (Millipore) with 0.45 µm pore size and 47 mm diameter. The bacteria present in the water sample retained on the surface of filtration membrane. Membrane lauryl sulfate broth (MLSB) was used as media for bacterial growth, poured on absorbent pads and then filtered membrane was placed on absorbent pads in petri dishes and incubated at 44°C in the kit's incubator for the 18 hours. After incubation period, yellowish appearance of *E. coli* colonies was counted and the results were expressed as Colony-forming units per 100 ml of water (CFU/100ml).

Arsenic was determined by HACH Arsenic kit (EZ Arsenic Test Kit 2822800; Hach Company, USA) for 0.01-0.5 mg/L. This test generates arsenic hydride, which reacts with the mercury bromide present in the analytical strip to form a yellow-brown miscellaneous arsenic mercury halogenide. The concentration of arsenic was analyzed through visual assessment of the reaction region of the analytical test strip with scales of fields of color (Yu, et.al 2007).

2.3. Exposure and risk assessment

Equation 1, adapted from US Environmental Protection Agency (US EPA 1992) was used to calculate the chronic daily intake (CDI).

$$CDI = C \times DI / BW \qquad \text{[Eq. 1]}$$

Where, CDI: chronic daily intake (µg/kg/d); C: contaminant concentration (ppb); DI: daily intake of drinking water (l/d); BW: body weight (kg).

The HQ for non-carcinogenic risk (chronic) can be calculated by the following equation 2 (USEPA. 1999).

$$HQ = CDI / RfD \qquad \text{[Eq. 2]}$$

Where according to US EPA, the oral toxicity RfD value is 0.0003 mg/kg/day for arsenic (USEPA, 2005).

Cancer hazard (HQ Carcinogenic) linked with intake contact is considered by means of the subsequent formula (Patrick, 1994):

$$R = CDI \times SF \qquad \text{[Eq. 3]}$$

Where R is the surplus possibility of upward cancer overall life time as a consequence of contact to a contaminant (or carcinogenic risk). SF value is 1500 µg/kg-d for arsenic. By the USEPA, Risk (R) value greater than one in a million (10^{-6}) is normally measured intolerable (USEPA, 2005). On the other hand, along with national standards and environmental policies, this acceptable level could change and possibly as elevated as 10^{-4}(Health Canada, 1998; USEPA, 2000; WHO, 2004). SF and RfD standards were obtained from USEPA (USEPA, 1998). When the HQ values were >1, the health risk generally occurs (Khan et al., 2008).

3. Results and Discussion

3.1. Physical Parameters

The present study revealed that drinking water widely available to UC Mir Khuda Bux residents was canal and ground water (for the domestic purpose) and was observed highly turbid and saline. However, UC Tando Jan Mohammad and Soofan Shah residents mostly relied on ground water sources found slightly saline. One quarter samples were from open wells and water canals, which were non-saline, but highly turbid and unsafe for drinking due to unhygienic condition. The remaining 150 samples were from ground water, and out of 105 (52.5%) samples were slightly saline and remaining 45 (22.5%) samples were in normal acceptable range. It was observed that drinking water sources found in the hygienic and normal range were quite away from the community, distance variably from 1 to 5 acres (4047 to 20234 sq. meter). Because of unavailability of non-saline water, the residents were consuming slightly saline water and have become habitual of it and lost their ability to discriminate non-saline and light saline water. Questionnaire study revealed that 80% of the population were satisfied with saline water, and 20% were non-satisfied and declared water was saline. It should be noted here that non-resident in this place if have situation to drink water, which cannot quench their thirst and may cause diarrhea and vomiting.

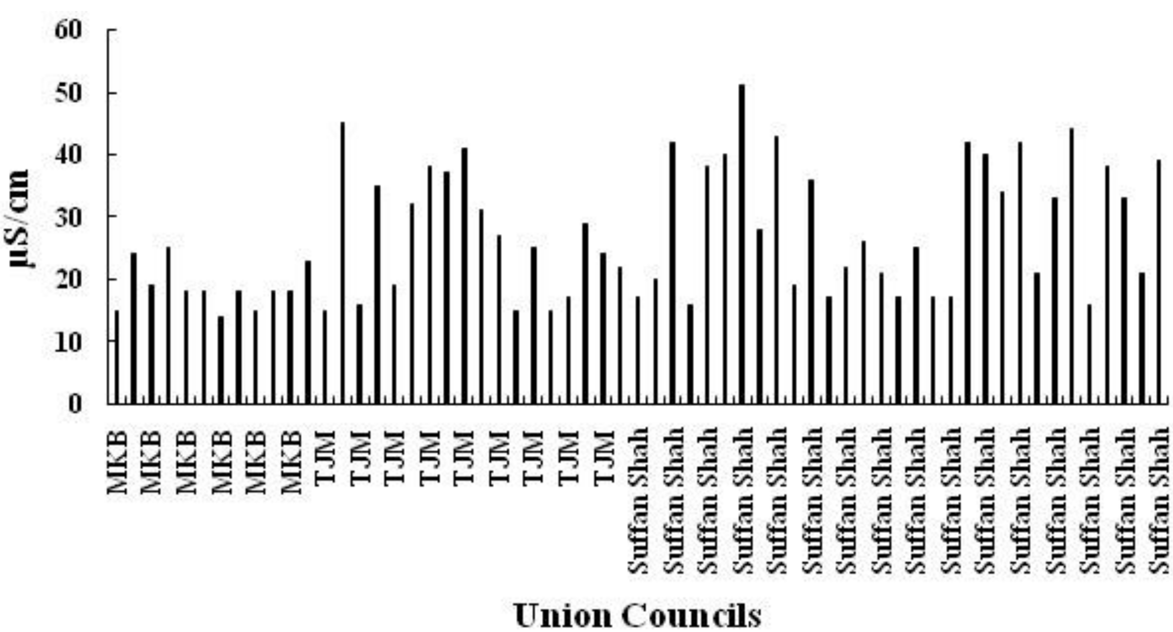

Figure 1. Electric conductance of selected water samples

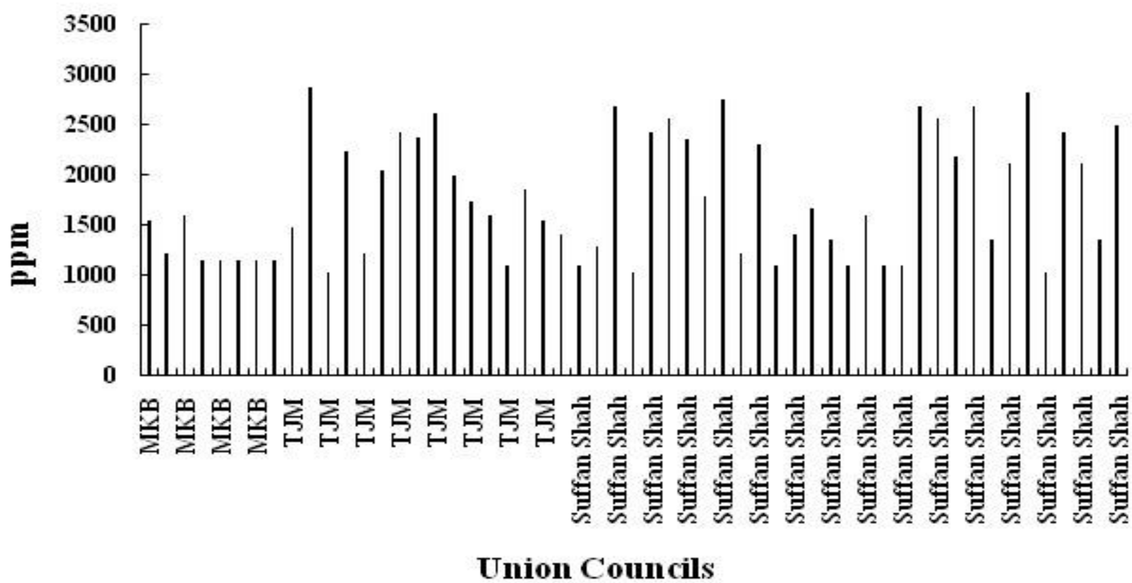

Figure 2. Total dissolved solids concentration ofselected water samples

Table 1: Arsenic concentration of water samples

District	UC	Village Name	Water Source	Arsenic
MPK	Soofan Shah	Mir Shah Muhammad	HP	100ppb
MPK	Soofan Shah	Rahmatullah Arain	HP	60ppb
MPK	Soofan Shah	Mevo Miyaron	HP	10ppb
MPK	MKB	Kambeer Khan Kaloi	HP	60ppb
MPK	MKB	Umar Laghari	HP	10ppb
MPK	MKB	M. Zaman Pathan	HP	10ppb
MPK	MKB	Kali khan jarwar	HP	10 ppb

MPK Mirpurkhas, MKB Mir Khuda Bux, HP had Pump, ppb Parts per Billion

Water samples from open wells and canals were highly turbid in the range of 20 to 200 Nephelometric Turbidity Unit (NTU), but samples from open well were much turbid due to stagnant water. However, water samples from hand pumps found less turbid, 130 samples were non-turbid <5 NTU and 20 samples were turbid in the range of 10-50 NTU. It may be due to hand pump sieve problem or nature of the soil. Thus, it may be deduced here that turbidity was not a serious problem as 70% of samples were non-turbid. The pH of water samples found alkaline, however this falls within the acceptable range of WHO standard i.e., 6.5-8.5. The pH of all 200 samples fluctuated by 7.4-8.3, about 70% samples found in the range of 7.8-8.0 pH, and 10 to 15% showed pH between 8.0-8.3 and remaining 15 to 20% samples had pH in the range of7.4-7.8. It may be deduced from the result that drinking water available to residents was alkaline in nature.

In the present study, significant number of water samples revealed high value of electric conductance than WHO limits reflecting the standard of drinking water of Dighri area and contamination of water by the trace metals. Upper threshold of TDS described by WHO is 1000mg/L. In case of ground water samples TDS observed as non-saline <1000ppm in 30% of samples, slightly saline 1000-3000 ppm in 60% of samples and moderately saline 3000-10000 ppm in 10% of samples.

The figure 1 and 2 shows the EC and TDS of selected water samples. TDS examined from the other water samples found in agreement with WHO range. Drinking of high TDS water may cause diarrhea, and sometimes it takes severe condition in newborn babies and becomes fatal, especially in dry season when the ground water is not refilled. High values of total dissolved solids have serious implications for skin and cause rashes and disturb body hair as well. Wide range of responses can observed in population using high TDS water including kidney stone (above 500 ppm), an occurrence widely reported from various parts of the country. Because of increased concentration of total dissolved solids in water, it may reduce tastiness of drinking water and cause gastrointestinal problems in human and it may also have laxative effect mainly upon transits (Khaiwal et, al., 2007).

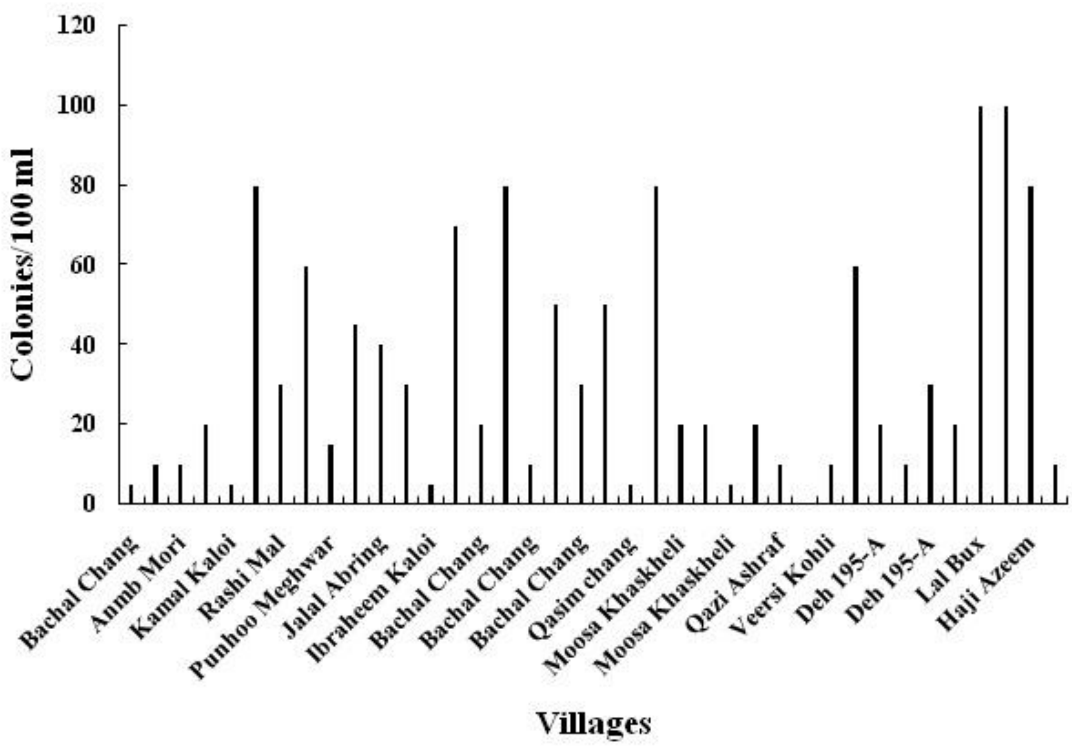

Figure 3. Bacterial contamination found in water samples

Consuming arsenic contaminated drinking water over a long period such as from 5 to 20 years causes arsenic poisoning or arsenicosis. Long-term drinking of arsenic rich water causes several health issues including skin (skin color changing and hard patches on the palms and soles of the feet), skin, lung, kidney and bladder cancers, and reproductive disorders. As per WHO standards less than 10 ppb is a normal range. In our findings, seven samples from UC MKB and Soofan Shah displayed arsenic contamination (Table No. 1), out of these seven samples, four were in the normal range according to WHO and three samples were out of permissible range. Because ground water from UC MKB and Soofan Shah was alkaline and saline favored the mobility and solubility of arsenic in this area.

3.2. Biological Parameters

The present study found bacterial contamination a serious problem in this area. Every third sample was *E. coli* contaminated and contained ranges of colonies from less than 10 colonies/100 ml to more than 80 colonies/100ml(figure No. 3), because of this reason, residents has been suffering from the diarrheal problems. The reason of ground water contamination is open defecation, poor sewerage system surrounding the hand pumps and lack of awareness about the apron of hand pumps (mostly was without the apron and if present, was not properly protected). Open wells and water canals were also found bacterial contaminated due to open nature and unsafe handling like cattle's involvement and bathing in the canals. According to United Nations, contaminated drinking water contributes to diarrhea, accounts for 80% of all diseases and more than one third of deaths in developing countries (Al-Khatib et al., 2003**)**.

3.3. Arsenic Health Risk Assessment

Health quotient (HQ) is a probabilistic chronic measurement of heavy metals (like arsenic) by certain formula that shows health impacts on the consumer of contaminated water. Findings of the present study showed thatsamples with high concentration of arsenic than WHO Range identified with more HQ level as compared to the normal value (HQ <1). In three out of seven areas, arsenic concentration has been found more than WHO limits, this reflects chronic disease causing threats for the consumers of that area. Cancer Risk (CR) value identified in all samples within safe range10^{-3} to10^{-4} (CR normal value is $< 10^{-6}$) out of the cancer-causing threat. The results indicate that drinking water generally available to Dighri residents has low CR value except for the residents of UC Soofan Shah. The cancer risk of this study area was lower than those reported in Vietnam and Bangladesh, respectively (Nguyen et al., 2009; Karim, 2000).

3. Conclusion

In the present study area, physicochemical parameters such as pH found within limited range fluctuated by 7.4 to 8.2 revealed the slight saline nature of drinking water sources. Turbidity observed in order of ground water sources> water canals>open wells. Total dissolved solids found more than normal values. Every third sample found *E. coli* contaminated, which is a major health risk of water-borne diseases for the residents and particularly children. The level of arsenic in drinking water sources of UC Soofan Shah found 10 times higher than the normal range, and HQ observed more than limit reflects seriousness of the contamination level and its health impacts on local residents. In the end, it can be concluded that water available to residents of Dighri area is unsafe for drinking purpose, so it's suggested to the local water administration to provide safe drinking water after treatment of drinking water sources discussed above to prevent damage to residents.

Acknowledgements: Authors are grateful to Dr. Allah Bux Ghanghro and Dr. Taj Muhammad Jahangir for their help and suggestions during this study.

Competing Interests: The authors declared that they have no conflict of interest about the contents of this article.

References

Abernathy, C.O., D.J. Thomas and R.L. Calderon. 2003. Health effects and risk assessment of arsenic. J. Nutr. 133:1536S–1538S.

Ahmad, T., M.A. Kahlown, A. Tahir and H. Rashid. 2004. Arsenic an emerging issue, Experiences from Pakistan.30th WEDC international conference, Vientiane, Lao PDR.

Al-Khatib, I., S. Kamal, B. Taha, J. Al-Hamad and H. Jaber. 2003. Water-health relationships in developing countries: a case study in Tulkarm district in Palestine. Int. J. Environ. Health Res. 13: 199-206.

Uqaili, A.A., A. H. Mughal and B.K. Maheshwari. 2012. Arsenic contamination in ground water sources of district Matiari and Sindh. Int. J. Chem. Environ. Engg. 3:4.

Arain, M.B., T.G. Kazi, J.A. Baig, M.K. Jamali, H.I. Afridi, A.Q. Shah, N. Jalbani and R.A. Sarfraz. 2009. Determination of arsenic levels in lake water, sediment, and foodstuff from selected area of Sindh, Pakistan: Estimation of daily dietary intake. Food Chem. Toxicol.47(1):242–248.

Azizullah, A., M.N.K. Khattak, P. Richer and D.P. Hader. 2001. Water pollution in Pakistan and its impact on public health- A review. Environ. Int. 37: 479-497.

Caussy, D. 2005. Afield guide for detection, management and surveillance of arsenicosis cases. Regional Office for South-East Asia: World Health Organization.

Chowdhury, U.K., B.K. Biswas, T.R. Chowdhury, G. Samanta, B.K. Mandal, G.C. Basu, C.R. Chanda, D. Lodh, K.C. Saha and S.K. Mukherjee. 2000. Groundwater arsenic contamination in Bangladesh and West Bengal, India. Environ Health Perspect. 108(5):393.

Fatmi, Z., I. Azam, F. Ahmed, A. Kazi, A.B. Gill, M.M. Kadir, M. Ahmed, N. Ara and N.Z. Janjua. 2009. Health burden of skin lesions at low arsenic exposure through groundwater in Pakistan, is river the source? Environ Res. 109: 575–581.

Garg, D.K., R.N. Goyal and V.P. Agrawal. 1990. Correlation among water quality parameters of ground water, Roorkee City. Indian J. Environ. Protec. 10(5): 355-359.

Gasana, J., J. Morin, A. Ndikuyeze and P. Kamoso. 2002. Impact of water supply and sanitation on diarrhea morbidity among young children in the socioeconomic and cultural context of Rwanda (Africa). Environ Res. 90: 76-88.

Gupta, A., V.S. Chauhan and N. Sankararamakrishnan. 2009. Preparation and evaluation of iron–chitosan composites for removal of As (III) and As (V) from arsenic contaminated real life groundwater. Water Res. 43: 3862–3870.

Halim, M.A., R.K. Majunder, S.A. Nessa, K. Oda, K. Hiroshiro, B.B. Saha, S. M. Hassain, Sk. A. Latif, M. A. Islam and K. Jinno. 2009. Groundwater contamination with arsenic in Sherajdikhan, Bangladesh: geochemical and hydrological implications. Environ Geol. 58: 73–84.

Health Canada. 1998. Assessment and Management of Cancer Risks from Radiological and Chemical Hazards. 98-EHD- 216 AECB INFO-0684(E) AC-5..

International Agency for Research on Cancer (IARC). 2004. IARC Monographs on the Evaluation of Carcinogenic Risk to Human. Some Drinking-water Disinfectants and Contaminants, Including arsenic, Lyons, France. 84: 39–270.

Islam-Ul-Haque, M.A. Baig, D. Nabi and W. Hayat.2007. Groundwater arsenic contamination — a multi-directional emerging threat to water scarce areas of Pakistan, 6th International IAHS Groundwater Quality Conference (2–7 December), Fremantle, Western Australia.

Karim, M.M.D. 2000. Arsenic in groundwater and health problems in Bangladesh. Water Res. 34: 304–310.

Kavcar, P., A. Sofuoglu and S. Sofuoglu. 2009. A health risk assessment for exposure to trace metals via drinking water ingestion pathway. Int. J. Hyg. Environ. Health. 212:216–227.

Khaiwal, R. and V.K. Garg. 2007. Hydro-chemical survey of groundwater of Hisar city and assessment of defluoridation methods used in India. Environ. Monit. Assess. 132(1–3):33–43.

Khan, N.I., G. Owens, D. Bruce and R. Naidu. 2009. Human arsenic exposure and risk assessment at the landscape level: a review. Environ. Geochem. Health. 31:143–66.

Khan, S., Q. Cao, Y.M. Zheng, Y.Z. Huang and Y.G. Zhu. 2008. Health risk of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing China. Environ. Poll. 152: 686–692.

Mandal, B.K and K.T. Suzuki. 2002. Arsenic round the world: a review. Talanta. 58(1):201–235.

Muhammad, S., M.T. Shah and S. Khan. 2010. Arsenic health risk assessment in drinking water and source apportionment using multivariate statistical techniques in Kohistan region, northern Pakistan. Food Chem. Toxicol. 48:2855–2864.

Nduka, J.K., O.E. Orisakwe and L.O. Ezenweke. 2008. Some Physicochemical parameters of potable water supply in Warri, Neger delta area of Nigeria. Sci. Res. Essays. 3(11): 547-551.

Nguyen, V.A., S. Bang, P.H. Viet and K.W. Kim. 2009. Contamination of groundwater and risk assessment for arsenic exposure in Ha Nam province, Vietnam. Environ Int. 35: 466–472.

Nordstrom, D.K. 2002.Worldwide occurrences of arsenic in ground water. Sci. 296:2143–2145.

Patrick, D.R. 1994. Risk assessment and risk management. In: Patrick, D.R. (Ed.), Toxic Air Pollution Handbook. Van Nostrand Reinhold, New York. p. 347.

Paul, S., S. Chakraborty, N Ali and D.P. Ray. 2015. Arsenic distribution in environment and its bioremediation: A review. Int. J. Agri. Environ. Biotechnol. 8: 189-204.

PCRWR. 2004. Water Quality Profile of Pakistan (22 Cities). Report (Phase -III) 2003–2004. Pakistan Council for Research in Water Resources, Islamabad.

Phan, K., S. Sthiannopkao, K.W. Kim, M.H. Wong, V. Sao, J.H. Hashim, M.S. M. Yasin and S.M. Aljunid. 2010. Health risk assessment of inorganic arsenic intake of Cambodia residents through groundwater drinking pathway. Water Res. 44:5777–5788.

Shah, M.C., P. Shilpakar and S. Sharma S. 2007. Correlation Regression study on Physico-chemical parameters and water quality assessment of ground water of Mansa Taluka in Gujarat. Asian J Chem. 19(5): 3449-3454.

Simeonov, V., J.A. Stratis, C. Samara, G. Zachariadisb, D. Voutsa, A. Anthemidis, M. Sofoniou and T. Kouimtzis. 2003. Assessment of the surface water quality in Northern Greece. Water Res. 37(17):4119-4124.

Smith, A.H., E.O. Lingas and M. Rahman. 2000. Contamination of drinking-water by arsenic in Bangladesh: A public health emergency. Bull. World Health Organ. 78(9): 1093-103.

US EPA. 1992. Guidelines for Exposure Assessment, EPA/600/Z-92/001, Risk Assessment Forum, Washington, DC.

US EPA. 1998.. Arsenic, inorganic. Integrated Risk Information System (IRIS), (CASRN 7440-38-2).

US EPA. 1999. Guidance for Performing Aggregate Exposure and Risk Assessments. US Environmental Protection Agency, Office of Pesticide Programs, Washington, DC.

US EPA. 2000. Water Quality Standards, Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California.

US EPA. 2005. Guidelines for Carcinogen Risk Assessment, EPA/630/P-03/001F, Risk Assessment Forum, Washington, DC.

WHO. 1981. Task Group on Environmental Health Criteria for Arsenic: Arsenic. Environmental Health Criteria 18. World Health Organization, Geneva.

WHO. 2004. Guidelines for Drinking-Water Quality, third ed., vol. 1. Recommendations. World Health Organization, Geneva.

Yu, G., D. Sun and Y. Zheng. 2007. Health effects of exposure to natural arsenic in groundwater and coal in china: An overview of occurrence. Environ Health Perspect. 115:636-42.