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Drinking water quality and human health risk in Charsadda district, Pakistan

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A B S T R A C T

Access to safe drinking water is one of the basic human rights and essential for healthy life. The present study investigated the concentrations of various pollutants in drinking water and health risk in Charsadda district, Khyber Pakhtunkhwa, Pakistan. Water samples were collected from dug-wells, tube-wells and hand pumps which were the most common sources of drinking water and analyzed for physical parameters, anions, heavy metals and coliform bacteria using standard methods. The concentrations of nitrate (10.3–14.84 mg L^{-1}) in 13 sites exceeded the permissible limit (10 mg L^{-1}) set by US-EPA, while sulfate concentrations (505–555 mg L^{-1}) in 9 sites exceeded the permissible limit (500 mg L^{-1}) set by WHO. Similarly, the concentrations of Pb, Cd, Ni and Fe exceeded their respective permissible limits set by different organizations in some locations. Furthermore, the coliform bacterial contamination (2–5 MPN 100 mL^{-1}) was also found in some sources of water, confirming the bacterial contamination of drinking water. In the study area, improper disposal of sewage and solid wastes, over application of agrochemicals (pesticides and fertilizers), deteriorating condition of piping network and transportation were the major sources responsible for contamination of drinking water. Water contamination with coliform bacteria was the main source of waterborne diseases like gastroenteritis, dysentery, diarrhea and viral hepatitis as complained by most of the respondents during questionnaire survey. In order to reduce the health risk, it is necessary to immediately stop the uses of drinking water from contaminated sources and government should supply treated/clean water with supply lines far away from solid waste, sludge and sewage sites. The farmers should be properly trained to avoid the overusing of agrochemicals responsible for drinking water contamination, while both women and men should be properly educated with water knowledge through awareness and training programs needed for sustainable use and management of drinking water.

1. Introduction

Drinking water contamination with different chemicals and heavy metals, released from different anthropogenic sources has become a global concern (Rapant and Krcmova, 2007). Drinking water pollution is a relatively new problem and increases the stress arising as a result of unprecedented population growth, urbanization, and industrialization since 1990s (Chen, 2002; Velea et al., 2009). The contamination of water resources has important repercussions for the environment and human health (Emmanuel et al., 2009; Muhammad et al., 2011).

Generally, drinking water containing different anions and heavy metals including Cd, Cr, Co, Hg, Ni, Pb, Zn etc, has significant adverse effects on human health either through deficiency or toxicity due to excessive intake. Nitrate (NO_3) and nitrites (NO_2) are found naturally in water (Jordao et al., 2002) and the toxicology of nitrate to humans is mainly attributable to its reduction to nitrite. The major biological effect of nitrite is its involvement in the oxidation of normal hemoglobin to methaemoglobin, which is unable to transport oxygen to the tissues. The dominant human health risk associated with nitrate consumption is considered to be of methaemoglobinaemia by nitrate-derived nitrite (Gupta et al., 2000). Heavy metal concentrations in water can be attributed to both geogenic and anthropogenic sources. The most significant geogenic sources of metals are weathering of rocks, ore deposits and volcanic activities from which the released metals find their way into the water bodies. The excessive ingestion of all these heavy metals including Cd, Cr, Co, Hg, Ni, Pb and Zn has carcinogenic effects on human health (Muhammad et al., 2011).

Many researchers have also worked on the water and human right. Kemp et al. (2010) suggested that different developmental

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activities, such as mining, pose great risk to human rights to access to clean drinking water. There are a number of human rights that are not included in international laws as distinct rights, but are agreed by many international frameworks, one of them is the right of access to clean drinking water. However, international campaigns for access to clean drinking water and anti-privatization campaign could augment the political priority towards water and well enforce government and state to insure basic water needs (Bakker, 2007). Furthermore, fresh water scarcity is increasing globally because of overpopulation (Domènech and Saurí, 2011; Lambooy, 2011).

Governments of many developing countries consider the provision of safe water supplies as one of their major responsibilities. In developing countries most of the people do not have access to safe drinking water. Drinking water contaminated with animal and human feces is the major route of transmission of pathogens to human beings. Intermittent water supply, insufficient chlorination and sewage flooding seem to be associated with self-reported diseases (Abu-Amr and Yassin, 2008). Many developing regions suffer from either chronic shortages of fresh water or the readily accessible resources are heavily polluted. Accelerated population growth coupled with impoverished socioeconomic development with limited water resources and poor sanitation leads to an increase in diseases associated with poor living conditions among which water related and water borne diseases play a major role (Lehloesa and Muyima, 2000). Globally, women play a major role in health, sanitation and household water supply and are involved in management and conservation of water resources.

Being a developing country, Pakistan needs to address a vast array of problems regarding water availability, quality, usage and death caused by water-borne diseases. In Pakistan, potable groundwater has given a greater boost to the availability in general and is being utilized through tube wells, hand pumps and open wells. The rising interest of the private sector in groundwater development has encouraged the Government of Pakistan to the transfer of operational responsibilities of public sector boreholes to the private sector. In Khyber Pakhtunkhwa, more than half of 6 million inhabitants in Peshawar, Mardan, Charsadda and Nowshera districts have no access to clean drinking water. The remaining half of the population draws the drinking water from tube wells, while most of the wells are shallow and are liable to be contaminated with heavy metals and biological pollutants from the surrounding sources such as toilets, underground damaged sewerage lines, seepage/percolation of contaminated surface water. In some rural areas of Charsadda district, the water table is at the depth of just 4 m, which increases the chances of contamination from agrochemicals containing heavy metals, SO_4 and NO_3. Furthermore, a well published and detailed data are not available regarding the drinking water quality situation and the prevailing waterborne diseases in the Charsadda district. The purpose of this study was to investigate the level of drinking water contamination with anions, heavy metals and coliform bacteria and human health risks associated with the intake of contaminated water in study area. Questionnaire survey was also conducted among the residents including both male and female genders to collect information about the water pitching/collection, uses and water born diseases in the study area.

2. Materials and methods

2.1. Study area description

The Charsadda district is situated in the Khyber Pakhtukhwa, Pakistan and lies between 34–03′ and 34–38′ north latitudes and 71–28′ and 71–53′ east longitudes. It is bounded by Malakand District on the north, Mardan District on the east, districts Nowshera and Peshawar on the south and the Mohmand Agency on the west. This district covers an area of 996 km^2 and has a total population approximately 1 million persons with women and men ratio 1.08:1 (DCR, 1998). It is officially divided into three tehsils such as Charsadda, Tangi, and Shabqadar. The inhabitants of the study area are enjoying four seasons in a year namely summer, autumn, winter and spring with an average rainfall of 16.5 cm. Agriculture is the main profession of the people, while scattered poultry, livestock, bee and fish farms are also present in the study area. Industrial sector is not well developed and sugar mills and paper mills are closed. However, some cottage (small scale) industries including leather shoes (Chappal), handmade weaving cloth (Khamta), embroidery and brown sugar industries are the major economic activities in the Charsadda district. Dug-wells, tube-wells and hand pumps are the most common sources of drinking water in the Charsadda district.

2.2. Water sampling

Water samples were collected from different sources including tube wells, dug wells and hand pumps, as shown in Fig. 1. From each sampling point, two samples were collected in separate clean polythene bottles. Different sampling procedures were employed for different types of water sources and all the precautions were taken. Water of tube well and hand pump was allowed to run for a couple of minutes before filling the bottles and then reduced the water flow to permit filling of bottle without splashing. First of all, gases from the bottles were expelled by filling up, then emptying over the source, and refilled in the same manner. In case of hand pump sources, water was left to run for about 5 min before collecting samples. Separate samples were collected for chemical and biological analyses with necessary precautions for sampling and sample preservation. At each point, one bottle was filled with water having no acid and air bubbles, while the other bottle was filled with the water from the same site and acidified by adding a few drops of 5% HNO_3 to stop the microbial activities. After transportation to laboratory the non-acidified samples were analyzed for physical parameters and anions, while acidified samples were used for heavy metals analysis.

2.3. Analytical procedures

The basic parameters such as pH, electrical conductivity (EC), dissolved oxygen (DO), temperature and salinity were noted on site by using water checker U-10. The major anions such as NO_3 and SO_4 were determined using ultraviolet spectrophotometer, HACH 2800 (APHA, 1992). Chloride (Cl^-) was determined using titration method as given by APHA (1992). However, heavy metal concentrations in water samples were determined using Atomic Absorption Spectrophotometer (Perkins Elmer-700) equipped with HGA graphite furnace, in the National Center of Excellence in Geology, University of Peshawar. Reliability and reproducibility of analysis were checked by analyzing blank, standard and pre-analyzed sample after every 10 samples. Total coli form bacteria as maximum probability number (MPN) in water samples were counted using standard method (APHA, 1992).

2.4. Questionnaire survey

To find out the prevailing adverse impacts of contaminated water on public health, a questionnaire survey was conducted among the residents of Charsadda district through a survey team consisting of medical experts and Environmental Science students. Representative respondents were randomly selected and belonged to 4740 households out of 1 million persons approximately (DCR, 1998). It was a sort of public involvement in the research work. The respondents included both male and female genders having primary level of education. The age of adults ranged from 17 to 65 years, while the

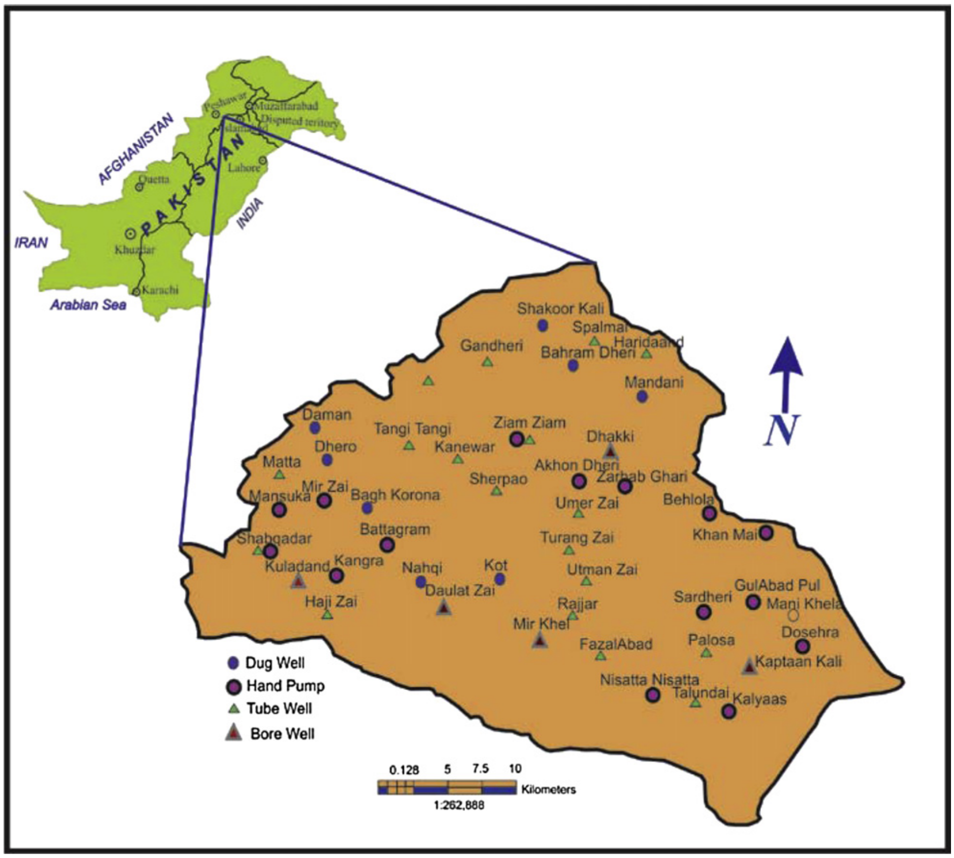

Fig. 1. Location map and sampling points of study area.

children age ranged from 10 to 16 years. During the questionnaire survey information regarding age, education, body weight, monthly income, smoking or non-smoking habits, occupational exposure, waterborne diseases and other health related problems were collected. Questionnaires were filled from the respondents of the study area with great care. The inhabitants were also interviewed directly by the members of survey team and terminology of questions was designed in such a way to avoid any confusing questions. However, the respondents were helped out on site by the members of survey team and sometimes questions were explained in their local language. Comments section was also included in the questionnaire to encourage the respondents to give reply freely or add some comments. This survey was conducted in the whole study area and all questions were asked from the consumers of each water source. Furthermore, meetings/interviews were also conducted with doctors in the local hospitals and basic health units to collect the data regarding the water born diseases in the study area.

2.5. Statistical analyses

All the data were statistically analyzed using the SPSS 11.5 computer package and statistical significance was computed using ANOVA with a significance level of $P < 0.05$. The maps were prepared using Arc GIS computer package and presented the mean values of triplicates.

3. Results

3.1. Physical parameters

Table 1 summarizes the pH, temperature, EC, DO and salinity values in the water samples of the study area. ANOVA indicate that there was no significant variation ($P < 0.01$) in the values of these parameters. The pH values ranged from 6.29 to 7.2 and were within the permissible limit set by Pakistan Environmental Protection Agency (Pak-EPA, 2008), World Health Organization (WHO) and United States Environmental Protection Agency (US-EPA) (Table 2). Maximum pH value (7.2) was found in the sample collected from village Nisatta (tehsil Charsadda), while minimum value (6.2) was found in the sample of hand pump of hospital at village Kangra (tehsil Shabqadar). Similarly, the EC values ranged from 0.28 to 0.91 mS/cm in drinking water samples of the study area and were within permissible limits. The highest EC (0.91 mS/cm) was found in the sample of hand pump collected from village Zarbab Gari (tehsil Charsadda). Similarly, the salinity values ranged from 0.01 to 0.02% and there was no great variation in the values of salinity detected in drinking water samples.

3.2. Anions

The mean concentrations of major anions determined in the drinking water samples are given in Table 3. The SO_4 concentrations were within the permissible limit (500 mg L^{-1}) set by WHO at most sites. However, in some locations of the study area the SO_4 concentrations reached to alarm level and exceeded the permissible limit (500 mg L^{-1}) as shown in Fig. 2. Highest contamination with SO_4 was observed in tehsil Tangi followed by tehsil Charsadda, while one dug well sample exceeded the permissible limit in tehsil Shabqadar. The SO_4 concentrations were significantly higher ($P < 0.01$) in rural areas as compared to urban and great variation was found among different sources of drinking water. Similarly, the NO_3 concentrations ranged from 7.5 to 14.84 mg L^{-1} (Fig. 3) and in some locations exceeded the permissible limit (10 mg L^{-1}) set by US-EPA but found within Canadian limit. Tehsil Shabqadar water was significantly ($P < 0.01$) contaminated with NO_3 as compared to tehsil Charsadda and Tangi. However,

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Table 1
Mean concentrations of selected physical parameters in drinking water collected from various sources of district Charsadda.

Locations	Water source	pH	Conductivity (mS/cm)	DO ($mg\,L^{-1}$)	Salinity (%)
Tangi	Tube well ($n=40$)	6.80 ± 0.25	0.41 ± 0.11	0.09 ± 0.00	0.01 ± 0.01
	Hand pump ($n=80$)	6.50 ± 0.00	0.32 ± 0.00	0.09 ± 0.00	0.01 ± 0.00
	Dug well ($n=90$)	6.72 ± 0.21	0.48 ± 0.12	0.09 ± 0.00	0.016 ± 0.01
	Bore well ($n=140$)	7.00 ± 0.01	0.49 ± 0.00	0.09 ± 0.00	0.016 ± 0.01
	Tube well ($n=35$)	7.02 ± 0.30	0.37 ± 0.05	0.09 ± 0.01	0.01 ± 0.00
Charsadda	Hand pump ($n=85$)	6.78 ± 0.22	0.66 ± 0.18	0.06 ± 0.03	0.02 ± 0.01
	Dug well ($n=80$)	6.84 ± 0.23	0.57 ± 0.00	0.07 ± 0.02	0.02 ± 0.01
	Bore well ($n=97$)	6.87 ± 0.09	0.56 ± 0.29	0.09 ± 0.01	0.02 ± 0.01
	Tube well ($n=40$)	6.61 ± 0.04	0.54 ± 0.01	0.08 ± 0.0	0.02 ± 0.01
Shabqadar	Hand pump ($n=100$)	6.61 ± 0.28	0.49 ± 0.15	0.09 ± 0.01	0.01 ± 0.01
	Dug well ($n=86$)	6.65 ± 0.09	0.37 ± 0.09	0.09 ± 0.01	0.01 ± 0.01
	Bore well ($n=78$)	6.81 ± 0.04	0.43 ± 0.23	0.09 ± 0.01	0.01 ± 0.01

DO, dissolved oxygen, ±standard deviation.

the Cl values ranged from 13.15 to 118.43 $mg\,L^{-1}$ and were within the permissible limit (250 $mg\,L^{-1}$) set by Pak-EPA (2008) (Table 2).

3.3. Heavy metals

Table 4 summarizes the heavy metal concentrations in different sources of drinking water of the study area. The concentrations of Pb in drinking water samples ranged from 1.59 to 372.2 $\mu g\,L^{-1}$ (Fig. 4), and some of these sources exceeded the permissible limit set by Pak-EPA (2008) (50 $\mu g\,L^{-1}$) and WHO (10 $\mu g\,L^{-1}$) as given in Table 2. Minimum concentration of Pb (1.59 $\mu g\,L^{-1}$) was found in the sample collected from village Mira khel (tehsil Charsadda), while maximum concentration (372.2 $\mu g\,L^{-1}$) was found in the sample of village Dora khel (tehsil Tangi). Cd concentrations ranged from 0.15 to 20.38 $\mu g\,L^{-1}$ (Fig. 5). In tehsil Tangi and Shabqadar, two water sources each showed significantly higher concentrations ($P < 0.01$) with Cd, while in tehsil Charsadda, three water sources exceeded the permissible limit. In the study area, there was no significant variation ($P < 0.01$) in Cd concentrations detected in different sources of drinking water. However, Cr concentrations ranged from 0.402 to 35.52 $\mu g\,L^{-1}$ (Table 4) and were within the permissible limit (Table 2) set by different organizations. Similarly, the Cu concentrations in drinking water samples of the district Charsadda ranged from 0.876 to 270.8 $\mu g\,L^{-1}$ (Table 4) and were within the permissible limit (Table 2).

Furthermore, Zn concentrations in drinking water samples of the district Charsadda ranged from 4.41 to 8830.14 $\mu g\,L^{-1}$ (Fig. 6) and were within the permissible limit except in water samples collected from village Karewar and Bariband kali (tehsil Tangi). Ni concentrations ranged from 0.089 to 25.892 $\mu g\,L^{-1}$ (Table 4 and

Table 2
Drinking water quality guidelines given by different organizations.

Contaminant	Pak-EPA limits[a] ($mg\,L^{-1}$)	Canadian limits[b] ($mg\,L^{-1}$)	US limits[c] ($mg\,L^{-1}$)	WHO limits[d] ($mg\,L^{-1}$)
Cd	0.01	0.005	0.005	0.003
Cl	250	<251	–	–
Cr	0.05	0.050	0.01	0.05
Total coliform (including fecal Coliform and *E. coli*)	0/100 mL	0/100 mL	5.0%	–
Cu	2	1.0	1.3	2
Fe	–	0.300	0.3	–
Pb	0.05	0.010	0	0.001
Ni	0.02	–	–	0.020
NO_3	–	45	10	–
pH	6.5–8.5	6.5–8.5	6.5–8.5	–
SO_4	–	500	–	500
Zn	5	5.00	5	–

A dash (–) indicates that there is no information available regarding possible limits.
[a] As per Pakistan Environmental Protection Agency (Ministry of Environment), Government of Pakistan, 2008.
[b] As per Canadian or BC Health Act Safe Drinking Water Regulation BC Reg 230/92, & Sch 120, 2001. Task force of the Canadian Council or Resource and Environment Ministers Guidelines for Canadian Drinking Water Quality, 1996.
[c] As per the U.S. Environmental Protection Agency Drinking Water Standards.
[d] As per the WHO (1998) Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

Table 3
Mean values ($mg\,L^{-1}$) of anions in groundwater samples collected from various sources of district Charsadda.

Location	Water source	NO_3	Cl	SO_4
Tangi	Tube well ($n=40$)	9.4 ± 1.10	40.19 ± 35.67	456 ± 126.9
	Hand pump ($n=80$)	8.10 ± 0.001	92.11 ± 0.004	286 ± 0.01
	Dug well ($n=90$)	9.50 ± 0.32	21.81 ± 7.71	407 ± 132.08
	Bore well ($n=140$)	10.30 ± 0.004	19.73 ± 0.003	535 ± 0.01
Charsadda	Tube well ($n=35$)	9.20 ± 1.44	22.78 ± 7.57	466 ± 55.01
	Hand pump ($n=85$)	9.06 ± 1.22	75.64 ± 86.74	347 ± 102.06
	Dug well ($n=80$)	8.99 ± 0.29	26.31 ± 6.97	417 ± 60.81
	Bore well ($n=97$)	8.95 ± 0.49	48.49 ± 3.52	393 ± 133.71
Shabqadar	Tube well ($n=40$)	12.12 ± 1.57	53.5 ± 6.44	465 ± 27.44
	Hand pump ($n=100$)	10.02 ± 1.25	58.53 ± 49.48	437 ± 19.37
	Dug well ($n=86$)	11.09 ± 1.79	35.9 ± 11.07	465 ± 54.12
	Bore well ($n=78$)	12.07 ± 3.91	42.76 ± 41.87	376 ± 161.57

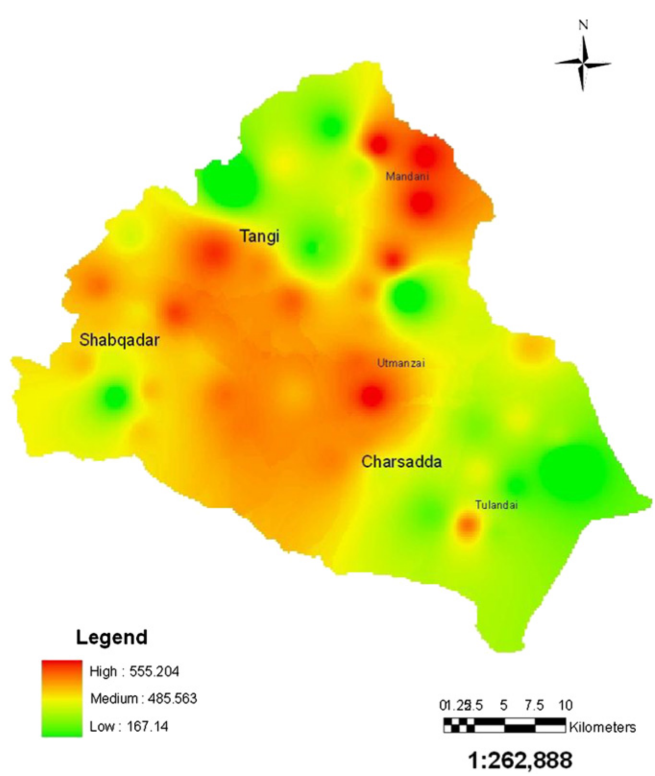

Fig. 2. SO_4 concentrations ($mg\,L^{-1}$) in drinking water of Charsadda District.

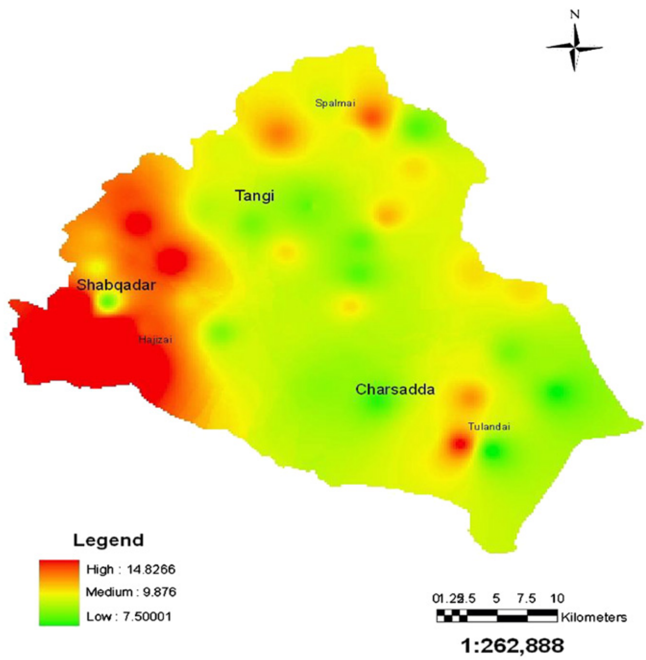

Fig. 3. NO_3 concentrations ($mg\ L^{-1}$) in drinking water of Charsadda District.

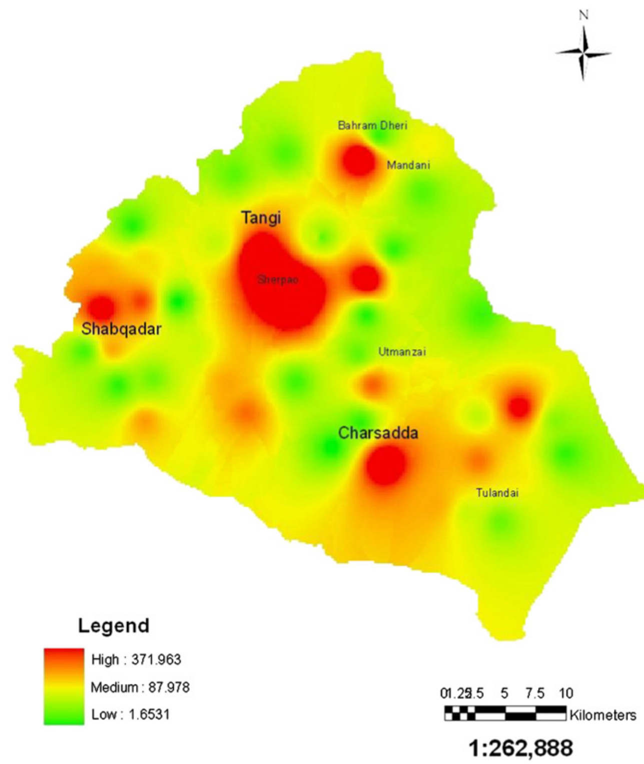

Fig. 4. Pb concentrations ($\mu g\ L^{-1}$) in drinking water of Charsadda District.

Fig. 7). Nearly all water sources showed the concentrations of Ni within the permissible limits except in water samples collected from village Dora khel and Dosehra which were 25.892 $\mu g\ L^{-1}$ and 23.689 $\mu g\ L^{-1}$, respectively. Fe concentrations in drinking water samples of Charsadda district ranged from 21.3 to 1675 $\mu g\ L^{-1}$ (Table 4). The concentrations of Fe in drinking water samples of the district Charsadda fell within the permissible limit except in the water samples collected from village Hakim abad and Bahram dheri in tehsil Tangi, village Akhon dheri in tehsil Charsadda and village Kangra and Mir zai in tehsil Shabqadar (Fig. 8).

3.4. Bacterial contamination

Table 5 shows the mean values of coliform bacteria in drinking water collected from the study area. All drinking water samples collected from Charsadda district were analyzed for coliform bacteria and ranged from 0 to 5 per 100 mL. In tehsil Tangi, both tub well and dug well samples showed the presence of coliform (villages such as Yousaf Khanai, Spalmai and Gandheri). All drinking water samples showed the presence of total coliform bacteria in tehsil Charsadda, whereas in tehsil Shabqadar, water samples contaminated with coliform bacteria except the samples of bore wells. ANOVA indicate a significant ($P < 0.05$) variation among the samples of rural and urban areas. In Charsadda district, total coliform bacteria in drinking water samples generally exceeded the permissible limit (0 per 100 mL) set by Pak-EPA (2008) (Table 2).

3.5. Health problems

Table 6 summarizes the major health problems reported during health survey conducted in the study area. The gastroenteritis, dysentery and diarrhea were reported by 40–50%, 28–35% and 47–59% respondents, respectively. In the study area, the hepatitis-

Table 4
Mean values ($\mu g\ L^{-1}$) of heavy metals in drinking water samples collected from various sources of district Charsadda.

Water source	Pb	Cd	Cr	Cu	Zn	Ni	Fe
Tehsil Tangi							
Tube well ($n = 40$)	107.9 ± 128.4	3.9 ± 5.6	10.3 ± 4.1	20.7 ± 20.7	1490.4 ± 839.7	5.5 ± 8.0	57.4 ± 34.7
Hand pump ($n = 80$)	70.2 ± 0.1	3.2 ± 0.2	4.9 ± 0.05	27.7 ± 0.1	53.6 ± 0.1	0.86 ± 0.02	407.1 ± 0.04
Dug well ($n = 90$)	113.5 ± 112.2	4.1 ± 5.2	9.1 ± 7.3	17.5 ± 12.3	2373.2 ± 504.4	9.4 ± 8.7	185.4 ± 181.2
Bore well ($n = 140$)	14.4 ± 0.1	2.0 ± 0.1	35.5 ± 0.1	1.7 ± 0.0	504.5 ± 0.2	BD	34.7 ± 0.1
Tehsil Charsadda							
Tube well ($n = 35$)	99.3 ± 82.5	2.3 ± 1.9	5.6 ± 5.4	15.5 ± 1.1	97.8 ± 50.5	3.3 ± 3.6	85.0 ± 32.5
Hand pump ($n = 85$)	85.5 ± 74.4	4.6 ± 6.4	10.0 ± 8.5	39.0 ± 45.3	803.7 ± 580.0	4.8 ± 8.1	196.3 ± 14.6
Dug well ($n = 80$)	30.7 ± 17.4	1.9 ± 2.5	2.0 ± 2.3	5.3 ± 3.9	60.7 ± 79.6	2.1 ± 0.2	346.6 ± 3.0
Bore well ($n = 97$)	47.4 ± 64.7	0.7 ± 0.1	3.9 ± 1.8	10.3 ± 2.7	383.2 ± 541.9	0.7 ± 0.8	59.6 ± 3
Tehsil Shabqadar							
Tube well ($n = 40$)	86.4 ± 57.5	0.6 ± 0.2	4.3 ± 2.7	20.3 ± 15.6	159.0 ± 80.2	2.4 ± 2.1	60 ± 29.2
Hand pump ($n = 100$)	117.5 ± 69.5	3.2 ± 0.5	3.3 ± 1.2	70.7 ± 114.0	575.3 ± 60.4	1.9 ± 3.2	712.28 ± 7
Dug well ($n = 86$)	57.7 ± 58.8	3.2 ± 3.6	2.3 ± 0.7	6.5 ± 7.7	396.6 ± 463.1	0.3 ± 0.4	80.3 ± 17.8
Bore well ($n = 78$)	76.8 ± 90.6	4.4 ± 4.8	2.1 ± 0.7	10.9 ± 4.3	BD[a]	BD	68.77 ± 48.3

±Standard deviation.
[a] Below detection limits.

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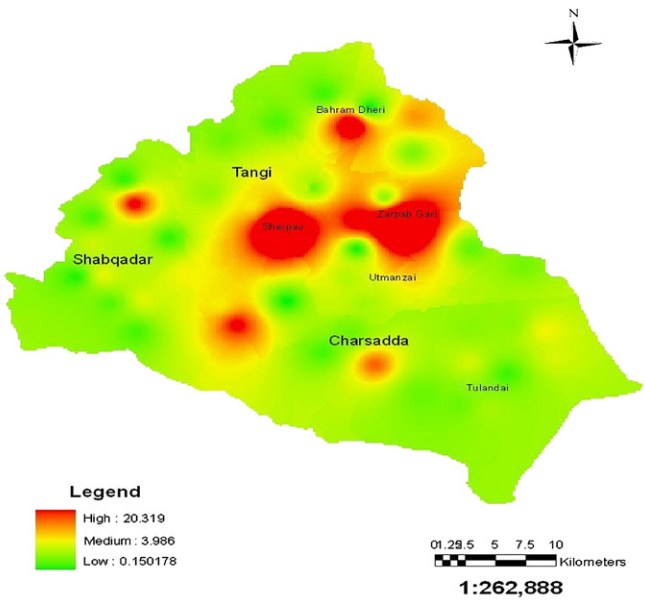

Fig. 5. Cd concentrations (μg L^{-1}) in drinking water of Charsadda District.

A, hepatitis-B and hepatitis-C ranged from 32 to 38%, 16–19% and 6–7%, respectively. Similarly, other health problems including cancer, anemia, sleeping disorders, poor appetite, constipation, vomiting kidney problems and abdominal pain were also reported by the respondents at different percentage as given in Table 6.

4. Discussion

The present and previous studies indicated that surface and groundwater contaminated with different chemicals and heavy metals are responsible for causing numerous human health risks

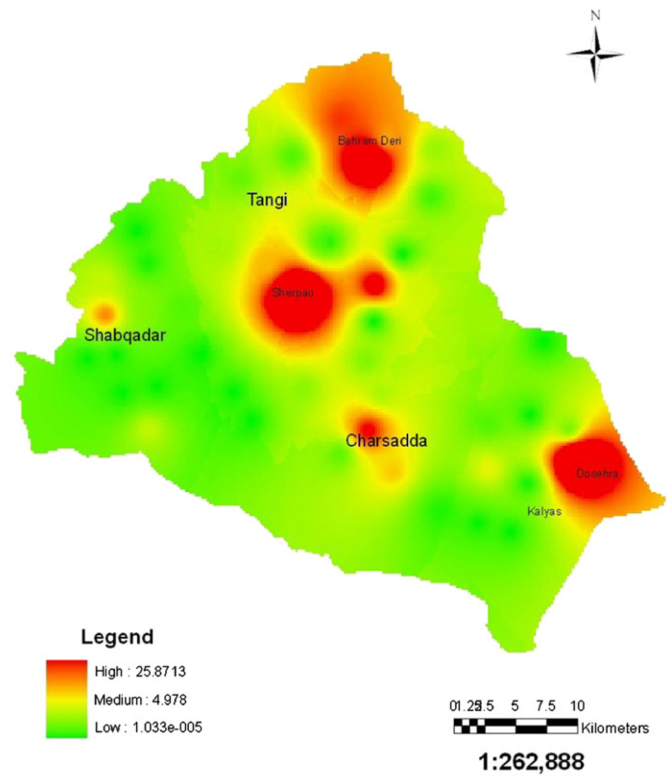

Fig. 7. Ni concentrations (μg L^{-1}) in drinking water of Charsadda District.

(Nickson et al., 2005; Kalita et al., 2006; Nguyen et al., 2009). In the study area, the population was mostly belong to low-income class and was unable to afford bottled water (mineral water) from markets. Like other societies, in Charsadda mostly women were acting as household managers and responsible for collection and

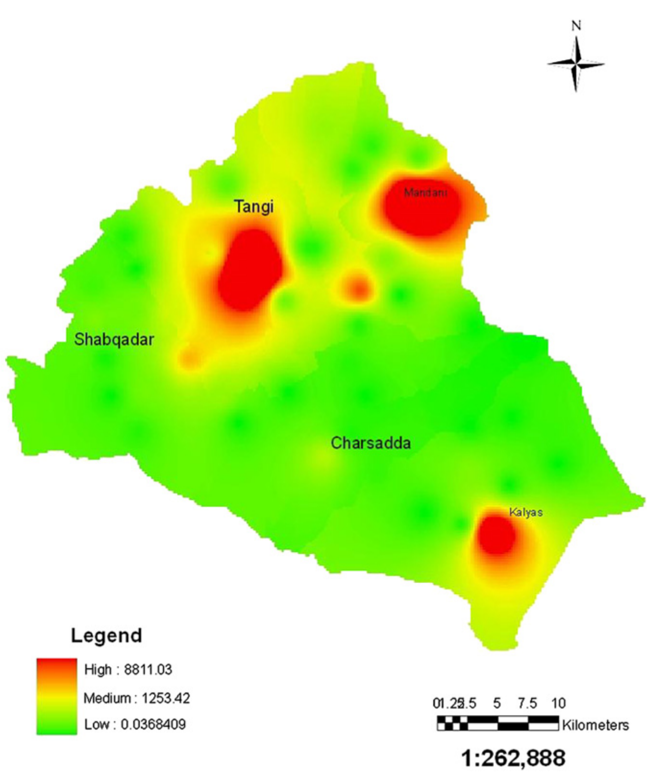

Fig. 6. Zn concentrations (μg L^{-1}) in drinking water of Charsadda District.

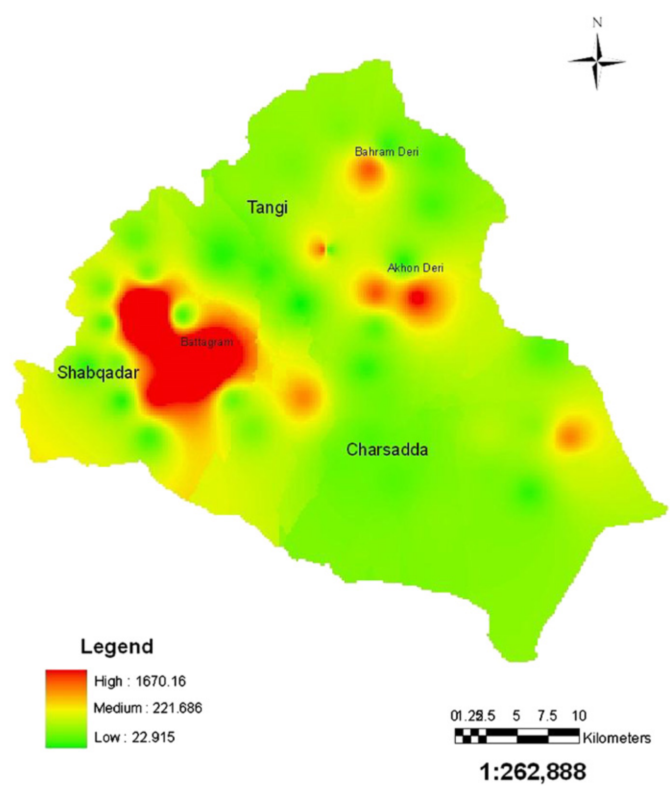

Fig. 8. Fe concentrations (μg L^{-1}) in drinking water of Charsadda District.

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Table 5
Number of coliform bacteria (MPN/100 mL) in drinking water samples collected from various sources of Charsadda District.

Locations	Water source	Total coliform
Tangi	Tube well ($n = 40$)	3.3 ± 1.01
	Hand pump ($n = 80$)	ND[a]
	Dug well ($n = 90$)	2.1 ± 1.0
	Bore well ($n = 140$)	ND
Charsadda	Tube well ($n = 35$)	1.9 ± 1.04
	Hand pump ($n = 85$)	4.7 ± 1.8.
	Dug well ($n = 80$)	2.5 ± 1.4
	Bore well ($n = 97$)	1.8 ± 0.9
Shabqadar	Tube well ($n = 40$)	2.4 ± 1.2
	Hand pump ($n = 100$)	2.9 ± 1.4
	Dug well ($n = 86$)	4.6 ± 1.3
	Bore well ($n = 78$)	ND

±Standard deviation.
[a] Not detected.

management of water for daily uses. In some rural areas, the women have to fetch water from neighboring houses, mosque or hand pumps constructed by Governmental or nongovernmental organizations. Being housewives, women have also basic responsibility for sanitation, health, cleaning and washing of cloths and dishes. It means that women folk can play a major role in conservation and management of fresh water resource. Women have great dependency and relationship with water resources, therefore, they know about general water quality and storage techniques.

Generally, there was no concept of treated/filtered water at the household level. However, 2 water filtration plants were present in the entire Charsadda district and all the schools were supplied with untreated water. Due to shortage of water, local people have installed a large number of bore holes, tube wells and hand pumps without following the governmental guidance for their installations (i.e. depth of digging, strata penetration, lining and distance from sewage system). These sources of water were usually shallow, therefore, their quality was not satisfactory. However, people were of the opinion that groundwater is safe, i.e. without any risk of surface contamination. Some people even considered that water lying below the gravel is free from contamination and, therefore, they did not consider any treatment for groundwater before intake.

Previously, several research works have demonstrated that many factors change the quality of drinking water and cause health problems (Mora et al., 2009; Tamasi and Cini, 2004). The pH of drinking water has no immediate direct effects on human health but has some indirect health effects by bringing changes in other water quality parameters such as solubility of metals and survival of pathogens (Ho et al., 2003). In sensitive individuals gastrointestinal irritation may also occur, however, occasional pH changes may not have any direct impact on consumers.

Table 6
Number of households and different diseases reported during health survey.

Parameters	Tangi	Charsadda	Shabqadar
Number of households	1620	1554	1566
Male (adults and children)	3000	3500	4000
Female (adults and children)	3200	3157	3200
Gastroenteritis (%)	46	50	40
Dysentery (%)	30	35	28
Diarrhea (%)	59	47	56
Hepatitis-A (%)	35	32	38
Hepatitis-B (%)	17	16	19
Hepatitis-C (%)	6	7	6
Cancer (%)	0.5	1	0.8
Tiredness (%)	36	40	53
Anemia (%)	29	32	30
Sleeping disorder (%)	32	41	35
Poor appetite (%)	40	38	41
Constipation (%)	21	22	19
Vomiting (%)	23	15	13
Kidney problems (%)	32	30	34
Abdominal pain (%)	17	13	18

Characteristically, the anions also play a very important role in quality of drinking water and affect the human health. In Charsadda district, drinking water in rural areas was highly contaminated with SO_4 mainly due to anthropogenic inputs such as the application of fertilizers on cultivated lands. The intake of elevated concentrations of SO_4 through drinking water may cause heath effect such as laxative action (WHO, 1996). During survey, 47–59% respondents reported diarrhea in the study area. Similarly, drinking water of rural areas was also highly contaminated with NO_3 as compared to urban areas. For instance, drinking water contamination with NO_3 was higher in tehsil Shabqadar as compared to tehsils Tangi and Charsadda. Like SO_4, the main sources of NO_3 contamination were over-application of fertilizers, sewage disposal, manure applications and wastewater of livestock farms (Chowdary et al., 2005; Liu et al., 2005). The primary health problem associated with high intake of NO_3 in drinking water is methemoglobinemia (blue baby syndrome) (Gupta et al., 2000). However, the adult individuals can tolerate high levels of NO_3 with little or no documented adverse health effects and may be able to drink water with nitrate concentrations considerably greater than the 10 mg L^{-1} with no acute toxicity effects (Bruning-Fann and Kaneene, 1993). In the study area, no case of methemoglobinemia was reported by respondents during questionnaire survey.

In Charsadda district, different heavy metals were detected in drinking water and some of them exceeded their respective permissible limits. Mostly in urban areas, the drinking water sources were highly contaminated with Pb due to leaching from plumbing system (WHO, 1996; Clement et al., 2000) and transportation. After ingestion, Pb accumulates in the skeleton and cause adverse impacts on health (Lehloesa and Muyima, 2000) including subencephalopathic, neurological and behavioral effects (WHO, 1993). Some of the symptoms of acute Pb toxicity are tiredness, lassitude, slight abdominal discomfort, irritability, anemia, neurophysiological effects and in the case of children, behavioral changes etc. (Gerlach et al., 2002). High levels of Pb contamination in a child can result in convulsions, major neurological damage, organ failure, coma, and ultimately death. Moderate to low levels of exposure may result in hearing loss, inhibit growth, and cause learning disabilities. There may be no signs to Pb poisoning or the signs could mimic flu or other gastrointestinal disease. The symptoms may include cramps, irritability, fatigue, vomiting, constipation, sleep disorder, poor appetite, and trouble sleeping. Unlike other metals, Pb accumulates within the body over time and tends to be stored in the brain, bones, kidneys and other major organs (USEPA, 1991). Cd contamination was mostly observed in drinking water of rural areas, may be released from phosphate fertilizers, sewage sludge and corrosion of some galvanized plumbing and water pipe materials (Fleischer et al., 1974). The Cd exposure can cause the health problems such as nausea, vomiting, diarrhea, muscle cramps, salvation, sensory disturbances, liver injury convulsions, shocks and renal failure (USEPA, 1977). Long term Cd exposure can cause certain effects such as kidney, liver, bone and blood damages (Kranjc et al., 1987).

Drinking water usually makes a negligible contribution to Zn intake unless high concentrations of Zn release as a result of corrosion of pipelines and fittings. In the study area, some sources of drinking water were highly contaminated with Zn, particularly in tehsil Tangi. Zn imparts an undesirable astringent taste to the water, therefore, in the study area the inhabitants could distinguish Zn contaminated water with taste, particularly at a level of 4 mg L^{-1}. Acute Zn toxicity symptoms include vomiting, dehydration, electrolyte imbalance, abdominal pain, nausea, lethargy, dizziness and lack of muscular coordination (WHO, 1991). Similarly, Ni concentrations also exceeded the permissible limit in drinking water of Charsadda district. The anthropogenic sources include production of electroplating, high grade steel alloy, fabrication, electronic component, automobiles, batteries, coins, jewellery, surgical implants, kitchen appliances, sinks and utensils (ASTOR, 2005). Ni exposure through drinking water can cause allergy and hand eczema (Filon et al., 2009). In the study area, drinking water was also contaminated with Fe and ingestion of high level of Fe can cause hemochromatosis with symptoms such as chronic fatigue, arthritis, heart disease, cirrhosis, diabetes, thyroid disease, impotence and sterility. Fe, which facilitates persistent hepatitis B or C infection, also induced malignant tumors, colorectal, liver, lung, stomach and kidney cancers (Huang, 2003).

In Charsadda district, drinking water sources were contaminated with coliform bacteria may be due to seepage/discharge from septic tanks, lack of sewage and solid waste disposal systems which were the major threats to water resources. Coliform bacteria may not cause disease, but used as one of the indicators of pathogenic contamination that can cause diseases such as intestinal infections, dysentery, hepatitis, typhoid fever, cholera and other illnesses (Emmanuel et al., 2009). Finally, due to ingestion of contaminated water in the district Charsadda, most residents suffered from waterborne diseases like gastroenteritis, cholera, dysentery, diarrhoea and viral hepatitis (A, B and C) etc. especially children, as reported during questionnaire survey. Significant influx of patients with complaints of vomiting, diarrhea and gastroenteritis also has been reported at local healthcare centers, hospitals and clinics. Finally, it is suggested to arrange walks, seminars and workshop for proper awareness of the people in the study area regarding the level of drinking water contamination and health risks. The government should supply treated/clean water with supply line far away from solid waste, sludge and sewage sites. The farmers should also be trained to avoid the overusing of agrochemicals responsible for drinking water contamination in the study area while both women and men should also be properly educated with water knowledge through awareness and training programs needing for sustainable use and management of drinking water. Further research work is needed about the treatment of contaminated water to protect the inhabitants from chronic health problems.

5. Conclusion

On the basis of findings, it was concluded that drinking water of the study areas was contaminated with SO_4, NO_3, and heavy metals such as Pb, Cd, Fe, Ni and Zn. Similarly, drinking water was also contaminated with coliform bacteria. In addition, the data collected during the questionnaire survey indicated that the residents of study area suffered with numerous health problems. Improper disposal of solid waste, sludge and sewage, and excessive applications of fertilizers and pesticides have contaminated the drinking water of the study area with the selected anions and heavy metals. In the study area, women are responsible for collection and management of water, therefore, they should be educated with water knowledge needed for sustainable use and management of drinking water.

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