Pol. J. Environ. Stud. Vol. 27, No. 2 (2018), 501-511
DOI: *10.15244/pjoes/75813* ONLINE PUBLICATION DATE: 2018-01-15

Original Research

Dietary Exposure of Contaminants through Drinking Water and Associated Health Risk Assessment

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Received: 24 May 2017
Accepted: 11 July 2017

Abstract

This study investigated physico-chemical drinking water quality of 115 water supply schemes of of District Mianwali along with estimating the health risks associated with the intake of arsenic and flouride in drinking water. One sample was collected from the source end while two samples were collected from consumer ends of each scheme. Overall results showed that 81% of the water samples were safe while 19% were unsafe for drinking purposes. Results showed that TDS (30%), chloride (15%), sulphate (40%), calcium (40%), sodium (14.2%), hardness (24%), nitrate (13%), flouride (30%), and arsenic (7%) exceeded World Health Organization (WHO) standards. Pearson correlation matrix also showed statistically significant relationships ($p<0.01$) between various physico-chemical parameters and statistically strong significant positive relationships ($r = 0.68-1.00$, $p<0.01$) between TDS, Ca, SO_4^{2-}, and hardness.There was no variation in the source and consumer end water quality. Risk assessment revealed a low potential health risk to the population of Mianwali for arsenic at source 0.4309<1 (mean) and consumer ends 0.70438<1 (mean), and F^- 0.4339<1 at source (mean) and 0.4068<1 (mean) at consumer ends. Hence, this study is in time for the authorities to act immediately, as Mianwali groundwater quality is deteriorating.

Keywords: water supply schemes (WSS), World Health Organization (WHO), human health risk assessment model, arsenic, flouride

Introduction

Water is regarded as the most important substance for all living organisms as it supports life processes. Earth contains almost 1.4 trillion m^3 of water, of which only 1% is available for living organisms to meet their daily requirements [1-2]. Use of clean and safe drinking water is the basic necessity and fundamental right of each and every person. The inability to access clean and safe

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drinking water is a potential source of nearly 75% of the world's waterborne diseases [3].

Groundwater is regarded as an important source for drinking and its quality can be threatened by a combination of physico-chemical and microbiological parameters that can be further linked to health-related illnesses [4-5]. For the effective assessment of water quality, it is important to identify the potential health effects of the pollutants in drinking water. For this, human health risk assessment (HHRA) is an effective tool for estimating potential health impacts caused by various contaminants [6-7]. HHRA is the identification, analysis, and characterization of potentially adverse health effects of various contaminants in humans from exposure to such agents in the environment [8]. Assessment of carcinogenic or non-carcinogenic risks of contaminants can be used to determine their carcinogenic risks at variable concentrations. Excessive exposure to any contaminant can cause a number of adverse effects. Long-term entry of arsenic (As) to the body may lead to disorders of the bladder, liver and kidney cancers, and skin lesions [9]. Excessive flouride (F^-) may lead to dental fluorosis. These ranges vary from mild dental fluorosis that causes mottling and embrittlement of teeth to skeletal fluorosis that is characterized by crippling as it varies with level and period of exposure [10].

Many multi-dimensional and cross-sectional studies in different parts of the world have been done to assess drinking water quality. Research has been carried out to investigate groundwater quality around Lonar Lake, India. The determination of water quality was done by taking samples and subjecting them to complete physico-chemical analysis, including pH, total hardness, calcium (Ca), magnesium (Mg), bicarbonates (HCO_3^-), chloride (Cl^-), nitrate (NO_3^-) sulphates (SO_4^{2-}), total dissolved solids (TDS), iron (Fe), manganese (Mn), and fluoride (F^-). Results revealed high concentrations of Fe, Cl^-, F^-, Ca, Mg, and total hardness as compared to WHO standards [11].

Exposure to various contaminants via drinking water remains a present health threat to many populations, particularly in areas of developing countries that have insufficient water treatment facilities [12-14]. In recent years, numerous health-related pollution incidents associated with heavy metals have been widely reported, for instance in a study conducted in Hanam, Australia, where arsenic (As) concentrations in 300 tube-well water samples were analyzed and the water consumption levels in 150 households were estimated. Cancer risk was characterized using cancer slope factor (CSF) and exposure doses (ED) with a probabilistic approach. The results showed that As concentrations in tube-well water ranged 8-579 ppb (mean 301 ppb). Daily consumption of As in 40% of the adults exceeded the level of ED at 1 μg/kg/day. The average cancer risk in adults due to consuming As-contaminated tube-well water was 25.3×10^{-5} [15]. The port of Dayyer port in southern Bushehr Province, Iran, has for many years been a typical endemic dental and skeletal fluorosis area caused by drinking water. In addition, symptoms of renal disorders and non-vertebral fractures were also evident in residents of this area [16].

In Mianwali, most of the population relies on groundwater for domestic purpose. Industrial and agricultural use of groundwater has also grown accordingly. However, groundwater development is largely unmanaged and unmonitored, resulting in serious threats that are emerging, such as groundwater mining, saline water ingression, secondary salinization, and increasing levels of physico-chemical parameters and their associated health impacts. Hence, quality of groundwater is, therefore, under severe threat and of major concern [17]. So this study is crucial for investigating significant physico-chemical quality of Mianwali drinking water and determining the various health risks of consuming the water by determining their Exposure Doses (ED), hazard quotient (HQ), and cancer risk (CR) in the population.

Fig. 1. Location of Mianwali District.

Study Area

Mianwali is a district in the northwest of Punjab, Pakistan. It covers an area of 5,840 km^2. According to the 1998 census of Pakistan, the district had a population of 1,056,620, out of which 20.39% (85,000) dwell in the district capital Mianwali, which has a population growth rate of 1.8%. The population of Mianwali is likely to increase to 149,689 individuals by 2033. The district lies at 32°0′ north and 71°30′ east. The district is administratively divided into three tehsils – Isakhel, Mianwali, and Piplan – and it has 56 union councils [18] (Fig. 1).

Existing Water Supply Schemes of the Study Area

There are a total of 55 water supply schemes in the study area. These schemes are further extended into 115 sub schemes, which were assessed for physico-chemical and bacteriological determination of the drinking water from sources and tap water. The total estimated population of the area at present is 206,210, out of which only 72,450 are served by these supply schemes [18].

Material and Methods

Collection of Secondary Data

The collection of secondary data was carried out with the help of various books, scientific journals, articles, case studies, reports, research, and recent publications.

Collection of Primary Data

Primary data was collected by conducting water quality sampling and analysis from water supply schemes (WSS) in Mianwali. A total of 115 WSSs were assessed for this purpose (among them 81 of the schemes that supply water directly and 34 of the schemes that supply water after storage). These schemes covered a variety of water sources (tubewells and handpumps), water storage facilities, and water distribution systems that collectively cater most of the drinking water demands of the population. From each scheme, one sample was collected from the source of the water (mostly hand pumps and tubewells) and two of the samples were collected from tapwater (mostly from commercial taps). In total,

Table 1. Water quality parameters and methods of analysis.

Sr. No.	Water Quality Parameters	Standard Test Methods
1.	Alkalinity (m. mol/l as $CaCO_3$)	2320, Standard Method (1992)
2.	Bicarbonate (mg/L)	Acid Base Titration, Standard Method (1992)
3.	Calcium (mg/L)	EDTA Titration, Standard Method (1992)
4.	Carbonate (mg/L)	2320, Standard Method (1992)
5.	Chloride (mg/L)	Argentometric Titration (Silver Nitrate), Standard Method (1992)
6.	Color (TCU)	Sensory Test
7.	Electrical Conductivity (mS/cm)	EC meter, Hanna Instrument Model HI 991301, Italy
8.	Hardness (mg/L)	EDTA Titration, Standard Method (1992)
9.	Magnesium (mg/L)	2340-C, Standard Method (1992)
10.	Odor	Sensory Test
11.	pH	pH Meter, Hanna Instrument Model HI 991301, Italy
12.	Potassium (mg/L)	Flame Photometer, DigiFlame
13.	Sodium (mg/L)	Flame Photometer DigiFlame,
14.	Taste	Sensory Test
15.	TDS (mg/L)	2540C, Standard Method (1992)
16.	Turbidity (NTU)	Turbidity Meter, Hanna Instrument Model HI 93703, Italy
17.	Fluoride (mg/L)	SPADNS Method using Colorimeter, Model DR/2800, HACH, USA
18.	Sulphate (mg/L)	4500 $NO_{3,}$ Standard Method (1992), UV- Visible Spectrophotometer, SPECORD 200, Analytikjena
19.	Nitrate- (mg/L)	Standard Method (1992), UV- Visible Spectrophotometer, SPECORD 200, Analytikjena
20.	Iron (mg/L)	SPADNS Method using Colorimeter, Model DR/2800, HACH, USA
21.	Arsenic (mg/L)	Atomic Absorption Spectrometer, Vario6, Analytikjena

345 samples were collected, out of which 115 samples were collected directly from the source end and 230 samples were collected from two tapwaters of each scheme. Mean value of both samples collected from tap water of each scheme was calculated to determine the variation in quality of water from sources and after passing through the distribution network from the tapwater. Each samping location was marked by the GPS coordinates obtained by using a Magnin GPS Explorist 600 unit.

Sample Collection

Water samples were collected in polyethylene (PET) bottles of 600 ml capacity each for physicochemical analysis. Before sampling, all the bottles were washed and cleaned properly. Before the collection of water samples, bottles were washed properly and rinsed thoroughly several times. Sterilization of the water samples was carried out with the help of distilled water.

Analytical Methods

The collected water samples were analyzed in the PCRWR Laboratory, Lahore. Investigated physical parameters include pH, EC, color, odor, taste, alkalinity, total hardness, turbidity, and TDS. The investigated chemical parameters include the various inorganic elements (Cl^-, K, F^-, Na, and $SO_4^{2-,}$ CO_3^-, HCO_3^-, NO_3^-) and metals (Ca, Mg, As, K, Fe). Standard methods and protocols were followed for determining 21 physico-chemical water quality parameters (Table 1).

Statistical Analysis

Statistical interpretation of the results was carried out through SPSS Software v. 21. The physico-chemical parameters were correlated against each other to determine their relationships using Pearson's correlation (r) coefficient values. In order to calculate correlation coefficients, correlation matrix was constructed by calculating the coefficients of different pairs of parameters and correlation for significance was further developed by applying p value. The variations are significant if $p<0.05$ or $p<0.01$, and non-significant if $p>0.05$. The significance is considered at the level of 0.01 and 0.05 (two-tailed analysis). Descriptive statistics were used to calculate mean, standard deviations (SDs), maximum (Max), and minimum (Min) values of ED, HQ, and CR.

Human Health Risk Assessment

Health risk assessment was done to determine the health risk in individuals exposed to flouride and arsenic [19].

Exposure Dose

$$ED = C * IR * ED * EF/ BW * AT \quad (1)$$

…where:
C = flouride/arsenic concentration in water (mg/l)
IR = Intake rate (2L/day)
ED = Exposure duration (assumed for 67 years)
EF = Exposure frequency (365 days/year)
BW = Body weight (72 kg)
AT = Average lifetime (24,455 days)

Hazard Quotient

Generally, hazard quotient (HQ) was calculated by the following formula [19]:

$$HQ = ED/RfD \quad (2)$$

If the calculated HQ is equal to or greater than 1, the intake of such water is considered to be a health risk. The reference dose (R_fD) of As is 0.0003 mg/kg/day, while the reference dose of F^- is 0.08 mg/kg/day.

Cancer Risk

Cancer Risk (CR) was calculated by the following formula [19]:

$$CR = ED*CSF \quad (3)$$

…where CSF is the cancer slope factor, and the CSF value for As is 1.5 mg/kg/day.

Comparison with WHO Standards

On the basis of the laboratory analysis and interpreted data the samples that lie within permissible ranges of WHO standards were regarded as fit for drinking purposes, while those samples whose values exceeded the permissible limits of WHO standards were rendered unfit for drinking purposes.

Results and Discussion

Laboratory analysis showed that the majority of the samples unfit for drinking purposes were contaminated directly from the source, as no significant variations were determined in the quality of water when obtained through consumer taps. Contamination of water directly from the source end lies in the fact that groundwater quality of the district is already contaminated, which has resulted in the deterioration of water quality. The key factors responsible for water quality deterioration directly from the source may include the geological strata of the area, surrounding pollution sources, age, poor construction, and old, corroded and un-maintained drinking water sources and sewage pipelines that allow intrusion of seepage water in the pipelines [20]. Groundwater quality could also get contaminated by industrial and agricultural activities. Industrial effluents, hazardous chemicals, toxic pollutants, heavy metals, nitrogenous fertilizers, and

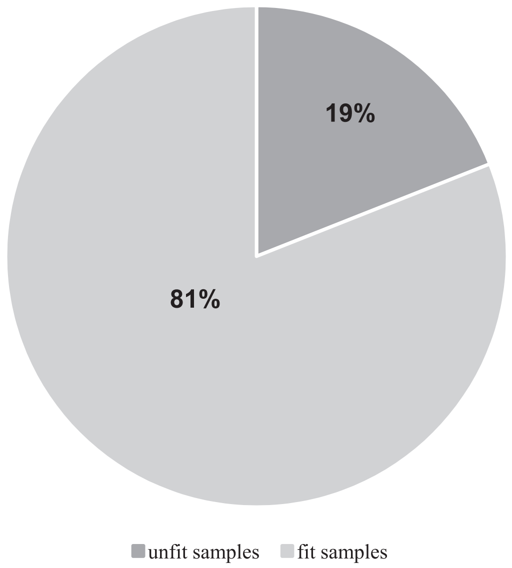

Fig. 2. Fit and unfit water samples with respect to physico-chemical parameters of Mianwali District.

pesticides seep through water and pollute the underground water reservoirs [21].

Physico-Chemical Parameters

On the basis of the laboratory analysis and analyzed data it was interpreted that the overall quality of Mianwali was 81% physico-chemically fit while 19% was physico-chemically unfit for drinking purposes (Fig. 2). The concentrations of most physico-chemical water quality parameters were found within the permissible limits of WHO, for instance the value of TDS ranged in-between 141.90 mg/L to 2,483.46 mg/L with a mean concentration of 842.427 mg/L obtained from source ends and 846.540 mg/L from consumer taps. The WHO for TDS is 1,000 mg/L. Of 345 samples, 102 samples (30%) were unfit while the remaining 243 samples (70%) were fit for drinking purposes. TDS is usually affected mainly by topography, lithology of aquifer, recharge, runoff, and discharge conditions of groundwater. It is an important parameter for assessing groundwater quality [22]. The taste of 22% of the samples obtained were analyzed to be objectionable. At higher EC levels drinking water may have an unpleasant taste or may cause gastrointestinal distress [23] (Table 2).

Total hardness in water is mainly due to the presence of Ca, Mg, CO_3, Cl^- HCO_3^-, and SO_4^{2-} in the groundwater

Table 2. Drinking water quality status in terms of fit and unfit samples from Mianwali District.

	Parameters	Total number of samples analyzed	Number of fit samples	Number of unfit samples	Percentage age of fit samples	Percentage of unfit samples	Concentration range	WHO standard
1	TDS (mg/L)	345	243	102	70	30	141.90 – 2483.46	1,000
2	Turbidity (NTU)	345	341	3	99	1	0.11 – 138	5
3	Taste	345	271	74	79	21	–	Unobjectionable
4	Chloride (mg/L)	345	293	52	85	15	9.6 – 893	250
5	Sulphate (mg/L)	345	208	137	60	40	9 – 1432	250
6	Magnesium (mg/L)	345	341	3.0	99	1	0.486 – 206.55	150
7	Calcium (mg/L)	345	208	137	60	40	3 – 500	75
8	Sodium (mg/L)	345	296	49	85.8	14.2	7 – 550	200
9	Potassium (mg/L)	345	337	8	98	2	1.2 to 26.9	12
10	Hardness (mg/L)	345	243	102	70.5	29.5	12 – 179	500
11	Nitrate (mg/L)	345	296	49	85.8	14.2	0.013 – 62.96	10
12	Flouride (mg/L)	345	237	108	69	31	0.01 – 4.04	1.5
13	Arsenic (ppb)	345	321	24	93	7	0.055 – 17.34	10

[24]. Results showed that the concentration of hardness in water samples (source ends and consumer ends) ranged from 12 mg/L to 179 mg/L. The permissible limit of WHO for hardness in drinking water is 500 mg/L. Concentration of hardness level in water samples were exceeding the limits in 29.5% of the water samples (Table 2). Elevated water hardness mainly contributes to economic damage such as corrosion and choking off of the pipes and utensils. It has been reported in previous studies that elevated hardness may cause diarrhea, gas trouble, kidney stones, and heart problems [25-26].

Results of the inorganic parameters showed that Nitrate (NO_3^-) levels ranged from 0.013 mg/L to 62.96 mg/L in the water samples obtained from source ends and consumer ends of the district. They showed 14.2% of the samples were found to be exceeding WHO standards, i.e., 200 mg/L. The increased levels of NO_3^- in the water samples were due to the intrusion of sewage and industrial effluents into the groundwater or may be due to the release of leachate from landfills or open dumpsites to the surrounding soil. Exceeding NO_3^- levels is indicative of high pollution load in the groundwater. Water with high NO_3^- concentration if consumed causes methemoglobinemia with the symptoms of paleness, bluish mucous membranes, and digestive and respiratory problems [27]. Chloride (Cl^-) concentration from the water samples ranged between 9.6 mg/L to 893.0 mg/L in the water samples obtained from source ends and consumer ends. 15% of the water samples were found to exceed WHO standards, i.e., 250 mg/L (Table 2). A high concentration of Cl^- in drinking water can produce hypertension, affect metabolism, and increase the EC of water [28]. Sulphate (SO_4^{2-}) occurs naturally as a result of leaching from gypsum and other common minerals. SO_4^{2-} originates from sedimentary and igneous rocks [29]. The concentration of SO_4^{2-} in the district ranged between 9 mg/L and 1,432 mg/L in the samples obtained from sources and consumer ends of the district. According to WHO, a water sample exceeding the SO_4^{2-} level of 250 mg/L in water is unfit for drinking purposes (Table 2). 40% of the water samples were found to be exceeding the recommended limits of WHO. This may be due to the fact that SO_4^{2-} may enter watercourses through waste discharge [17]. Sodium (Na) is an abundant element and is a common constituent of natural water. WHO guideline value for Na is 200 mg/L. Results showed that 14.2% of the samples exceeded the WHO limits in terms of Na concentration (Table 2). Higher Na concentrations in water may not cause any toxic health impact. The geological crust in Mianwali is rich in Fluoride (F^-)-bearing minerals that resulted in 31% of water samples getting contaminated in terms of F^- content. The F^- content of the water samples ranged from 0.01 to 4.04 mg/L (Table 2). High levels of F^- in groundwater can be due to weathering of primary rocks and leaching of F^--containing minerals in soils, or may be due to the reactions of water

Table 3a. Correlation Matrix of physico-chemical parameters of water obtained from source ends of water samples.

	pH	TDS	Cl^-	SO_4^{2-}	Ca	Mg	Na	K	Hardness	NO_3^-
pH	1									
TDS	.077	1								
	.415									
Cl^-	.068	.402**	1							
	.472	.000								
SO_4^{2-}	-.097	.868**	-.062	1						
	.306	.000	.514							
Ca^-	-.133	.791**	-.017	.872**	1					
	.161	.000	.859	.000						
Mg	.052	.616**	.534**	.398**	.280	1				
	.582	.000	.000	.000	.003					
Na	.035	.586**	.817**	.159	.064	.584**	1			
	.713	.000	.000	.090	.497	.000				
K	-.010	.553**	.167	.530**	.621**	.321**	.189	1		
	.920	.000	.077	.000	.000	.000	.044			
Hardness	-.108	.881**	.030	.938**	.916**	.436**	.135	.543**	1	
	.256	.000	.752	.000	.000	.000	.152	.000		
NO_3^-	.071	.339**	-.086	.324**	.317**	.157	.023	.128	.400**	
	.453	.000	.364	.000	.001	.096	.809	.173	.000	1

Correlation is significant at the 0.01 level (two-tailed)
Correlation is significant at the 0.05 level (two-tailed).

with minerals in rock and soil with which groundwater comes into contact. Calcium (Ca) level ranged between 3 mg/L to 500 mg/L. The WHO guideline for maximum level of Ca in drinking water is 75 mg/L, while Ca level in water samples (sources and consumer taps) exceeded the permissible limit in 40% of the samples (Table 2). Increased levels of Ca in drinking water can be due to the presence of calcareous rocks found in underground water sources, and a significant amount of which is being added into groundwater which is then supplied to WSS of the district for drinking purposes. Drinking water may represent a major contributor to dietary exposure to Arsenic (As) in areas with high natural levels of As in groundwater [30]. As content of the samples ranged between 0.055 to 17.34 ppb. The permissible range of As intake in drinking water recommended by WHO is 10 ppb. In the study, 7% of the water samples were unfit in terms of As content in drinking water.

Correlation Matrix between Various Physico-chemical Parameters

Table 3 shows Pearson's correlation between various physico-chemical parameters of water at a) source ends and b) consumer ends. No significant differences were determined in the correlation relationships among both source ends and consumer ends because insignificant variations were determined in the water samples obtained from consumer taps as compared to source ends. The correlation coefficient $r \leq 0.35$ represents weak correlations, an r value of 0.36-0.67 indicates moderate links, and an r value of 0.68-1.00 signifies strong relationships [31]. Results of the Pearson correlation matrix (Tables 3a-b) show a strong statistically significant positive relationship ($r = 0.68$-1.00, $p<0.01$) between the distribution of Ca, SO_4^{2-}, and hardness with TDS; a strong statistically significant positive relationship ($r = 0.68$-1.00, $p<0.01$) between the distribution of TDS, SO_4^{2-}, hardness and Ca; and a strong statistically significant positive relationship ($r = 0.68$-1.00 , $p<0.01$) between the distribution of Na with Cl^-.

Health Risk Assessment Model

A health risk assessment model derived from the USEPA was applied to calculate individual risks being posed to the locals of Mianwali associated with As and F^- in drinking water samples. Basically intake of any substance if taken more than the permissible level could result in various health risks that can be acute or chronic, depending on its concentration, consumption rate, type, and toxicity in the drinking water [19].

Exposure dose (ED) values of As and F^- were evaluated for health risk assessment through the health quotient (HQ). For F^-, ED values calculated for the water samples at source ends ranged 0.01-0.12mg/kg/day,

Table 3b. Correlation Matrix of physico-chemical parameters of water obtained from consumer ends of water samples.

	pH	TDS	Cl^-	SO_4^{2-}	Ca	Mg	Na	K	Hardness	NO_3^-
pH	1									
TDS	.027	1								
	.772									
Cl^-	.032	.404**	1							
	.735	.000								
SO_4^{2-}	-.010	.868**	-.059	1						
	.918	.000	.536							
Ca^-	-.086	.792**	-.016	.875**	1					
	.363	.000	.869	.000						
Mg	.018	.618**	.559**	.384**	.295	1				
	.846	.000	.000	.000	.001					
Na	.100	.586**	.818**	.180	.082	.594**	1			
	.289	.000	.000	.055	.386	.000				
K	-.002	.556**	.184	.531**	.623**	.321**	.233	1		
	.985	.000	.050	.000	.000	.000	.013			
Hardness	-.015	.885**	.047	.933**	.917**	.433**	.155	.530**	1	
	.872	.000	.623	.000	.000	.000	.099	.000		
NO_3^-	.019	.390**	-.090	.381**	.354**	.192	.001	.075	.465**	
	.844	.000	.341	.000	.000	.041	.994	.426	.000	1

Correlation is significant at the 0.01 level (two-tailed).
Correlation is significant at the 0.05 level (two-tailed).

Table 4. Descriptive Statistics of ED, HQ, and CSF of metals at source and consumer ends.

Parameter	Mean	Standard deviation	Minimum	Maximum
Exposure dose (mg/kg/day)				
As-S	0.000210	±0.000126	0.0001	0.0005
As-C	0.000221	±0.0001830	0.00001	0.00082
F⁻S	0.0356	±0.232	0.01	0.12
F⁻C	0.3255	±0.2068	0.002	0.086
Hazard quotient				
As-S	0.4309	±0.44954	0.012	1.52
As-C	0.70438	±0.61493	0.0004	2.73
F⁻S	0.4339	±0.29373	0.278	1.52
F⁻C	0.4068	±0.25851	0.0243	1.07
Cancer risk (mg/kg/day)				
As-S	0.0002430	±0.0002243	0.00002	0.00005
As-C	0.000390	±0.000485	0.0001	0.0022

while the ED values calculated for the water samples of consumer taps ranged 0.002-0.086mg/kg/day (Table 4). ED of As in drinking water samples from source ends ranged 0.0001-0.0005 mg/kg/day. The ED values calculated for the water samples of consumer taps ranged 0.00001-0.00082 mg/kg/day (Table 4). ED indices for mean concentrations of F^- were found: source ends > consumer ends (0.0356 > 0.3255 mg/kg/day) while the ED indices for mean concentrations of As were found: source end > consumer ends (0.000210 > 0.000221 mg/kg/day). The high ED values in some WSSs may be attributed to severe contamination from urban and industrial sewage and wastewater in the vicinity near water supply lines [32].

Table 4 shows HQ values of F^- in drinking water samples. HQ values for F^- in drinking water samples from source ends ranged between 0.027 to 1.52. HQ values for F^- in drinking water samples from consumer taps ranged between 0.015 to 1.08. If HQ value is greater than 1 (HQ>1), then intake of such water can pose serious health risks. In this study five water samples obtained from WSS Chapri Khel, WSS Chapri City, WSS Nasri Wala,WSS Kutki Nizam Khel, and WSS Dera Nooran Shah at source ends had values greater than 1 (HQ>1; i.e., 1.3125, 1.026, 1.180556, 1.013889, and 1.5277, respectively). Exceeding HQ values were also calculated from the two tapwater samples obtained from WSS Chapri City and WSS Nasri Wala, i.e, 1.20 and 1.56, respectively (Fig. 3). Hence,

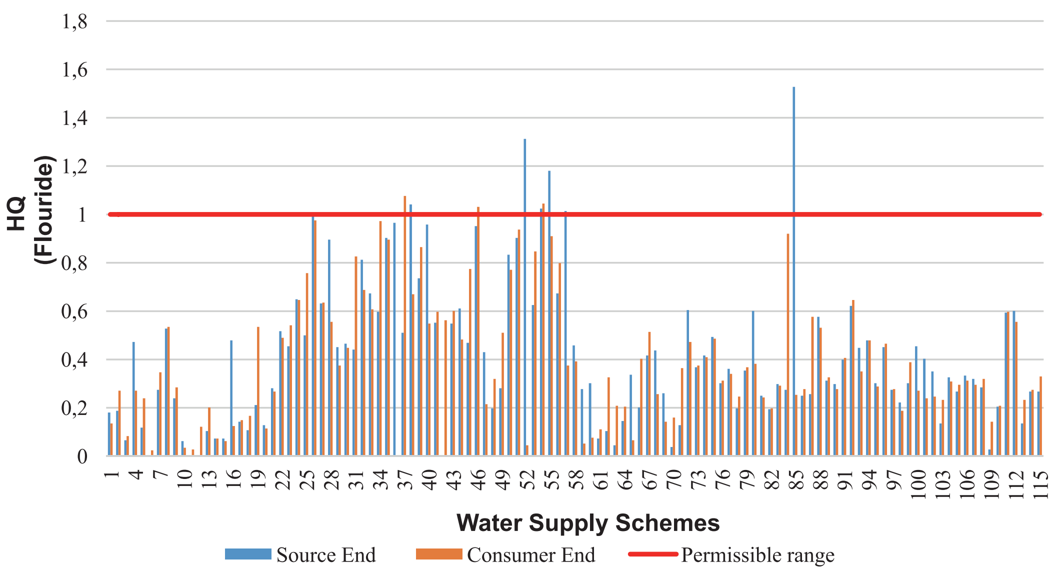

Fig. 3. Overview of HQ results of fluoride.

the population of Mianwali obtaining water from these WSSs are under threat related to various health risks like loss of calcium from the tooth matrix, dental flouro-sis, and increased non-vertebral fracture rate in osteoporotic women. Severe, chronic, and cumulative overexposure can cause incurable crippling of skeletal flouriosis. High exposure causes acute effects like crippling, renal disorder, and also affects the thyroid [33]. The calculated trend of mean HQ value through the consumption of F^- drinking water was greater in sources than that of consumer taps: source ends (0.433) > consumer ends (0.406).

Table 4 shows HQ values of As in drinking water samples. HQ values for As in drinking water samples from source ends ranged 0.012-1.52333. The highest value of HQ at source ends was calculated in the water samples of WSS (1.5233). If HQ value is greater than 1 (HQ>1), then intake of such water can pose serious health risks. Twelve water samples obtained from source ends of WSS Colla Mir Wala, WSS Lady Park, WSS Haki Ground, WSS Eid Ghah, WSS Mela Ground, WSS Whandi Ghund Wali, WSS Sarkia, WSS Kamrian Wala No. 1, and WSS Kundal. WSS Awanan Wala, WSS Kalur, WSS Khanu Wala, WSS Mithe Khatak, Sum Well, and WSS Lari Adda had values greater than 1 (HQ>1), i.e., 1.473, 1.5033, 1.52, 1.04, 1.29, 1.49, 1.09, 1.87, 1.05, 1.045, 1.56, and 1.0578, respectively (Fig. 4).

HQ values for As in drinking water samples from consumer taps ranged 0.0004-2.73. The highest value of HQ at consumer ends calculated in the water samples of WSS Mohabat Khel was 2.730. The HQ value of As in these water samples may be due to its toxic nature, high concentration, and low R_fD value [34]. However, no chronic exposure to local population via drinking water consumption was determined in the majority of the water samples as their HQ values were less than 1. A similar study conducted in River Gombe Abba in Gombe State, in northeastern Nigeria in which As posed no long-term health risk threats as all the values of HQ in this study fall below one [35].

However, a very low health risk could result in those water samples for which HQ values were calculated to be greater than 1 in terms of As contamination. The main adverse effects reported to be associated with long-term ingestion of As in humans are skin lesions, cancer, developmental toxicity, neurotoxicity, cardiovascular diseases, abnormal glucose metabolism, and diabetes. Neurotoxicity is mainly reported with acute exposure from deliberate poisoning or suicide, or at high concentrations in drinking water [36]. The calculated mean trend of mean HQ value through the consumption of As in drinking water was greater in tap water than that of sources: consumer ends > source ends (0.70438 > 0.4308). This may be due to the fact that when water passes through the distribution network its contamination is elevated [37].

Cancer risk of As values ranged 0.00002-0.00005 mg/kg/day at source ends and 0.0001-0.0022 mg/kg/day at consumer ends. Generally, a cancer risk value greater than one in a million is generally considered a cancer risk. However, these values get changed according to the local environment and national policies [38]. The risk of cancer associated with As concentration of 0.001 mg/L is calculated to be 5 x 10^{-4} for an adult weighing 70 kg and consuming 2 L of water/day [35].The results indicated that the calculated trend of mean cancer risk value through the consumption of As in drinking water was greater in consumer ends than that of source ends: consumer ends > source ends (0.0002430>0.000390 mg/kg/day). Results further revealed that few WSS were at threat to pose low cancer risk if preventive measures would not have been taken. Most evidence linking As in drinking water with elevated cancer risk of internal organs comes from ecological and HBM studies in populations of Chile and Pakistan, with high As exposures from underground wells [39-40].

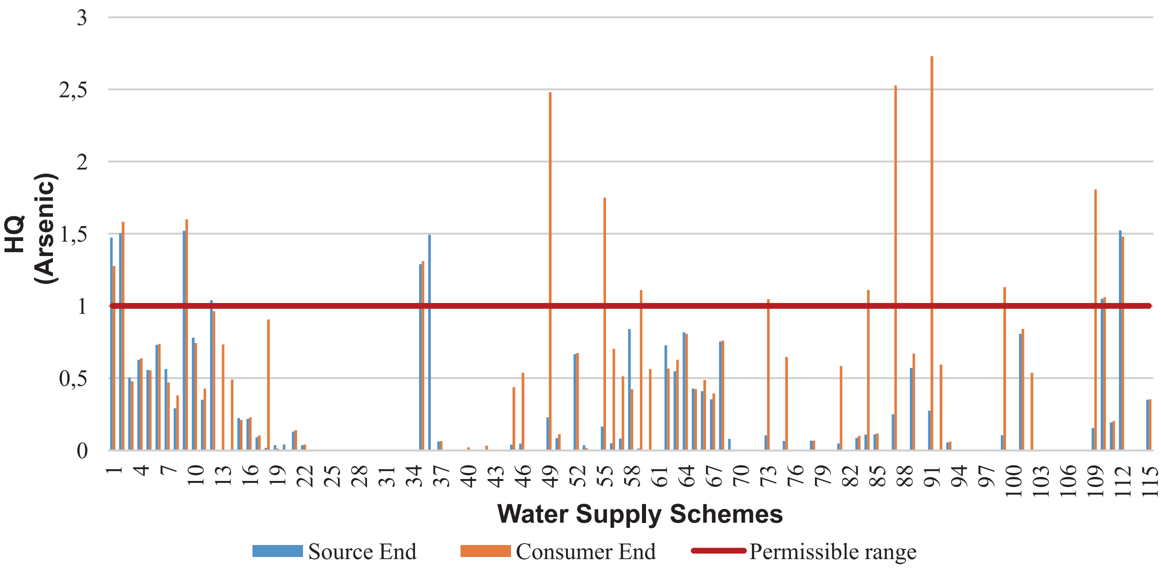

Fig. 4. Overview of HQ results of Arsenic.

Conclusions

On the basis of the laboratory analysis and the analyzed data, we can conclude that physico-chemical drinking water quality of Mianwali is 81% fit while 19% is unfit for drinking purposes. Some parameters that exceeded WHO standards include calcium (40%), sulphates (40%), flouride (31%), water hardness (29.5%), and TDS (30%). Mianwali District is also regarded as safe at present in terms of health risks related to arsenic and flouride in drinking water, but the resulting values indicate that they may pose health risks to the inhabitants in the future. Deterioration in drinking water quality directly from the source is a major cause that also has deteriorated drinking water quality obtained from the consumer ends. However, degradation of drinking water quality directly from the source cautions that the groundwater quality of Mianwali is gradually deteriorating, and this may continue with time. Hence local and international authorities need to initiate precautionary and remedial measures in the district.

Acknowledgements

The authors would like to thank PCRWR and UNICEF for providing complete research facilities and support for this study.

References

1. PERVEEN F., ASGHAR U., USMANI T.H. Evaluation of Water Quality of Different Colleges of Karachi City. J. Chem. Soc. Pak. **29** (5), 458, **2007**.
2. QADEER R. Pollutants in drinking water: Their sources, harmful effects and removal procedures J. Chem. Soc. Pak. **26** (3), 293, **2004**.
3. KHAN N., HUSSAIN S.T., SABOOR A., JAMILA N., KIM KS. Physicochemical investigation of the drinking water sources from Mardan, Khyber Pakhtunkhwa, Pakistan. IJPS. **8** (33), 1661, **2013**.
4. REID D.C., EDWARDS AC., COOPER D., WILSON E., MCGAW BA. The quality of drinking water from private water supplies in Aberdeenshire, UK. Water Res. **37** (2), 245, **2003**.
5. AL-KHATIB I., KAMAL S., TAHA B., AL HAMAD J., JABER H. Water health relationships in developing countries: A case study in Tulkarem district in Palestine. Int J Environ Health Res. J. **13** (2), 199, **2003**.
6. WU B., ZHANG Y., ZHANG X., CHENG S. Health risk from exposure of organic pollutants through drinking water consumption in Nanjing, China. B. Environ. Contam. Tox. **84** (1), 46, **2010**.
7. IQBAL J., SHAH M.H. Health Risk Assessment of Metals in Surface Water from Freshwater Source Lakes, Pakistan. Hum. Ecol. Risk Assess. **19** (6), 1530, **2012**.
8. PATTERSON J., HAKKINEN P.B., WULLENWEBER A.E. Human health risk assessment: selected Internet and World Wide Web resources. Toxicology. **173** (1), 123, **2002**.
9. RAFIEEIPOUR A., FAKHRY Y. Determination of concentration and carcinogenic risk of arsenic tap drinking water; City of Minab, Iran. IOSR-JESTFT. **9** (3), 33, **2015**.
10. ARVETI N., SARMA M.R., AITKENHEAD-PETERSON J.A., SUNIL K. Fluoride incidence in groundwater: a case study from Talupula, Andhra Pradesh, India. Environ Monit Assess. **172** (1), 427, **2011**.
11. GAIKWAD R.W., SASANE V.V. Assessment of ground water quality in and around Lonar lake and possible water treatment. IJES. **3** (4), 1263, **2013**.
12. ZHENG Y., AYOTTE J.D. At the crossroads: Hazard assessment and reduction of health risks from arsenic in private well waters of the northeastern United States and Atlantic Canada. Sci. Total Environ. **505**, 1237, **2015.**
13. BROUWER R., JOB F.C., VAN DER, KROON B., JOHNSTON R. Comparing willingness to pay for improved drinking-water quality using stated preference methods in rural and urban Kenya. Appl. Health Econ. Health Policy. **13** (1), 81, **2015**.
14. FOX D.I., PICHLER T., YEH D.H., ALCANTAR N.A. Removing heavy metals in water: The interaction of cactus mucilage and arsenate (As (V)). Environ. Sci. Technol. **46** (8), 4553, **2012**.
15. HUY T.B., TUYET-HANH T.T., JOHNSTON R., NGUYEN-VIET H. Assessing health risk due to exposure to arsenic in drinking water in Hanam Province, Vietnam. Int J Environ Res Public Health. 11 **(8)**, 7575, **2014**.
16. RAMEZANI GH H., VALAEI N., EIKANI H. Prevalence of DMFT and fluorosis in the students of Dayer city (Iran). J Indian Soc Pedo Prev Dent. **22** (2), 49, **2004**.
17. KAHLOWN M.A., MAJEED A., TAHIR M.A. Water quality status in Pakistan. Pakistan Council of Research in Water Resources (PCRWR)., Ministry of Science & Technology, Government of Pakistan; **2002**.
18. MUNNAWAR H. Flood UNICEF Report. Pakistan., UNICEF; **2011** (unpublished report).
19. United States. Environmental Protection Agency. Risk Assessment Forum. Guidelines for carcinogen risk assessment. Risk Assessment Forum, US Environmental Protection Agency, **2005**.
20. HANSEN A.J. Water quality analysis of the piped water supply in Tamale, Ghana., Massachusetts Institute of Technology; Africa, **2014**.
21. CANTER L.W., FAIRCHILD D., KNOX R.C., Ground water quality protection. Environmental and Ground Water Institute, Univ. of Oklahoma at Norman; U.S., **1986**.
22. OREBIYI E.O., AWOMESO J.A., IDOWU O.A., MARTINS O., OGUNTOKE O., TAIWO A.M. Assessment of pollution hazards of shallow well water in Abeokuta and Environs, Southwest, Nigeria. AJES. **6** (1), 50, **2010**.
23. HASHMI I., QAISER S., ASMA S., KHAN M.T., ABBAS S. Assessing microbiological safety of drinking water: A case study of Islamabad, Pakistan., Pakistan Engineering Congress, World Water Day; **2011**.
24. MEMON A.H., GHANGHRO A.B., JAHANGIR T.M., LUND G.M., SAHITO K., ABRO H.A., ARAIN S.R. Physicochemical Properties and Health Impacts of Flood and Post Flood on Drinking Water of Indus River System of Jamshoro, Sindh. Sci Lett. **4** (3), 193, **2016**.
25. FARID S., BALOCH M.K., AHMAD S.A. Water pollution: Major issue in urban areas. IJWREE. **4** (3), 55, **2012**.
26. MEHMOOD S., AHMAD A., AHMED A., KHALID N., JAVED T. Drinking water quality in capital city of Pakistan. Sci Rep. **2**, 637, **2013**.
27. MENSAH M.K. Assessment of drinking water quality in Ehi Community in the ketu-north District of the volta region of Ghana., Masters Dissertation, Ghana 1, **2011**.

28. SUSHMA J., MONIKA A. Study on physico-chemical characteristics of ground water of various villages around Raisar. JCBPS. **2** (3), 1551, **2012**.
29. PEINADO-GUEVARA H., GREEN-RUÍZ C., HERRERA-BARRIENTOS J., ESCOLERO-FUENTES O., DELGADO-RODRÍGUEZ O., BELMONTE-JIMÉNEZ S., LADRÓN DE GUEVARA M. Relationship between chloride concentration and electrical conductivity in groundwater and its estimation from vertical electrical soundings (VESs) in Guasave, Sinaloa, Mexico. Cienc Investig Agrar. **39** (1), 229, **2012**.
30. RICHARDSON S.D., PLEWA M.J., WAGNER E.D., SCHOENY R., DEMARINI D.M. Occurrence, genotoxicity, and carcinogenicity of regulated and emerging disinfection by-products in drinking water: a review and roadmap for research. Mutat Res. **636** (1), 242, **2007**.
31. TAYLOR R. Interpretation of the correlation coefficient: a basic review .J. Diag. Med. Sono. **6** (1), 35, **1990**.
32. MUHAMMAD S., SHAH M.T, KHAN S. Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan. Microchem J. **98** (2), 334, **2011**.
33. MEENAKSHI., MAHESHWARI R.C. Fluoride in drinking water and its removal. J. Hazard. Mater. **137** (1), 456, **2006**.
34. RASOOL A., FAROOQI A., MASOOD S., HUSSAIN K. Arsenic in groundwater and its health risk assessment in drinking water of Mailsi, Punjab, Pakistan. Hum Ecol Risk Assess. **22** (1), 187, **2016**.
35. MAIGARI A.U., EKANEM E.O., GARBA I.H., HARAMI A., AKAN J.C. Health Risk Assessment for Exposure to Some Selected Heavy Metals via Drinking Water from Dadinkowa Dam and River Gombe Abba in Gombe State, Northeast Nigeria. WJAC. **4** (1), 1, **2016**.
36. CANTOR K.P., LUBIN J.H. Arsenic, internal cancers, and issues in inference from studies of low-level exposures in human populations. Toxicol Appl Pharmacol. **222**(3), 252, **2007**.
37. KHAN S., SHAHNAZ M., JEHAN N., REHMAN S., SHAH MT., DIN I. Drinking water quality and human health risk in Charsadda district, Pakistan. J Clean Prod. **60**, 93, **2013**.
38. BOOBIS A.R., COHEN S.M., DELLARCO V., MCGREGOR D., MEEK M.E., VICKERS C., WILLCOCKS D., FARLAND W. IPCS framework for analyzing the relevance of a cancer mode of action for humans. Crit Rev Toxicol. **36**, 781, **2006**.
39. MARSHALL G., FERRECCIO C., YUAN Y., BATES M.N., STEINMAUS C., SELVIN S., LIAW J., SMITH A.H. Fifty-year study of lung and bladder cancer mortality in Chile related to arsenic in drinking water. J Natl *Cancer* Inst. **99** (12), 920, **2007**.
40. WASEEM A., ARSHAD J. A review of Human Biomonitoring studies of trace elements in Pakistan. Chemosphere. **163**, 153, **2016**.