Journal of Himalayan Earth Sciences Volume 52, No. 2, 2019 pp. 36-45

Measurement of physicochemical and heavy metals concentration in drinking water from sources to consumption sites in Peshawar, Pakistan

Saeeda Yousaf[1*], Muhammad Ilyas[1], Sardar Khan[1], Asif Khan Khattak[1] and Seema Anjum[2]
[1]*Department of Environmental Sciences, University of Peshawar*
[2]*National Centre of Excellence in Geology, University of Peshawar*
**Corresponding author's email: saeedayousaf@hotmail.com*
Submitted: Jan 25, 2019 Accepted: Aug 22, 2019 Published online:

Abstract

This research work was intended to explore and analyze the quality of drinking water and associated health risk assessment at sources and consumption sites at Peshawar, Pakistan. For this purposes, the water samples were collected and analyzed for various parameters. The selected physicochemical parameters were pH, alkalinity, hardness, total suspended solids (TSS), electrical conductivity (EC), chlorides (Cl^-), total dissolved solids (TDS), sodium (Na^+), potassium (K^+), nitrite (NO_2^-), magnesium (Mg^{2+}) and calcium (Ca^{2+}) while heavy metals included nickel (Ni), iron (Fe), copper (Cu), lead (Pb), manganese (Mn) and zinc (Zn). The physicochemical parameters were found within the limits set by World Health Organization's (WHO) except magnesium Mg^{2+} (246 mg/L) and Ca^{2+} (264 mg/L) at the end-user. In case of heavy metals, Pb (1.05 mg/L) concentration was higher in one sample at end-user point, while Ni (0.51 mg/L) was found above the allowable levels in all samples at water sources. The ADI (average daily intake) and HRI (health quotient) were calculated for heavy metals. HRI values were greater than 1 for Fe at source and for Fe, Cu, Zn, Ni, and Pb at end-user indicating that exposed populations could be at chronic risk. Comparison of source and end-user using unpaired t-test revealed that pH, TSS, Cl^- and Cu levels of end-user were significantly higher ($P<0.05$). It is concluded that that the distribution network for the supply of drinking water is damaged and causing the contamination of the drinking water with heavy metals. Therefore, serious steps should be taken to avoid hazardous effects of toxic heavy metals.

Keywords: Drinking water, End-user, Heavy metals, Source, Physicochemical parameters.

1. Introduction

Potable water is a scarce resource and its quality is of paramount importance to many communities. The quality of potable water is increasingly undermined due to contamination from industrial and municipal wastewaters, agricultural runoffs and sediments from eroded lands. Any change in chemical and physical composition of water especially the anthropogenic sources can make it unsuitable for human consumption. In developing countries, where there is lack of treatment facilities and the distribution system is faulty, drinking water quality is often compromised (Narayana, 2009). Surface water includes lakes, stream and rivers and groundwater such as tube well springs, dug well and bore well (Muhammad et al., 2010, 2011; Khan et al., 2013). Surface water sources are more prone to heavy metals and microbes contamination as compared to groundwater (Jan et al., 2010, Khan et al., 2011). That is why majority of population utilize groundwater as a prime source of drinking water (Reimann and Banks, 2004). However, a number of studies reported the heavy metal contaminations in groundwater (Muhammad et al., 2010, 2011; Khan et al., 2014; Ilyas et al., 2017; Ward et al., 2018; Ibrahim, 2019). Safe and clean water is essential for good health (Tahir, 2004).

Rapid urbanization, industrialization and human advancements have accelerated water pollution through disposal of heavy metals into the water (Ilyas et al., 2019). Contamination of drinking water with toxic metals from anthropogenic sources is a global concern (Rapant and Krcmova, 2007). Certain chemicals are added to the water within the distribution network to ensure safe water quality to the household (end-user). Deterioration of drinking water quality in a city is a major indicator for water supply network problems. Residual chlorine in the distribution network is usually undermined due to some chemical changes in the supply network (LeChevallier, 1990).

Groundwater is the main source of public water supply for 80% of population in Peshawar city. According to a report of Pakistan Council of Research in Water Resources (PCRWR) about 90% of the country's populations have exposure to unsafe drinking water (PCRWR, 2005). In Pakistan agro-chemicals, municipal and industrial wastes are further aggravating the rate of groundwater pollution, leading it to become a major problem. About 20 - 40% of diseases in Pakistan are water borne (Khalown, 2003). The city of Peshawar, like other metropolitans of the country, is also faced with similar situation. Peshawar is not only the most densely populated city of the Khyber Pakhtunkhwa (KP), Province but also the most urbanized. The quality of drinking water in Peshawar is steadily deteriorating over time with regular breakdowns in the distribution network. Corrosion and leakages are common that result in the sewage penetration in the supply distribution network, likely contributing to heavy metals and other contaminant addition in drinking water. Town-III locality in Peshawar is also a densely population region with an old water supply system which typically represent the state of water supply in Peshawar.

Clean and safe drinking water is essential for the wellbeing of human health (Shah at al., 2012, Gul et al., 2015, Khan et al., 2015). Drinking water quality monitoring on a regular basis gives valuable data about the prosperity status of a region (Rode and Suhr, 2007). In the investigation territory, so far, no examination has been done as for overwhelming metals pollutions in drinking water and their associated health risk. This research was aimed at finding the status of water quality in Peshawar with prime spotlight on physicochemical and overwhelming metal pollution by looking at the nature of water at source and at end-user. The study was conducted to determine physicochemical characteristics (pH, alkalinity, EC, TSS, hardness, TDS, K^+, NO_3^-, Na^+ and Cl^-) in the drinking water of Town-III, Peshawar and to evaluate the extent of heavy metals (Zn, Ni, Cu, Fe, Mn and Pb) contamination by comparing the water quality at source and delivery points and its associated health risk.

2. Experimental

2.1. Study area

District Peshawar is located in KP, Pakistan (Fig.1). It is one of the highly-populated region and largest economic centre of region having longitude 71° 30' 1" and latitude 34° 2' 29". Peshawar is situated in a large valley near the eastern end of the Khyber Pass, close to the Pak-Afghan borderlying between eastern latitude 71° 35′ 0″ and northern longitude 34° 1′ 0″. The total area of Peshawar is about 1,257 km^2 with population of 2,864,724 (Ali, 2009). The climate of Peshawar region is characterized as semi-arid with 22°C of mean annual temperature and 404 mm of mean annual rainfall (Ijaz et al., 2012). In the area water table depth varies between 30 to 45m. There exist 4 administrative towns in Peshawar, i.e. Town IV, III, II and I having 36 urban and 56 rural areas in 92 union councils (UCs). Town III is the most populous subunit of the city with 22UCs having more than 100 tube wells supplying drinking water (Ijaz et al., 2012).

2.2. Sampling

Samples were collected from thirteen densely populated UCs in Peshawar. In each UC, two samples were collected from each sample point (one at source and other at the delivery point in a distribution system) making a total of 52 samples as shown in Fig.1. Samples were collected in pre-cleaned water bottles following method as described by the American Public Health Association (APHA, 2005).

2.3. Data analysis

The samples were analysed for electrical-conductivity (EC), pH, colour, taste and odour, total hardness, alkalinity, total solids, Na^+, K^+, NO_3^-, $Mg2^+$, $Ca2^+$ and heavy metals (Cu, Pb, Fe, Zn, Ni and Mn). Total hardness and alkalinity were determined through APHA methods (APHA, 2005). For the determination of Na^+ and K^+, Flame Photometer ID No: PLC/MBC (Env.R)/001model Jenway PFP was used. Qualitative method was used to check the presence of NO_3^- within any given solution. Heavy metals were determined using Atomic Absorption Spectrophotometer (Z-2000 Hitachi, Japan).

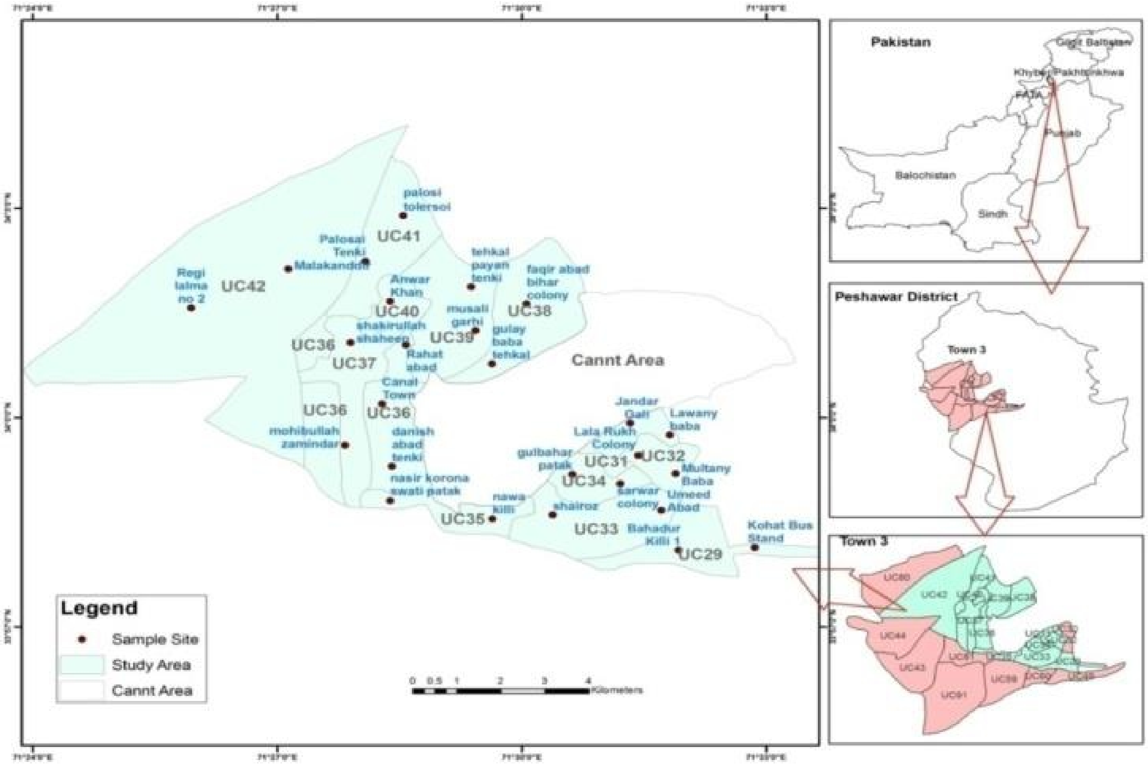

Fig. 1. Location of the study area and sampling sites

2.4. Risk assessment

Heavy metals enter human body through numerous pathways; however, admission from all other pathways are negligible in comparison to oral (ATSDR, 2000; Khan et al., 2013). Health risk assessment of the study area was calculated through chronic risk, such as ADI (average daily intake) and HRI (health risk index). The ADI via drinking consumptions in the study area was calculated according to the equation adopted from Muhammad et al. (2010) and USEPA (1998).

$$ADI = IR \times CW \times ED \times EF / AT \times BW \ldots\ldots\ldots (1)$$

Where IR is the rate of water ingestion (2 L day^{-1}), CW is the metals concentration in water (mg/L), ED is the duration of exposure (30 years), EF is the exposure frequency (365 days/year), BW is the weight of the body (70 kg), and AT is average time, that is, 365 days/year × ED for non-carcinogens and 365 days/year × 70 years for carcinogens (Muhammad et al., 2010; Khan et al., 2013).

In the study area the HRI via drinking consumptions for heavy metals was calculated using equation of USEPA (1998):

$$HRI = ADI / RfD \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where RfD is the reference dose (mg/kg-day-^{1}).

2.5. Statistical analysis

Statistical Package for the Social Sciences (SPSS) 16 was used for Unpaired T- test, the mean and standard deviation were calculated using Microsoft excel.

3. Results and discussion

3.1. Physicochemical characteristics of water

The levels found for the TSS, TDS, hardness, alkalinity, pH, Cl^-, Na^+ and K^+ at both the source and end-user points were all within the allowable levels of the WHO (1984) (Fig. 2 and Fig. 3).

The results of physicochemical parameters of water samples are summarized in Table 1. For EC, at end-user only one sample showed the value above the allowable levels, whereas for NO_3^-, the qualitative test revealed that NO_3^- was absent in both end-user and source in all the samples.

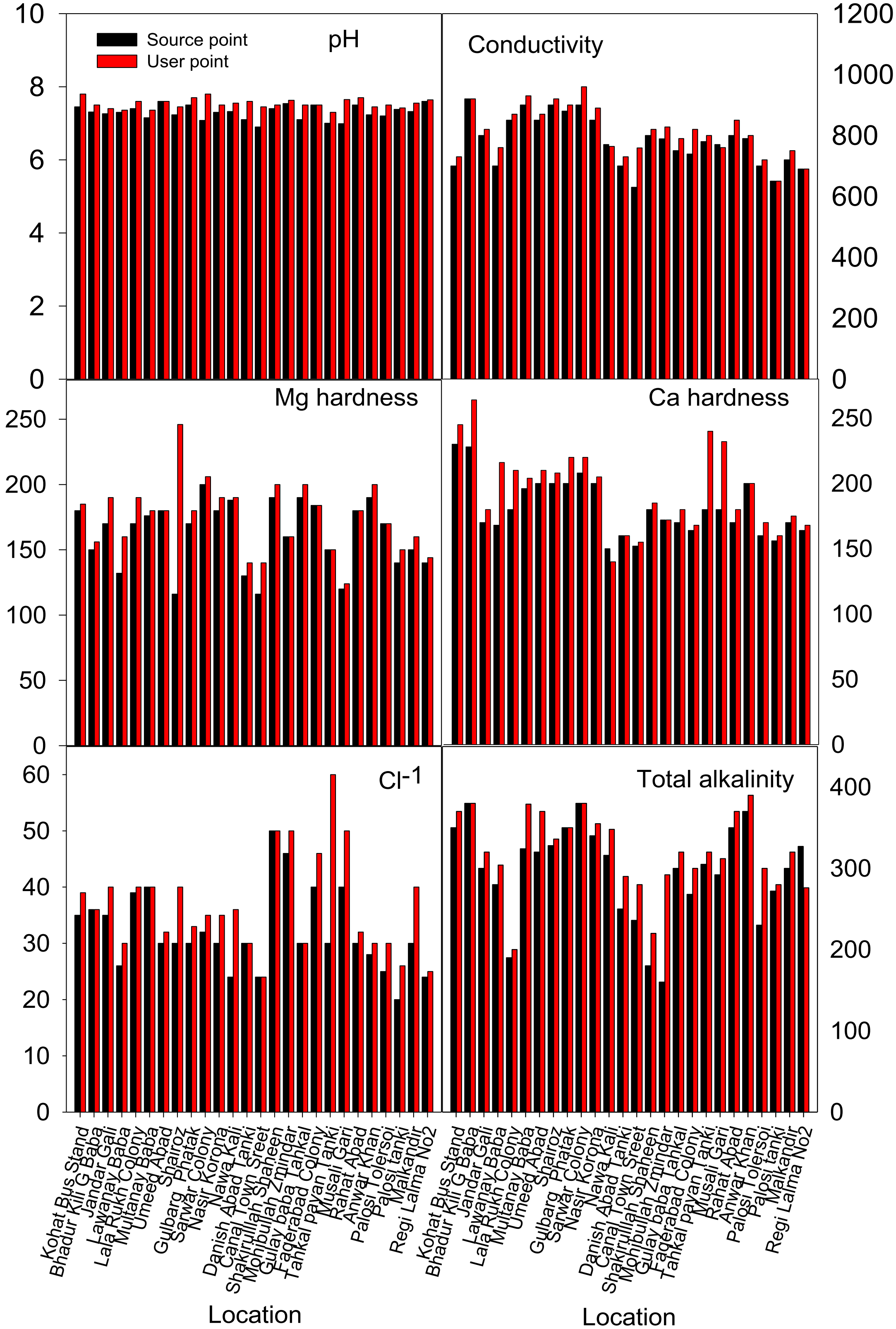

Fig. 2. Comparison of concentrations of physicochemical parameters in water collected from water sources and consumption sites in Peshawar.

The Ca^{2+} values in the source and end-user water samples ranged from 150-230 mg/L and 140-264 mg/L respectively (Table 1). The values of Mg^{2+} in the source ranged 116-200 mg/L and end-user water samples 140-246 mg/L respectively. A higher concentration of Ca^{2+} and Mg^{2+} in the end-user may be attributed to the deposition of these cations on the interior coating of the pipes, subsequently the deposited ions are released as the water pressure increased in the pipes into the water and caused increase in their concentration in drinking water (Uttley, 2000).

3.2. Heavy metal concentrations at source and end user

Among the heavy metals, Fe (as Fe^{2+} and Fe^{3+}), Mn, Zn and Cu were found within the WHO prescribed limits in both the source and end-users samples (Fig. 4 and Table 2). Pb was detected in higher concentration at an end-user point in UC-40 as 1.05 mg/L, well above the allowable levels (0.05 mg/L) of WHO (WHO, 1984). In the area the main cause of increased Pb contamination is due to the water supply network that is damaged at some points and passes through sewage drains.

Table 1. Concentration (Mean±SD) of physicochemical parameters

Parameters	Source		End-User		WHO Standard
	Range	Mean±SD	Range	Mean±SD	
pH	6.9-7.6	7.29±0.19	7.3-7.8	7.54±0.199	6.5-8.5
EC (µs/cm)	630-920	781.36±82.04	650-960	811.11±79.94	1400
TSS (mg/L)	1.00-3.00	1.79±0.51	1.00-3.00	2.46±0.58	10
TDS (mg/L)	371-680	564.36±76.42	454-700	596.25±70.46	1000
TotalHardness (mg/L)	268-408	355.29±38.71	280-420	373.21±35.04	500
Ca^{2+} (mg/L)	150-230	181.71±21.90	140-264	195.39±31.00	
Mg^{2+} (mg/L)	116-200	162.07±25.32	140-246	175.89±26.37	
Alkalinity (mg/L)	160-380	294.21±59.68	200-390	319.71±48.38	500
Cl^- (mg/L)	20-50	32.29±7.12	24-60	37.25±8.76	250
Na^+ (mg/L)	22.5-47	30.70±4.66	22.4-65.4	33.66±8.42	200
K^+ (mg/L)	2.00-4.40	3.32±0.53	2.8-8.9	4.11±0.16	75
NO_2^- (mg/L)	BDL	0.00±0.00	BDL	0.00±0.00	0.1

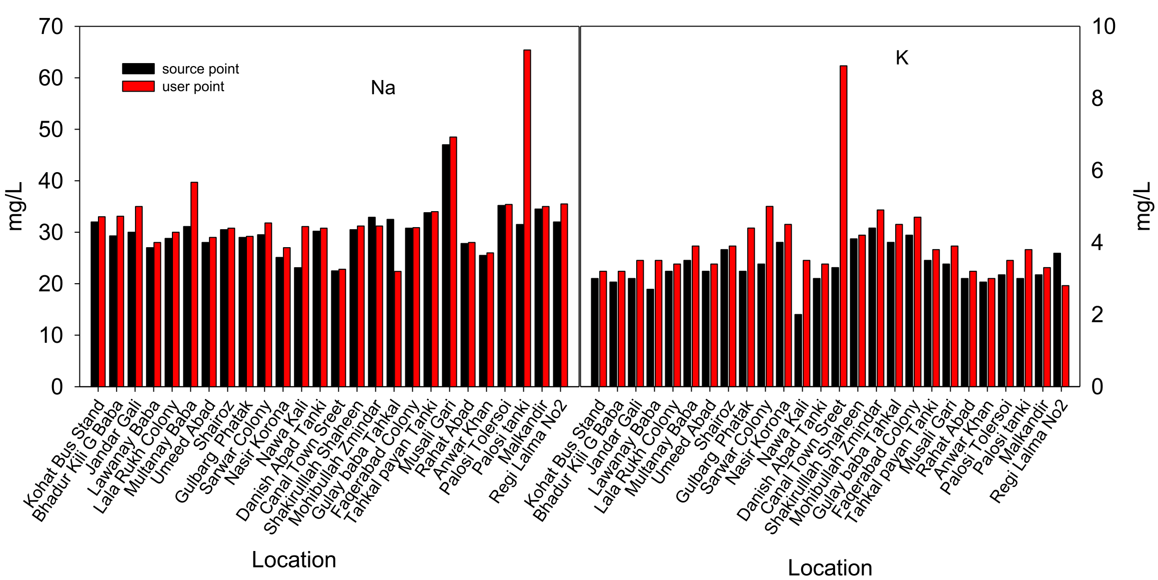

Fig. 3. Comparison of concentrations of Na^+ and K^+ in water collected from water sources and consumption sites in Peshawar.

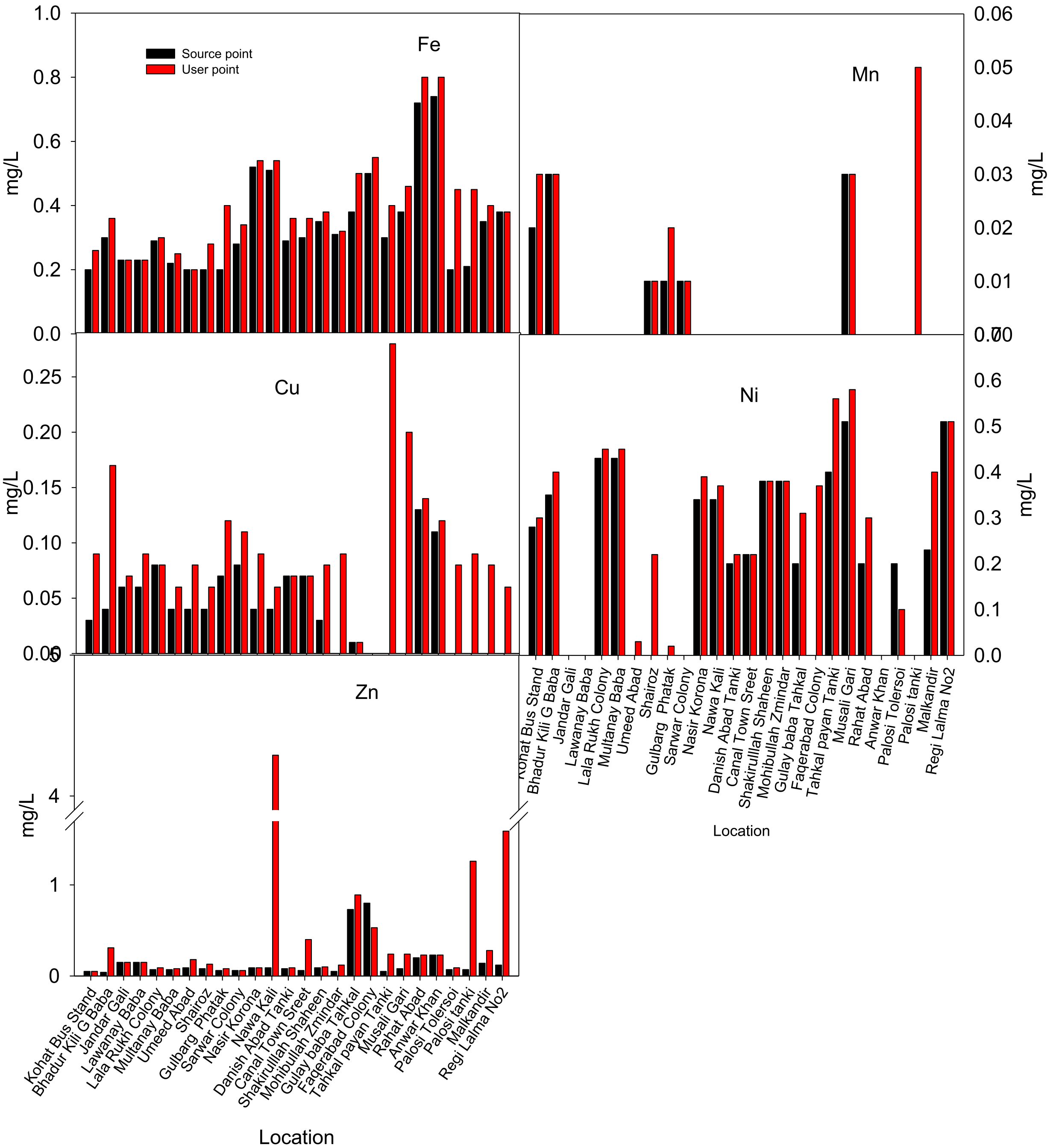

Fig. 4. Comparison of concentrations of heavy metal in water collected from water sources and consumption sited in Peshawar.

The heavy metal that was detected in higher concentration at both the source and end-user in most of the UCs was Ni, as shown in table 2. In source and end-user samples, it ranged from 0 to 0.51 mg/L and 0 to 0.58 mg/L with mean concentrations of 0.22±0.18 mg/L and 0.27±0.19 mg/L, respectively, hence exceeding the allowable WHO levels of 0.02 mg/L. The main source of Ni in water is pipes fittings and leeching of metals from pipes, alternative way should be considered to decrease its availability in water.

3.3. Risk assessment

Heavy metal concentrations in drinking water were evaluated for potential health risk assessment. The higher HRI value of Ni (9.4) at source and (11.5) at end-user pose great threat as HRI value was found exceeding than1 according to USEPA approach (1999). Similarly, heavy metals such as Fe, Cu, Zn and Pb indicated health risk as having HRI >1. The highest ADI value (0.30 mg/Kg-day-1) was observed for Fe and lowest for Pb (0.00 mg/Kg-day-1) at source while at end-user the maximum ADI value is for Zn (0.49) and lowest for Mn (0.01 mg/Kg-day^{-1}) the rest of metals are in between these two extreme (Fig. 5 and Table 3).

The presence of heavy metals in drinking water has been associated with various health issues. While Fe is vital for the growth of the body, excess of it can have negative consequences. The network of water supply is additionally polluted when by means of stagnation Ni enters the water (Devlin, 2006). Extreme intakes of Ni can prompt to severe health problems such as liver and heart damage, allergy and on long term exposure can lead to decrease body weight (Morgan and Flint, 1989). As Cu tends to be less vulnerable to erosion with the duration of time, Cu is usually detected less in potable water, and consequently a lesser quantity than Ni, Pb and Fe. Excessive Cu can also lead to mental diseases, with children being the most severely affected of Mn and Pb. This leads to behavioral disturbances as well as memory deterioration. Nerve damage can be caused as a result of Lead, alongside high blood pressure and kidney damage. Excessive Zn can also lead to anemia. The heaviest and most common metal found that affects health negatively is Pb when it becomes a part of drinking water (Khalown, 2003).

Table 2. Concentration (Mean±SD) of heavy metals

Parameters	Source		End-User		WHO Standard
	Range	Mean±SD	Range	Mean±SD	
Fe (mg/L)	0.20-0.74	0.35±0.15	0.2-0.54	0.412±0.15	1.0
Mn (mg/L)	BDL-0.03	0.01±0.01	BDL -0.05	0.01±0.01	0.5
Cu (mg/L)	BDL -0.13	0.04±0.04	BDL -0.28	0.10±0.06	1
Zn (mg/L)	0.04-0.80	0.17±0.19	0.05-4.29	0.58±0.87	5
Ni (mg/L)	BDL -0.51	0.22±0.18	BDL -0.58	0.27±0.19	0.02
Pb (mg/L)	BDL	BDL	BDL -1.05	0.07±0.21	0.05

BDL: below detection limit

Table 3. ADI and HRI values of heavy metals at source and end user

Parameters	**ADI (mg/Kg-day^{-1})**		**HRI (mg/Kg-day^{-1})**	
	Source	**End-user**	**Source**	**End-user**
Fe	0.30	0.35	1.16	1.16
Mn	0.01	0.01	0.06	0.06
Cu	0.03	0.08	0.92	2.29
Zn	0.14	0.49	0.48	1.63
Ni	0.19	0.23	9.40	11.50
Pb	0.00	0.06	0.00	1.66

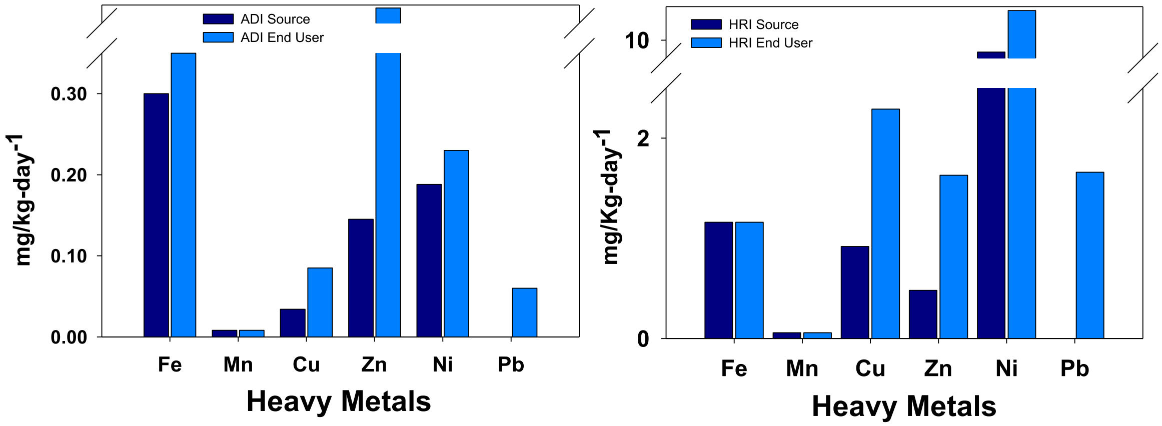

Fig. 5. Average Daily Intake (ADI) and Health Risk Index (HRI) of heavy metals through drinking water consumption.

Statistical comparison for the levels at the source and end-user was made using unpaired t-test. For pH, the values at the end-user were significantly higher than the source ($P<0.05$). Distribution network of water seems to be responsible for the reported significant difference. It is also found out that the P value for conductivity was not significantly different. The difference in TSS values between the source and end-user was significant ($P<0.05$). The difference between the mean was 37.43%, which showed that the P value for source were less significantly different than end-user. This significant difference is because contamination of water, when passes through the water supply network.

The results obtained from the unpaired T-test showed that the P value for Chlorides as Cl- was significantly different in the range $P<0.05$. The difference between the mean was 17.41%, which showed that the P value for end-user as compared with source were more significantly different. This significant difference is because contamination of water, when passes through the distributing network. However, the unpaired T-test showed that the P value for Sodium was not significantly different.

The unpaired T-test showed that the P value for Potassium was significantly different in the range of $P<0.05$. The difference between the mean was 23.79%, which showed that the P value for end-user was more significantly different than source. This significant difference was due to the contamination of water, when it passed through the water supply network.

The results obtained from the unpaired T-test revealed that the P values for Fe, Mn, Ni, Zn and TDS were not significantly different. However, the P value for Cu was significantly different in the range of 0.0001. The difference between the mean were 150%, which showed that the P value for end-user was more significantly different than source.

4. Conclusion

Results revealed that the physiochemical parameters were within permissible limit. The heavy metals concentrations of the samples at water sources were within the allowable levels, but at the end-user samples showed an increase in the concentration of heavy metals from the standards. It is concluded that the supply of drinking water through the existing distribution network is damaged, which result in heavy metals contamination of the drinking water. In the investigation territory, the main reason for the drinking water contamination is the physical damage of the supply network as the distribution network is not underground. Health risk, such as values of the ADI was observed in the order of Pb<Mn<Cu<Zn<Ni<Fe at source, Mn<Cu<Pb<Ni<Fe<Zn at the end-user while HRI values Ni>Fe>Cu>Zn>Pb at source, Ni>Cu>Pb>Zn>Fe>Mn at the end-user. The higher intake of heavy metals may pose carcinogenic risks and chronic toxicity to the population of the study area.

5. Recommendations

This study recommends the awareness campaign, proper designing of water supply pipelines and regular monitoring of the quality of drinking water.

Authors contribution

Muhammad Ilyas did data collection, sample analyses, and write up. Saeeda Yousaf did work in sample analyses and critically reviewed the manuscript. Sardar Khan provided guidelines and helped in drafting and reviewing the manuscript. The statistical calculations were conducted by Asif Khan. Seema Anjum checked the statistics and critically reviewed the manuscript.

References

Ali, D. N., 2009. District health profile (District Peshawar). Pakistan Initiative for Mothers and Newborns, Islamabad.

APHA (American Public Health Association), 2005. American Water Works Association (AWWA). Standards Methods for the examination of water and waste water, 21st Edition.

ATSDR (Agency for Toxic Substances and Disease Registry), 2000. Toxicological Profile for Arsenic, US Department of Health and Human Services, Atlanta, GA, USA.

Devlin, E. W., 2006. Acute toxicity, uptake and histopathology of aqueous methyl mercury to fathead minnow embryos. Ecotoxicology, 15 (1), 97-110.

Gul, N., Shah, M. T., Khan, S., Khattak, N. U., Muhammad, S., 2015. Arsenic and heavy metals contamination, risk assessment and their source in drinking water of the Mardan district, Khyber Pakhtunkhwa, Pakistan. Journal of water and health, 13(4), 1073-1084.

Ilyas, M., Ahmad, W., Khan, H., Yousaf, S., Yasir, M., Khan, A., 2019. Environmental and health impacts of industrial wastewater effluents in Pakistan: a review. Reviews on environmental health, 34(2), 171-186.

Ibrahim, M. N., 2019. Assessing Groundwater Quality for Drinking Purpose in Jordan: Application of Water Quality Index. Journal of Ecological Engineering, 20(3), 101-111.

Ilyas, M., Khan, S., Khan, A., Amin, R., Khan, A., Aamir, M., 2017. Analysis of drinking water quality and health risk assessment- A case study of Dir Pakistan. Journal of Himalayan Earth Sciences, 50 (1A), 100-110.

Ijaz, A., B., Khan, U., Hussain, R., Ali, I., Hamid, W., Abdul, U., Azhar, A. K., Murad, I., Fozia, 2012. Physico-chemical analysis of drinking water sources at sampling point of Billitang, KDA, Nasrat Khel and Chongee of District Kohat, K.P.K. Pakistan, International Journal of Science Innovations and Discoveries, An International peer Review Journal for Science, 2, 598-609.

Jan, F. A., Ishaq, M., Khan, S., Ihsanullah, I., Ahmad, I., Shakirullah, M., 2010. A comparative study of human health risks via consumption of food crops grown on wastewater irrigated soil (Peshawar) and relatively clean water irrigated soil (lower Dir). Journal of Hazard Mater, 179(1-3), 612-621.

Khan, S., Shah, I. A., Muhammad, S., Malik, R. N., Shah, M. T., 2015. Arsenic and heavy metal concentrations in drinking water in Pakistan and risk assessment: a case study. Human and Ecological Risk Assessment: An International Journal, 21(4), 1020-1031.

Khan, S., Shahnaz, M., Jehan, N., Rehman, S., Shah, M. T., Din, I., 2013. Drinking water quality and human health risk in Charsadda district, Pakistan. Journal of Cleaner Production, 60, 93-101.

Khalown, M. A., Majeed, A., 2003. Water-resources situation in Pakistan: challenges and future strategies. Water Resources in the South: present scenario and future prospects, 20.

LeChevallier, M. W., 1990. Coliform regrowth in drinking water: a review. Journal of the American Water Works Association, 82 (11), 74-86.

Muhammad, S., Shah, M. T., Khan, S., 2011. Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, Northern Pakistan. Microchemical Journal, 98 (2), 334-343.

Muhammad, S., Shah, M. T., Khan, S., 2010. Arsenic health risk assessment in drinking water and source apportionment using multivariate statistical techniques in Kohistan region, Northern Pakistan Food Chemical Toxicology, 48(10), 2855-2864.

Morgan, L. G., Flint., 1989. In (Eds.), Nickel and the Skin: Immunology and Toxicology, Maibach HI, Menne T, CRC

Press; Boca Raton, FL, 46–54.
Narayana, P., 2009. Environmental Pollution. Principles, Analysis and Control, CBC Publications Limited, New Delhi, 124–154.
PCRWR (Pakistan Council of Research and Water resources), 2005. National Water Quality Monitoring Programme, Report, Islamabad.
Rapant, S., Krčmová, K., 2007. Health risk assessment maps for arsenic groundwater content: application of national geochemical databases. Environ. Geochem. Health, 29(2), 131-141.
Rode, M., Suhr, U., 2007. Uncertainties in selected river water quality data. Hydrology and Earth System Sciences, 11(2), 863-874.
Reimann, C., Banks, D., 2004. Setting action levels for drinking water: are we protecting our health or our economy (or our backs!)?. Science of the Total Environment, 332(1-3), 13-21.
Shah, M. T., Ara, J., Muhammad, S., Khan, S., Tariq, S., 2012. Health risk assessment via surface water and sub-surface water consumption in the mafic and ultramafic terrain, Mohmand agency, northern Pakistan. Journal of Geochemical Exploration, 118, 60-67.
Tahir, M. A., 2004. Arsenic in Ground Water of Attock and Rawalpindi Districts, Joint Venture PCRWR & UNICEF, Islamabad, Pakistan.
Uttley, C., 2000. The elements: Magnesium, Marshall Cavendish Corporation, New York, USA.
USEPA (US Environmental Protection Agency), 1998. Arsenic, Inorganic. United States Environmental Protection Agency, Integrated Risk Information System (IRIS) (CASRN 7440-38-2). Available at http://www.epa.gov/iris/subst/0278.htm.
Ward, M., Jones, R., Brender, J., de Kok, T., Weyer, P., Nolan, B., Villanueva, C., Van-Breda, S., 2018. Drinking water nitrate and human health: an updated review. International Journal of Environmental Research and Public Health, 15(7), 1557.
WHO, 1984. Guidelines for drinking-water quality, Vol. 2, Health criteria and other supporting information, Geneva, 16, 145-15.