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HEALTH RISK ASSESSMENT OF DRINKING WATER IN BATHINDA DISTRICT, PUNJAB, INDIA

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ABSTRACT

Water is the second most vital element on Earth, which supports the human life. In the race of development, although the quality of life is improving, but it is posing tremendous pressure on natural resources, resulting in deterioration of air, water, and soil quality. The contaminated natural resources may pose serious health problems and are threat to the nature as well as mankind. In the present study, an attempt has been made to evaluate the drinking water quality and its associated health risk. The pH, turbidity, EC, TDS, and alkalinity of the analyzed samples ranged from 6.65-7.43, 0.36 - 3.47 NTU, 177 - 4300 µS/cm, 113 - 2752 mg/L, and 66 - 660 mg/L, respectively. Cr and Hg were detected above the permissible limit for drinking water for all the samples, and the concentrations were 70 – 360 µg/L and 4.6 – 20 µg/L, respectively. The concentration of Se, Cd, As, Be, Co, Zn, and U were in the range of 2.3315-17.583µg/L, 0.144-0.75 µg/L, 0.81-2.912 µg/L, 0.022-0.286 µg/L, 0.569-0.966 µg/L, 2.402-223.77 µg/L and 1.169-189.754 µg/L, respectively. The computed Hazards Quotients (HQ) due to trace metals indicated that 5% samples were highly hazardous to human health and 47% samples were moderately hazardous to human.

Keywords: *Drinking water, Water quality, Trace elements, Health risk assessment*

INTRODUCTION

Water is the second most vital elements for human survival. The social and economic development in this twenty-first century occurred at the of cost natural resources. Freshwater is an essential natural resource for flourishing the human society (Kumar et al., 2016). The rapid growth of industrialization, modernization, urbanization and extensive agricultural practice are depleting the valuable freshwater and other natural resources (Kumar et al., 2016). Human activities and agricultural practices mainly depend on the groundwater present in the aquifers. Freshwater bodies become contaminated due to high rate of pumping result in leaching of the pollutant. The amount and types of the pollutant is very diverse and if these pollutants consumed through drinking water may cause serious health problems (Kumar et al. 2017). Drinking water polluted with trace metals and pesticides have carcinogenic nature, which have potential to cause critical disease such as cancer also.

In India, rural area tenants entirely depend upon groundwater for their daily water needs. Moreover, 48% of the urban share is acquired directly from groundwater (Kulkarni., 2015). Punjab is an agriculture based states of India and is considered as prosperous state in the country. High dose of chemicals (Pesticides and chemical fertilizers) are commonly used in these regions to increase the production (Mittal et al., 2014). Such inconsistent use of chemicals in agriculture is worsening the groundwater quality and affecting consumer's health. It has become a critical task to provide clean and safe drinking water to the tenants of mainly South-West (S-W) region of Punjab. Physico-chemical parameters (conductivity, pH, turbidity, TDS etc.) of water are important in the sense of suitability of water for drinking purposes (Kumar et al., 2011). Total dissolved solids (TDS) comprise inorganic salts such as calcium, magnesium, potassium, sodium, bicarbonates, chlorides, sulphate and organic matter that are dissolved in small amount in water. The source of these salts in drinking water may be geogenic as well as anthropogenic. In the present study, an attempt has been made to identify the types and concentration of different trace metals or carcinogenic compounds present in drinking water of, Bathinda, South-West region of Punjab.

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METHODOLOGY

Study Area

The study area lies in the region of Bathinda district, S-W Punjab, India (Fig. 1). The mean sea level of Bathinda district is 216 m and it is located between 30.2110° N and 74.9455° E. The soil of Bathinda is calcareous, sandy and it cover a 3367 sq. km, which is second largest district in S-W Punjab after Ferozepur district. The climate of Bathinda is semi-arid having large difference in winter and summer temperature with an annual rainfall of about 407 mm (MSN World Weather). The mean maximum and minimum temperature was 43º C and 3.8º C, respectively. The sampling site (Table 1) was decided based on number of cancer patients existing at particular given time. The data of cancer patient was obtained from the government and public hospital.

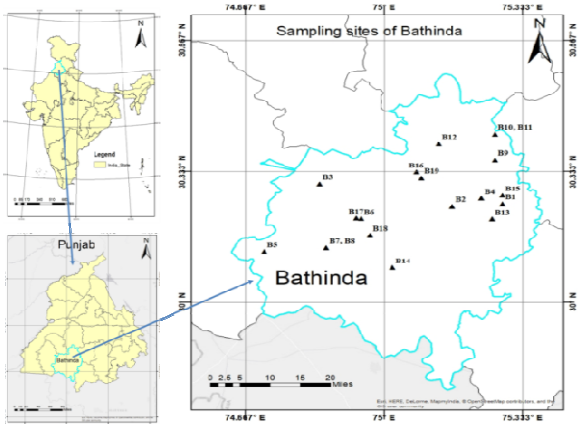

Fig. 1 Showing sampling site of Bathinda, Punjab, India.

Table 1. Sampling locations in Bathinda district of South-Western region Punjab, India.

Sr. No	Sampling code	Sampling location	Longitude (E)	Latitude (N)
1	B1	Pitho	30.25094°	75.28457°
2	B2	Lehra Mohabbat	30.24499°	75.16401°
3	B3	Mehma Sarja	30.30200°	74.84476°
4	B4	Rampura Paul	30.26499°	75.23445°
5	B5	Bambiha	30.12956°	75.71142°
6	B6	Hanuman Chowk	30.21329°	74.94445°
7	B7	JSW*1	30.13910°	74.86087°
8	B8	JSW2	30.13910°	74.86087°
9	B9	Dhupali	30.36291°	75.26682°
10	B10	Bhai Rupa1	30.42879°	75.26682°
11	B11	Bhai Rupa2	30.42879°	75.26682°
12	B12	Dayalpur Mirza	30.40415°	75.13204°
13	B13	Mandi Kalan	30.21212°	75.25963°
14	B14	Nasibpura	30.08812°	75.01995°
15	B15	Gill Kalan	30.27275°	75.27658°
16	B16	Ganga	30.33182°	75.07812°
17	B17	Bathinda	30.2144°	74.93299°
18	B18	CUP**	30.1714°	74.9659°
19	B19	Nathana	30.31686°	75.08968°

*JSW-Jai Singh Wala; **CUP-Central University of Punjab

Sample Collection and Preservation

The total population of Bathinda district is 1388525 with population density 441 per sq. km (Census, 2011). Groundwater samples were collected on the basis of number of cancer patient found in different villages of the district. Three times sample bottle was washed before collecting the sample. Then, water samples were collected using standard protocol (APHA, 2012). Each drinking water samples were collected in 2 variable size bottles for different analysis. Pre-cleaned 500 ml and 100 ml polypropylene bottles for physical parameter testing and heavy metals analysis, respectively. 100 ml samples bottle fixed on field by conc. HNO3 and then all collected samples were stored at 4 ℃ until analysis.

Chemical and Reagents

Milli-Q water (ELGA Lab Pure System) was used throughout the dilution and other analysis. Concentrated nitric acid, hydrogen peroxide and other reagents are used in digestion and extraction of analytical grade.

Health Risk Assessment

Health risk assessment in human is conducted to evaluate the toxic effects of contaminants present in drinking water on human health. Contaminants in drinking water, especially trace elements, are major stressor and health hazard to the consumers. Assessment of health hazards from trace element exposure can be definitely accomplished by health effect studies. However, the epidemiological study for the contaminants on human health at several locations and large population is usually impractical; therefore, health risk assessment methods have been developed to estimate the health hazards associated with the contaminant exposure. One of the basic strategies used to perform these types of assessment is to compare the concentration of the trace elements with the regulatory standards and guidelines, resulting from the toxicological criteria, and is known as the quotient approach to hazard assessment (Nimick et al., 2004). The hazard quotient (HQ) due to trace metals in the drinking water was computed by total daily intake (TDI) and chronic daily intake (CDI) according to Kumar et al. 2017. The TDI was determined by using the following equation

$$TDI = CR_D \text{ X } CE_D \quad (1)$$

Where CR_D = Water consumed per day, CE_D = Trace metal concentration in drinking water.

$$CDI = TDI / \text{Body weight} \quad (2)$$

And the HQ for the toxic metals in drinking water was calculated by the following equation given below:

$$HQ = CDI / \text{References oral dose} \quad (3)$$

The HQ less than 0.1 indicates no adverse effects on health, 0.1 to 1.0 value indicates low hazard and potential for adverse effects, 1.0 to 10.0 value indicates moderate hazard, and values above 10.0 indicates high health hazard (Nimick et al., 2004).

Instrument Used

An inductively coupled plasma mass spectrometer was used to determine the concentration of trace metals in water samples. The instrumental ICP-MS detects the following elements Arsenic (As), Chromium (Cr), Mercury (Hg) Selenium (Se), Cobalt (Co), Uranium (U), Beryllium (Be), Cadmium (Cd), Nickel (Ni), Copper (Cu), Zinc (Zn) up to the limit of parts per trillion (ppt).

RESULT AND DISCUSSION

Organoleptic Properties of Drinking Water

Different physio-chemical parameter of drinking water of Bathinda district was checked and compared with BIS and WHO limit. pH of drinking water samples was found within permissible limit and it range from 6.8-7.3 (Fig. 2a). The turbidity of the samples ranged from 0.36-3.47 NTU and mean turbidity was 2 NTU (Fig. 2b). In the study region, 31.58% of the total samples have turbidity above the BIS permissible limit.

The alkalinity was lowest at Hanuman Chowk (66mg/L) and highest at Bambiha village (660 mg/L) (Fig. 2e). The mean concentration of the alkalinity was 373 mg/L. Kaur et al. (2017) and Bajwa et al. (2017) reported that the pH in Bathinda district was within the permissible limit which matches with our finding. But the turbidity in the study region was higher than the safe limit and Kaur et al. (2017) also reported the similar result.

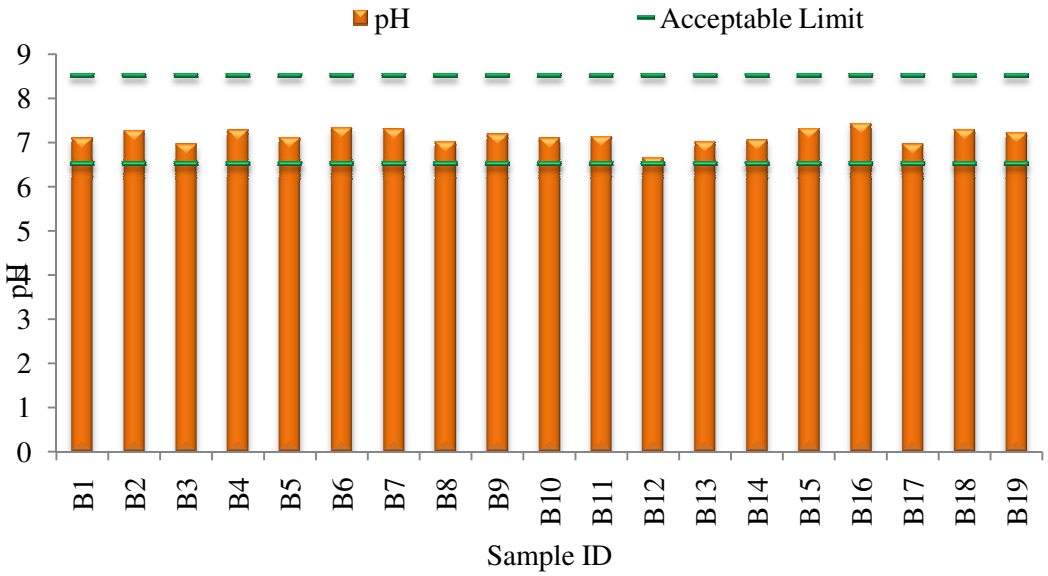

Fig. 2a pH variation in the study region of Bathinda district

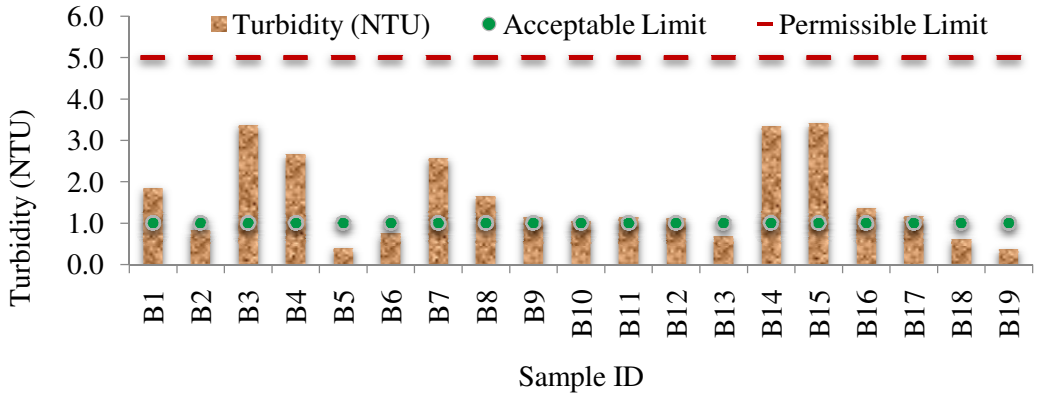

Fig. 2b Turbidity variation in the study region

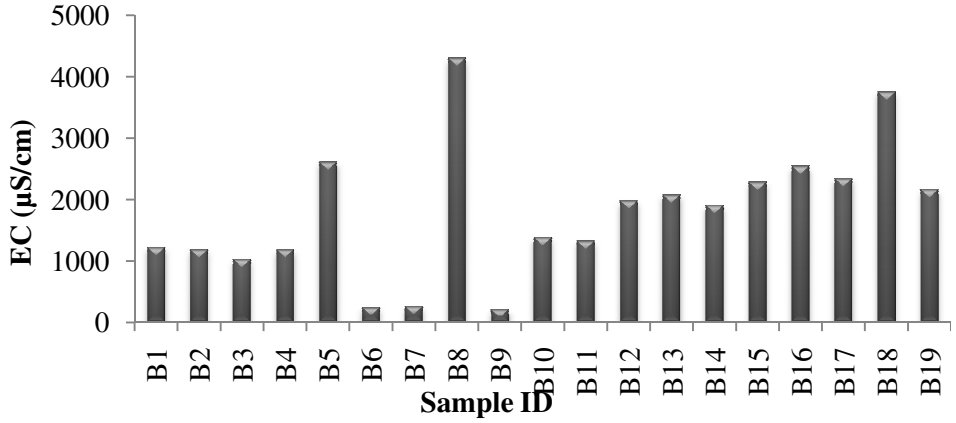

Fig. 2c Electrical conductivity variation in the study area

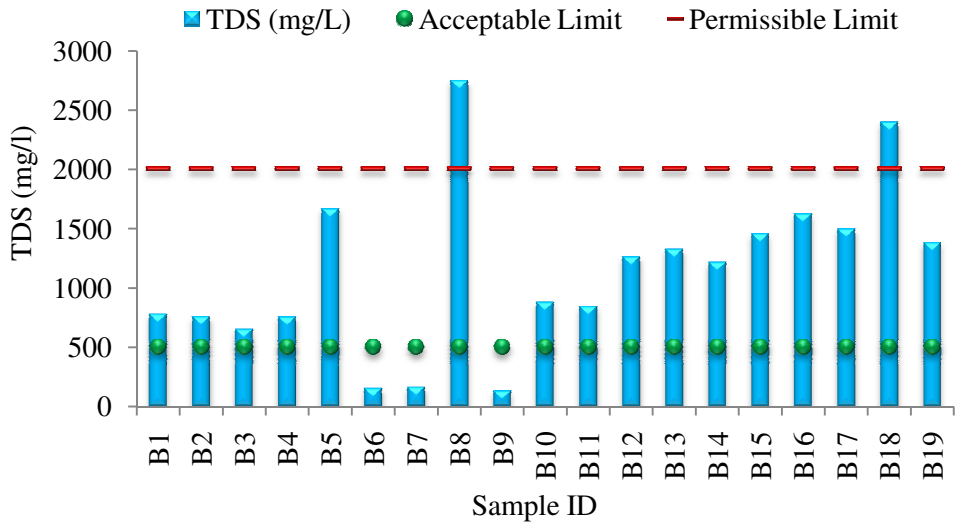

Fig. 2d Total dissolved solid variation in the study area

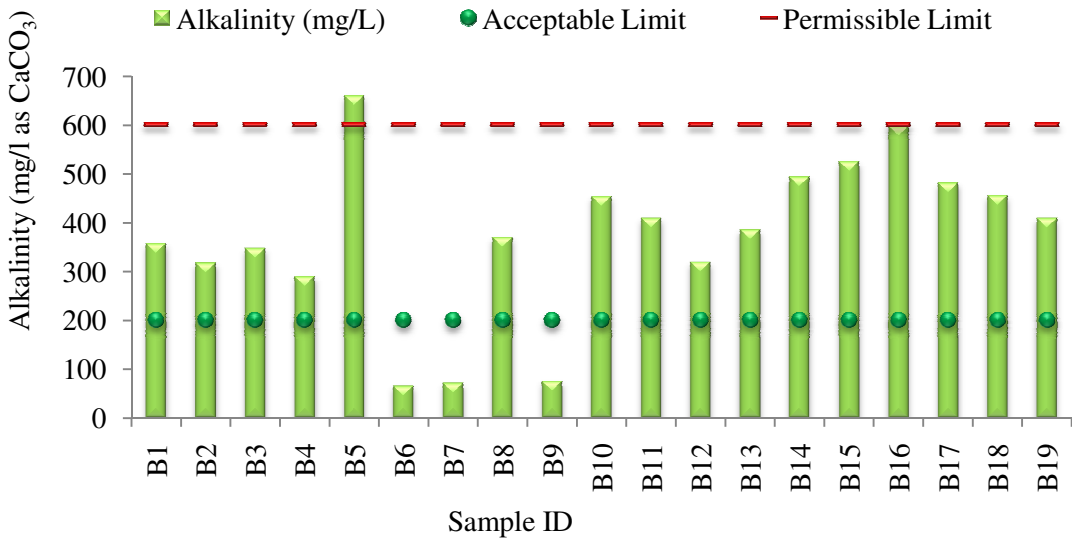

Fig. 2e Alkalinity variation in the study area

Distribution of Cations and Anions

The cations (Sodium [Na], Potassium [K], Calcium [Ca], Magnesium [Mg], Ammonium ions [NH_4^+] and Lithium [Li]) and anions (Chloride [Cl^-], Sulfate [SO_4^{2-}], Nitrate [NO^{3-}], Nitrite [NO_2^-] and Fluoride [F^-]) are the major ions/constituents in drinking water, representing the water quality. Table--2 and Table-3 represents the concentration of cation and anions, respectively. Na concentration in the study region was ranged from 6.04 to 665 mg/L and the mean concentration in the region was 227 mg/L. The mean concentration of K, Ca, Mg, NH_4^+ and Li was 17.53, 43.39, 40.10, 0.41 and 1.01 mg/L, respectively. It has been found that K is present in most of the collected samples (84.21% samples). Ca in collected water samples varied from 7.48 to 43.39 mg/L (Table-2). The mean concentration of the Mg, NH_4^+ and Li was 40.10, 0.41 and 1.01 mg/L, respectively in the study area.

Among the major anions, the concentration of Cl^- ions ranged from 4.38 to 475 mg/L and its mean concentration was 115 mg/L in the drinking water of the study area (Table-3). Cl^-, SO_4^{2-}, NO_2^- and F^- were detected in all samples, however NO_3^- was present in only 63.16% samples. Mean concentration of SO_4^{2-} was 235 mg/L and it's varied from 7.61 to 1020mg/L in the drinking water samples (Table-3). Maximum and minimum concentration of SO_4^{2-} was in Jai Singh Wala-2 (1020 mg/L) and Dhuplai (7.67 mg/L), respectively. Nitrate and nitrite in drinking water of the study area ranged from 0 to 36.60 mg/L and 0.05 to 1.84mg/L, respectively (Table-3). F^- ion concentration was highest in the sample collected from Central University of Punjab (1.55 mg/L).

Distribution of Carcinogenic Elements in Study Area

Table-4 shows the concentration of 11 trace elements which exist in different carcinogenic group. Drinking water of the study area was affected by carcinogenic elements such as As, Be, Cr, Cu, Co, Hg, Se, U, Cd, Ni and Zn. As was detected in all samples (n=19) but the concentration of the As in the drinking water of the Bathinda district was below the permissible limit (Table-4). Similar observation has been reported by Sharma et al. 2017 for the drinking water of Bathinda. The maximum concentration of Cr was 359.96 ppb (Lehra Mohabbat) and minimum concentration was 66.24 ppb (Dayalpur Mirza). Cr concentration in drinking water was found above the permissible limit for all the

Table 2 Cations distributions in drinking Water of Bathinda district of Punjab, India

Sampling site	Compound names					
	Sodium (mg/L)	Potassium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Ammonium (mg/L)	Lithium (mg/L)
B1	131	0.33	43.8	40.5	0.36	0.00
B2	155	6.15	32.8	27.1	0.38	0.05
B3	72	6.93	69.5	33.2	0.41	0.00
B4	141	4.95	24.1	20.8	0.31	0.00
B5	509	12.41	35.9	39.7	0.56	0.00
B6	18.65	18.08	7.48	6.32	0.07	18.7
B7	6.13	2.97	33.7	8.72	0.00	0.02
B8	665	22.54	140	118	1.54	0.00
B9	6.04	4.13	18.2	12.0	0.10	0.00
B10	202	0.00	30.5	30.6	0.00	0.00
B11	193	0.00	29.0	27.1	0.00	0.00
B12	313	9.50	55.9	57.3	0.67	0.00
B13	287	7.73	50.5	65.1	0.49	0.15
B14	297	11.60	65.5	65.4	0.51	0.00
B15	454	7.96	26.3	32.5	0.64	0.00
B16	445	10.56	28.7	34.4	0.00	0.00
B17	271	101	62.0	67.5	1.13	0.18
B18	654	1.30	47.5	47.4	0.00	0.00
B19	244	105	23.1	28.3	0.57	0.00
Mean	227	17.53	43.39	40.10	0.41	1.01
Minimum	6.04	0.00	7.48	6.32	0.00	0.00
Maximum	665	105	140	118	1.54	18.70

samples of the study area. Bajwa et al. 2017 also reported the Cr concentration in drinking water of South-Western Punjab is up to 228 ppb. Hg concentration ranged from 4.6 to 21.3 ppb and the mean concentration was 11.9 ppb in the study area, higher than the BIS permissible limit. The highest concentration of Hg was found at Bambiha (21.3 ppb). The prescribed safe limit for nickel (Ni) in drinking water is 20 ppb and the concentration of Ni exceeded the permissible limit for all 19 sites. The concentrations of Ni in the study area have been observed in the range of 25.49 - 39.93 ppb, with mean concentration of 32.25 ppb. In the study conducted by Bajwa et al. 2017, the Ni concentration was reported 308 ppb, which is almost 10 times higher than the mean concentration of our observation. In the study region, Be was detected in the drinking water samples, however, the concentration was below the BIS and WHO permissible limits. Out of 19 samples, only two samples exceeded the acceptable limit of Cu concentration (Nasibpura-442 ppb and Mehma Surja-400 ppb) however, it was within the BIS permissible limit. The Uranium (U) concentration ranged from 1.17 to 190 ppb in the drinking water samples, with mean concentration 32.04 ppb. Das et al. 2017 also reported U in South-West Punjab varying from 0.5 to 579 ppb. Mean concentration of Zn, Cd and Co in the study area was 32.29 ppb, 0.60 ppb and 0.75 ppb, respectively.

Health Risk Assessment

The health risk assessment due to oral exposure through drinking water was computed for humans. Table 5 lists the Hazards Quotients (HQ) of different carcinogenic trace metals

compounds. The drinking water sample collected from Mandi Kalan (B13) is highly hazardous to human health due to the Hg content. Moreover, the concentration of Cr & Ni can pose moderate health hazard, and other trace elements (As, Cu, Se, U, & Cd) have the potential for the adverse effect. Drinking water samples from Pitho (B1), Lehra Mohabbat (B2), Rampura Paul (B4), Jai Singh Wala (B7), Dhupali (B9), Bhai Rupa (B11), Gill Kalan (B15), Ganga (B16), and Bathinda (B17) were low in health hazard, but have potential for adverse health impacts. Samples from Mehma Sarja (B3), Bambiha (B5), Hanuman Chowk (B6), Jai Singh Wala (B8), Bhai Rupa (B10), Dayalpur Mirza (B12), Central University of Punjab temporary campus (B18), and Nathana (B19) were found to be moderately hazardous to human health due to high concentration of Hg.

Table 3 Anions distributions in drinking water of Bathinda district of Punjab, India

Sampling site	Compound names				
	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Fluoride (mg/L)
B1	61.4	85.2	24.0	0.82	0.33
B2	4.38	41.3	1.02	0.07	0.12
B3	475	1020	0.00	1.38	0.95
B4	67.3	93.0	19.3	0.85	0.50
B5	17.3	103	4.53	0.34	0.21
B6	43.7	109	20.1	1.84	0.72
B7	147	320	31.6	0.49	1.36
B8	7.59	12.3	25.7	0.06	0.13
B9	4.47	7.61	3.69	0.05	0.23
B10	49.6	123	0.00	0.33	0.74
B11	52.0	134	0.00	0.32	0.63
B12	149	417	0.00	0.51	0.61
B13	188	203	0.00	0.51	1.47
B14	90.7	325	7.52	0.44	1.05
B15	147	314	21.2	0.42	1.50
B16	143	304	36.6	0.54	0.66
B17	150	262	0.00	0.67	1.25
B18	270	754	4.70	1.21	1.55
B19	111	183	0.00	0.69	1.39
Mean	115	235	10.5	0.61	0.81
Minimum	4.38	7.61	0.00	0.05	0.12
Maximum	475	1020	36.60	1.84	1.55

Table 4 Concentrations of trace elements in groundwater samples of Bathinda district of South-Western region of Punjab.

Elements	Detection limits of ICP-MS	Drinking water (n=19); Unit (ppb).						
		Range	Mean	Median	BIS limits	WHO guideline values	No of samples exceeding BIS limits values	No of samples exceeding WHO limits values
As	0.01	0.81-2.91	1.54	1.28	10	10	0	0
Be	0.10	0.2-0.29	0.05	0.03	700	700	0	0
Cr	0.03	66.3-359	89.96	75	50	50	**19**	**19**
Cu	0.02	2.33-442	51.52	6.72	50	2000	2	0
Co	0.05	0.57-0.97	0.75	0.72	*	*	--	--
Hg	0.001	4.6-21.3	11.9	11.95	1	*	**19**	--
Se	0.2	2.32-17.6	6.73	5.97	10	40	3	0
U	0.001	1.17-190	32.04	14.71	*	*	--	--
Cd	0.03	0.12-3.00	0.6	0.28	3	3	0	0
Ni	0.1	25.5-40	32.25	32.34	20	70	**19**	0
Zn	0.01	2.40-224	32.29	4.21	1500	--	0	--

*Guideline not established

Table 5 Hazard Quotient (HQ) of the trace metals in the drinking water

Sample code / Element	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19
As	0.006	0.007	0.008	0.010	0.011	0.009	0.017	0.022	0.018	0.008	0.011	0.008	***0.121***	***0.205***	0.013	0.012	0.010	0.017	0.009
Be	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cr	***0.101***	***0.539***	***0.115***	***0.112***	***0.128***	***0.116***	***0.116***	***0.110***	***0.115***	***0.102***	***0.127***	0.099	**1.500**	**1.448**	0.100	***0.108***	***0.109***	***0.126***	***0.119***
Cu	0.027	0.011	***0.599***	0.006	0.010	0.009	0.004	0.013	0.004	0.006	0.008	0.008	0.103	**8.838**	0.010	0.010	0.051	0.013	0.007
Co*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hg	***0.896***	***0.376***	**1.151**	***0.752***	**1.598**	**1.129**	***0.378***	**1.308**	***0.740***	**1.028**	***0.677***	**1.141**	**11.545**	**4.614**	***0.911***	***0.447***	***0.517***	**1.383**	**1.321**
Se	0.044	0.045	0.023	0.033	0.089	0.023	0.017	0.132	0.019	0.030	0.047	0.052	0.824	0.502	0.054	0.080	0.031	0.067	0.072
U	0.035	0.033	0.021	0.032	0.411	0.004	0.003	0.037	0.011	0.041	0.035	0.044	0.665	0.701	0.474	0.089	0.019	0.084	0.048
Cd	0.003	0.003	0.010	0.010	0.005	0.020	0.005	0.015	0.007	0.003	0.020	0.005	0.173	0.044	0.052	0.004	0.026	0.075	0.004
Ni	0.121	0.122	0.150	0.125	0.111	0.134	0.132	0.107	0.141	0.120	0.121	0.118	**1.549**	**1.822**	0.096	0.106	0.122	0.105	0.115
Zn	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.095	0.000	0.000	0.011	0.000	0.000

*HQ of Co cannot be calculated, as the references dose guideline is not established.

Sample from Nasibpura (B14) was moderately hazardous to human health due to the prevailing concentration of Cr, Cu, Hg, and Ni. In this study, the HQ value of Hg, Cr, Ni, and Cu exceeded the value of 1 in 10, 2, 2, and 1 numbers of samples, respectively, and can be considered as the key metals causing carcinogenicity.

CONCLUSIONS

Based on this study following conclusions can be drawn-

1. All the analyzed organoleptic parameters except turbidity and TDS were well within the limits prescribed by BIS for drinking water. The turbidity was higher than the desirable limit for 57.8% of the samples, but was within the permissible limit for drinking water. The TDS content of 84.2% samples exceeded the desirable limit for drinking water, however only 10.5% exceed the permissible limit.
2. In the study area, Ca, Mg and NH_4 content in the analyzed drinking water samples exceeded the desirable limit for 5.3%, 63.1%, and 31.6% samples, respectively. Similarly, Cl, SO_4, and F content exceeded the desirable limit for drinking water in 10.5%, 47.4%, and 5.3% samples, respectively. Also, the total hardness and total alkalinity exceeded the desirable limit in 84.2% and 52.6% samples, respectively.
3. Based on Hazards Quotients (HQ), sample from Mandi Kalan is highly hazardous to human health and samples from Mehma Sarja, Bambiha, Hanuman Chowk, Jai Singh Wala, Bhai Rupa, Dayalpur Mirza, Nasibpura, Central University of Punjab temporary campus, and Nathana are moderately hazardous to human health, and rest were low in health hazard.

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REFERENCES

1. *APHA, 2012. Standard methods for the examination of water and wastewater, 22nd edn. American Public Health Association/American Water Works Association/Water Environment Federation, Washington, DC, USA*
2. *Bajwa, B. S., Kumar, Sanjeev, K., Singh, S., Sahoo, S.K., Tripathi, R. M., 2017. Uranium and other heavy toxic elements distribution in the drinking water samples of SW-Punjab, India. Journal of Radiation Research and Applied Sciences. 10, 13-19*
3. *Bhutiani, R., Kulkarni, D. B., Khanna, D. R., Gautam, A., 2016. Water Quality, Pollution Source Apportionment and Health Risk Assessment of Heavy Metals in Groundwater of an Industrial Area in North India. Exposure and Health, 8:3-18.*
4. *Dash, R. K., Ramanthan, A.L., Yadav, S. K., Kumar, M., Kuriakose, T., Gautam, Y. P., (2017) Uranium in groundwater in India: A review. Journal of Applied Geochemistry. 19, 138-144.*
5. *Kaur, T., Bhardwaj, R., Arora, S., 2017. Assessment of groundwater quality for drinking and irrigation purposes using hydrochemical studies in Malwa region, southwestern part of Punjab, India. Applied Water Science, 7, 3301–3316*
6. *Kulkarni, H., Shah, M., Shankar, P. S. V., 2015. Shaping the contours of groundwater governance in India, Journal of Hydrology: Regional Studies, 4, 172-192.*
7. *Kumar, A., Usha, N., Sawant, P. D. S, Tripathi, R. M., Raj, S. S., Mishra, M., Rout, S., Supreeta P., Singh, J., Kumar, S., Khushwaha, H. S., 2011. Risk Assessment for Natural Uranium in Subsurface Water of Punjab State, India, Human and Ecological Risk Assessment, 17, 381–393.*
8. *Kumar, M., Ramanathan, A. L., Tripathi, R., Farswan, S., Kumar, D., Bhattachrya, P., 2017. A study of trace element contamination using multivariate statistical techniques and health risk assessment in groundwater of Chhaprola Industrial Area, Gautam Buddha Nagar, Uttar Pradesh, India. Chemosphere, 166, 135-145.*
9. *Kumar, S. S., Kadier, A., Malyan, S. K., Ahmad, A., Bishnoi, N. R., 2017. Phytoremediation and Rhizoremediation: Uptake, Mobilization and Sequestration of Heavy Metals by Plants. Plant-Microbe Interactions in Agro-Ecological Perspectives, 367-394.*
10. *Kumar, S. S., Malyan, S. K., Kumar A., Bishnoi, N. R., 2016. Optimization of Fenton's Oxidation by Box-Behnken Design of Response Surface Methodology for Landfill Leachate. Journal of Materials and Environmental Science, 7(12), 4456-4466.*
11. *Mittal, S., Kaur, G, Vishwakarma, G. S. 2014. Effects of Environmental Pesticides on the Health of Rural Communities in the Malwa Region, of Punjab, India: A Review. Human and Ecological Risk Assessment, 20, 366–387.*
12. *Nimick, D. A., Church, S. E., Finger, S. E., (2004) Integrated Investigations of Environmental Effects of Historical Mining in the Basin and Boulder Mining Districts, Boulder River Watershed, Jefferson County, Montana. U.S. Geological Survey, Reston, Virginia.*
13. *Sharma, D. A., Rishi, M. S., Keesar, T., 2016. Evaluation of groundwater quality and suitability for irrigation and drinking purposes in southwest Punjab, India using hydrochemical approach. Applied Water Science, 7, 3137-3150.*