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Evaluation of Ground Drinking Water Sources of Haridwar Using Heavy Metal Pollution Index

A. Gupta[1,*], R. Singh[1], P. Singh[2] and R. Dobhal[3]

[1]Department of Chemistry, D.B.S. (P.G.) College, Dehradun-248001, India
[2]Department of Chemistry, D.A.V. (P.G.) College, Dehradun-248001, India
[3]Uttarakhand State Council for Science and Technology, Vigyan Dham, Jhajra, Dehradun-248005, India

*Corresponding author: E-mail: abhishekguptadbs@gmail.com

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Advance statistical technique as heavy metal pollution index (HPI) was used for assessment of suitability of 17 ground water sources of district Haridwar for drinking purpose. Water samples were analyzed for Cu, Mn, Pb, Zn, Cr and Fe as water quality parameters using atomic absorption spectroscopy (AAS) as per BIS and APHA standards. Results showed that the concentration of all the analyzed heavy metals were found in all the selected ground drinking water sources below their standard limit during the study, except one *i.e.* only lead was found (0.011 mg/L) more than its standard limit (0.01 mg/L) at H13 during PRM 2014. Suitability of studied drinking water sources have also been evaluated on the rating scale along with determination of seasonal and spatial variations. Results may attribute that HPI of the water sources were generally below its critical limit and studied water sources were safe for human consumption with respect to analyzed heavy metals. The results of the present research work provide significant information for water resources management, which helps to better meet the future challenges.

Keywords: Heavy metal pollution index, Haridwar, Drinking water.

INTRODUCTION

Haridwar is a famous pilgrim destination and one of the most important districts of Uttarakhand State of India. In Haridwar district, both ground and surface water sources are used for drinking and other domestic purposes. Water supply and distribution of water of ground water sources to the mass population of Haridwar for drinking purposes is done by the water supply and maintenance agency of Uttarakhand. Whereas, groundwater sources are conventionally considered as safe water reserves for drinking purposes, but due to increasing urbanization and industrialization, their quality has also declined. Being a famous religious destination, there is always a huge influx of pilgrims in Haridwar district, due to which there is always a large-scale water requirement for drinking as well as for domestic purposes. The large rush of pilgrims throughout the year not only increases the water demand but also has a great stress and serious impact on the water sources owing to large quantities of municipal waste. Further, continuous prolonged over exploitation of underground water sources creates insufficiency of water along with the deterioration of water quality. Several factors, including heavy metals due to natural as well as anthropogenic activities also affect the quality of drinking water sources [1].

Heavy metals are naturally present in geological structures of earth and usually exposed to underground water sources through natural processes occurring inside the earth such as leaching due to heavy rain and interaction of flowing water with geological structures [2]. Various anthropogenic activities such as untreated effluents from industries, unsafe disposal of agricultural waste and domestic sewage are responsible for release of heavy metals into surface as well as ground water sources and may cause many adverse effects on their water quality [3,4]. Low quality and excess use of fertilizers usually consist several impurities including heavy metals, which increases the impact of heavy metals on natural resources due to leaching [5,6]. Other anthropogenic sources of contamination including heavy metals, mining, excess use of pesticides, dumping of untreated and partially treated solid waste as well as metal chelates from different industries [7-11].

The impact of heavy metals on the environment depends on their diversified chemical properties. In a specific limit some of the metals are essential for the development and growth of the organisms to sustaining ecosystem, but there is a very small gap between their specific requirement and toxicity. Contamination of trace metals can be toxic for the environment as well as human beings [12,13].

Heavy metal pollution impose serious impact on living beings and can cause various diseases upto lethal health effects depending on the nature and quantity of metal intake [14]. Bioaccumulation of heavy metal ions above its critical limit cause neurological impacts and some of them are carcinogenic in nature [15]. They also undergo chemical processes with different environmental matrices.

The above background clearly shows that the contamination in water sources including heavy metals arise a great impact on environmental as well as socio-economic status of society. Thus, the qualitative as well as quantitative measurements of water quality parameters are necessary to assess their impacts on water quality of drinking water sources [16]. It was therefore thought worthwhile to evaluate the impact of such stress with respect to spatial variations, emerging water quality issues, nature and extent of pollution control needed as well as to examine the sustainability of ground water sources for drinking purposes presently in use by state's concerned agency for public supply.

In Haridwar, a large number of ground drinking water sources are being used for public supply but continuous evaluation of water quality of all the water sources is not being done, which is necessary to check their suitability in terms of heavy metals of water sources used for drinking purposes. For the estimation of heavy metals in water samples, atomic absorption spectroscopy (AAS) technique is most commonly used due to its accuracy, rapid processing capability, cost effective, reproducibility of results and detection of metals in the sample at very low concentration and hyphenated in nature [17]. Further, the evaluation of suitability with respect to heavy metals cannot be done on the basis of one or two parameters, but an integrated approach like heavy metal pollution index (HPI) is a better tool. HPI is a rating system, used to integrate the comprehensive water quality data with respect to heavy metals. The rating scale, reflecting the relative significance of individual quality consideration for each parameter for suit-ability of water for drinking purpose [18,19].

Bio-monitoring of metals in Ganga water at different ghats of Haridwar has been done by Rai *et al.* [20] and the results of the study attributed that chromium was more than its standard limit at each site. Ground water quality of Haridwar was analyzed by Gaur *et al.* [21] for the various drinking water quality characteristics. Results of the study showed that most of the water quality parameters were within the permissible limit, while, the concentrations of Cd, Cr and Pd were found more than permissible limit of BIS for drinking water.

Deepali and Gangwar [22] assessed the impact of effluents of textile and tannery on soil and ground water quality. Various physico-chemical parameters including metals such as Cr, Fe, Mn, Cu, Pb and Cd have been analyzed in this study, whereas, most of the studied parameters were within the permissible limits, while, contamination of chromium was found in samples of water sources nearby of tannery.

Tyagi *et al.* [23] assessed the ground water quality of different sources of Bhagwanpur industrial area, Haridwar, Uttarakhand. The results of the study showed that the ground water quality of analyzed ground water sources fall under the moderately polluted category in respect of heavy metal contamination.

Bhutiani *et al.* [24] assessed the environmental risk on the water quality of ground water sources around integrated industrial estate, Haridwar due to heavy metals *viz.* cobalt, chromium, cadmium, iron, nickel and zinc. Results showed that contamination level of the studied ground water sources ranged from low contamination to moderate contamination.

Thakur and Kumar [25] reported the pollution load of SIDCUL area effluents with reference to heavy metals such as chromium, cadmium, copper, iron, manganese and zinc at Haridwar using pollution load index and geoaccumulation index revealed that iron was accumulated at higher rate as compared to other heavy metals in the different areas receiving SIDCUL area effluents.

However, most of the studies have been limited up to the determination and evaluation of concentration of heavy metals in water sources and impact of their contamination on health only. There has been no detailed and distinct research available for evaluation of sources and causes of heavy metals contamination by using HPI of the drinking water sources of Haridwar selected for the study. The present study includes analysis of water quality of 17 ground water sources of Haridwar for six heavy metals as water quality parameters during pre-monsoon (PRM) and post-monsoon (POM) seasons of 2014 and 2015 using HPI to assess their suitability for drinking purpose, which is source of drinking and domestic water supply for public. The results of this research work based on HPI has been presented and discussed.

EXPERIMENTAL

Study area: Seventeen ground drinking water sources of Haridwar district along with the site codes (H1-H17), longitude, latitude and elevation above mean sea level (MSL) are given under Table-1. The selected water sources are being used for local community supply by state's drinking water supply and maintenance agency *i.e.* Uttarakhand Jal Sansthan (UJS), Dehradun and were analyzed during pre-monsoon (PRM) and post-monsoon (POM) seasons of 2014 and 2015 for qualitative and quantitative status of six heavy metal contamination as per BIS: 10500:2012 specification [26].

Sampling procedure: Water samples of selected ground drinking water sources of Haridwar were collected during twice a year *i.e.* PRM season (April-May) and POM season (October-November) along with the determination of GPS coordinates and height above mean sea level (MSL) of sampling sites by using Global Positioning System (GPS) (Make-Garmin-CSX76). Water samples were collected and stored in high-density polyethylene 'Tarson' bottles after 2-3 times rinsing with the samples. Particularly for heavy metal analysis, acid-

TABLE-1
WATER SAMPLING SITES OF GROUND WATER SOURCES OF HARIDWAR DISTRICT, UTTARAKHAND, INDIA

Drinking water site (source)	Site code	Latitude	Longitude	Elevation height (m)
Laksar (Nalkoop No.1)	H1	N 29°44'51.9"	E 078°01'01.5"	221
Devpura (Pump No.38)	H2	N 29°56'26.5"	E 078°08'49.3"	284
Pandeywali (Nalkoop)	H3	N 29°55'35.9"	E 078°06'11.8"	282
Jhabreda (Nalkoop -1)	H4	N 29°48'51.3"	E 077°46'34.0"	255
Bahadrabad (Nalkoop-1)	H5	N 29°55'04.6"	E 078°02'42.0"	286
Padao (Roorkee)	H6	N 29°52'43.4"	E 077°53'03.7"	270
Gyanlok Jal Nigam TW	H7	N 29°55'50.5"	E 078°08'36.9"	279
Trimurti Nagar Jal Nigam TW	H8	N 29°55'18.1"	E 078°05'24.0"	284
Shiwalik Nagar Phase-II, TW 1	H9	N 29°56'07.7"	E 078°04'23.2"	283
Bahadrabad New Block Office TW	H10	N 29°55'15.1"	E 078°02'22.9"	262
Nagar Palika Office Campus TW No. 4	H11	N 29°52'27.7"	E 077°53'23.5"	270
Avas Vikas TW No. 12	H12	N 29°56'19.9"	E 078°08'05.9"	284
Adarsh Nagar TW 15	H13	N 29°52'27.7"	E 077°53'44.6"	247
Ganeshpur TW No. 16	H14	N 29°51'30.5"	E 077°52'33.4"	262
Laksar Zone-I TW No. 2	H15	N 29°45'18.3"	E 078°01'39.3"	224
Landora TW No. 3	H16	N 29°48'19.7"	E 077°55'40.0"	250
Mangalore TW No. 3	H17	N 29°47'14.7"	E 077°52'56.9"	262

leached polyethylene bottles were used and sample was preserved by adding ultra pure nitric acid (5 mL/L) to minimize the adsorption and precipitation of heavy metals by reducing pH < 2 of water sample. Further, water samples were brought to the laboratory by maintaining cold storage chain at 4 °C. Sample preservation and digestion were performed as per standard methods of APHA (2012) protocols [27].

Instrumental analysis: For the analysis of water samples only analytical grade chemicals and reagents were used for the analysis and purchased from Merck, India. During the analysis for preparation of all the standards, stock solutions and for dilutions, only ultrapure analytical grade water of Millipore water purification system (Make: Millipore, USA; Model: Elix and Synergy) was used. Analysis of six heavy metals chromium, copper, iron, manganese, lead and zinc of water samples were executed in laboratory by using Atomic Absorption Spectrophotometer (AAS) of Varian (Model AA240) and the adopted procedure is described below:

Principle of procedure for the analysis of metals: Determination of metal characteristics in drinking water is an important aspect which in present study includes ground water sources. For the metals analysis atomic absorption spectroscopy (AAS) technique (APHA 22nd Ed. 3111 D; APHA 22nd Ed. 3111 B) was used. AAS is a highly sensitive technique used to determine metals in water samples. Therefore, ultra pure demineralized water was used for dilution of samples and obtained through Millipore Water Purification System (Make: Millipore; Model: Elix with Synergy and Surepro). All reagents of analytical grade, high grade quality metal standards (Merck) and different hollow cathode lamps (Make: Varian, Heraeus and Photron) as a light source were used for analysis of metals. All the details of instrumental conditions used in the analysis of different metals through AAS. Samples were used after digestion with ultrapure HNO_3 for analysis, before which preparation of standards and calibration of AAS carried out as per standard procedure.

Data analysis: After analyzing, concentration of particular metal ion in mg/L was recorded through the instrument. If concentration of any metal ion in a particular water sample was recorded higher than the standards of that metal used for calibration of instrument, then the sample is diluted with ultrapure demineralized water and again analyzed. Further, result was multiplied by the appropriate dilution factor to find out accurate result. Metals, which are present in significant amount in water samples such as Cu, Fe, Mn and Zn were analyzed without digestion. While, the metals below the considerable concentration such as Cr and Pb were analyzed after digestion process for proper analysis and accurate results.

Seasonal and spatial variations: To evaluate the significant variations between two or more means of a data set of variables, Analysis of variance (ANOVA) is an important statistical method [28]. The ANOVA test is used in the analysis of data set having more than two groups of variables [29]. ANOVA test was implemented to determine the seasonal and spatial variations in analyzed water quality data sets of 17 water sources of Haridwar for selected 6 heavy metals during the study period of 2 years. To evaluate the seasonal variations through ANOVA, the mean of data sets of each drinking water quality parameter remained same for each season. While, during the determination of spatial variation (sites variation) the mean of data sets of each drinking water quality parameters was same at each site.

Metal pollution indices: Metal pollution indices are most reliable scientific methods to determine the contamination by heavy metals of water samples. In this work, heavy metals pollution index (HPI) was used for determination the overall water quality with respect to heavy metals in analyzed water samples. After determining the concentration of selected heavy metals by using AAS, water quality pollution indices were calculated.

Heavy metal pollution index (HPI): HPI is a rating scale, which represents the total water quality with respect to heavy metals and gives the rating of each suitable parameter in the form of an arbitrary value less than 100 or more than 100. Determination of HPI is based on the weighted arithmetic quality mean method and representing the comparative characteristic of individual quality consideration [30]. Computation of HPI is carried out in two steps. The first step is the development of rating scale for each selected water quality parameter *i.e.* metal by giving weightage and the second step involved index based selection of pollution parameter. The rating system established by making values inversely proportional to the standard permissible value (S_i) for corresponding parameter [30].

Metal Pollution Index (HPI) can be calculated with the following equation:

$$HPI = \frac{\Sigma(W_i \times Q_i)}{\Sigma W_i} \quad (1)$$

where, Q_i is the sub-index for i^{th} water quality parameter, W_i is the weight associated with i^{th} water quality parameter.

The sub-index (Q_i) of the parameter is calculated by:

$$Q_i = \sum \frac{[M_i - I_i]}{[S_i - I_i]} \times 100 \quad (2)$$

where, M_i is the monitored value of heavy metal of i^{th} parameter, I_i is the ideal value of the i^{th} parameter and S_i is the standard value of the i^{th} parameter.

The sign (-) indicates numerical difference of the two values, ignoring the algebraic sign. The maximum allowed value for drinking water (S_i) represents to the maximum acceptable concentration in drinking water in absence of any alternate water source [permissible limit as per Bureau of Indian Standards (BIS) 2012]. The desirable maximum value (I_i) indicates the standard limits for the same metal parameters in drinking water [desirable limit as per (BIS) 2012]. Usually, the critical pollution index for HPI value of drinking water is 100 rating [18,19] and for potability HPI should always be less than 100 for drinking water. If HPI is found more than 100, water cannot be used for drinking of such water sources. The standard value of HPI and corresponding scale are given under Table-2.

TABLE-2
CATEGORIZATION OF WATER QUALITY GRADE AS PER HEAVY METAL POLLUTION INDEX SPECIFICATIONS

HPI standard value range	Rating
1-100	Suitable for drinking
> 100	Not suitable for drinking

RESULTS AND DISCUSSION

Results of the analysis of 6 heavy metals of 17 ground drinking water sources (H1-H17) of Haridwar during twice in a year *i.e.* during pre-monsoon (PRM) and post-monsoon (POM) seasons of both 2014 and 2015 are described and discussed under this section. Corresponding heavy metals have been analyzed and thereafter assessed by advanced statistical technique as heavy metal pollution index (HPI) along with various other statistical techniques such as mean, median, standard deviations and Pearson correlation matrix. The results of water quality data of analyzed heavy metals in the form of minimum, maximum, mean, median and standard deviation of individual water quality parameter have been given under Tables 3 and 4 during PRM and POM seasons, respectively of both years.

Results of water quality data by using atomic absorption spectroscopy (AAS) suggested that the concentration of all the analyzed heavy metals were found in all the selected ground drinking water sources below their standard limit during both the seasons of 2014 and 2015, except one *i.e.* only lead was found (0.011 mg/L) more than its standard limit (0.01 mg/L) at H13 during PRM 2014. This factor highlights the impact of various geographical activities such as precipitation, weathering of rocks, soil erosion and excessive growth of phytoplankton *etc.* on water quality of analyzed water sources [31].

TABLE-3
STATISTICAL DATA OF DRINKING WATER SOURCES OF HARIDWAR DURING PRM SEASON OF 2014 AND 2015 (mg/L)

Metals	Si (mg/L)	Ii (mg/L)	Minimum		Maximum		Mean		Median		Standard deviation	
			PRM 2014	PRM 2015	PRM 2014	PRM 2015	PRM 2014	PRM 2015	PRM 2014	PRM 2015	PRM 2014	PRM 2015
Cu	1.5	0.05	0	0	0.04	0.045	0.014	0.024	0.011	0.024	0.013	0.015
Mn	0.3	0.1	0	0	0.152	0.139	0.035	0.027	0.027	0.013	0.041	0.038
Pb	0.01	NR	0	0	0.011	0.005	0.002	0.001	0.002	0	0.002	0.002
Zn	15	5	0	0	0.045	0.127	0.012	0.024	0.005	0	0.014	0.038
Cr	0.05	NR	0	0	0.003	0.005	0	0.001	0	0	0.001	0.002
Fe	0.3	NR	0	0	0.212	0.174	0.065	0.057	0.026	0.049	0.078	0.054

PRM = Pre-monsoon.

TABLE-4
STATISTICAL DATA OF DRINKING WATER SOURCES OF HARIDWAR DURING POM SEASON OF 2014 AND 2015 (mg/L)

Metals	Si (mg/L)	Ii (mg/L)	Minimum		Maximum		Mean		Median		Standard deviation	
			POM 2014	POM 2015	POM 2014	POM 2015	POM 2014	POM 2015	POM 2014	POM 2015	POM 2014	POM 2015
Cu	1.5	0.05	0.005	0	0.015	0.037	0.01	0.012	0.01	0.008	0.003	0.012
Mn	0.3	0.1	0	0	0.097	0.097	0.039	0.032	0.038	0.027	0.033	0.031
Pb	0.01	NR	0	0	0.003	0.007	0.001	0.002	0.001	0.001	0.001	0.002
Zn	15	5	0.002	0	0.143	0.148	0.027	0.041	0.012	0.026	0.038	0.052
Cr	0.05	NR	0	0	0.1	0.006	0.013	0.001	0.005	0	0.024	0.002
Fe	0.3	NR	0	0	0.288	0.225	0.055	0.074	0.014	0.067	0.082	0.069

POM = Post-monsoon.

Statistical techniques such as mean, median and standard deviations showed the significant variations in the concentration of heavy metals in analyzed drinking water samples of different water sources. Statistical study also helps to assess the impact of seasonal variation on the quality of water at each sampling site. In terms of statistics, the standard deviation determines the amount of variation in the concentration of particular metal from the mean value of a set of six metal concentrations during the study period. Results of the statistics, observed significant variation in standard deviation of among heavy metals from their mean values.

Most of the dissolved heavy metals were found with slightly higher concentration during POM season than that of the PRM season. On the basis of the mean value of all the analyzed 6 heavy metals of 17 drinking water sources of each season, the significant variation in overall concentration was found higher in POM season as compared to PRM season during both years and results are depicted in Figs. 1 and 2, respectively. This kind of pattern represented the accumulation of heavy metal concentration during high flow conditions. It indicates that the accumulation of heavy metals in the soil is influenced bt precipitation conditions, due to which water sources are exposed to industrial effluents, dumped domestic and agricultural wastes [32].

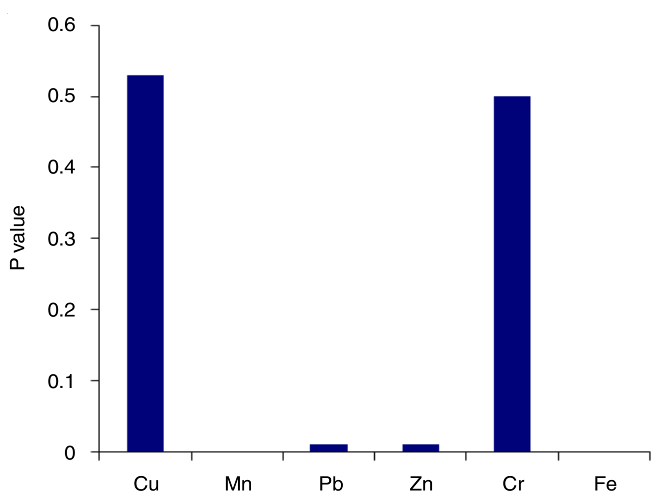

Fig. 1. Seasonal variation of heavy metals against P value

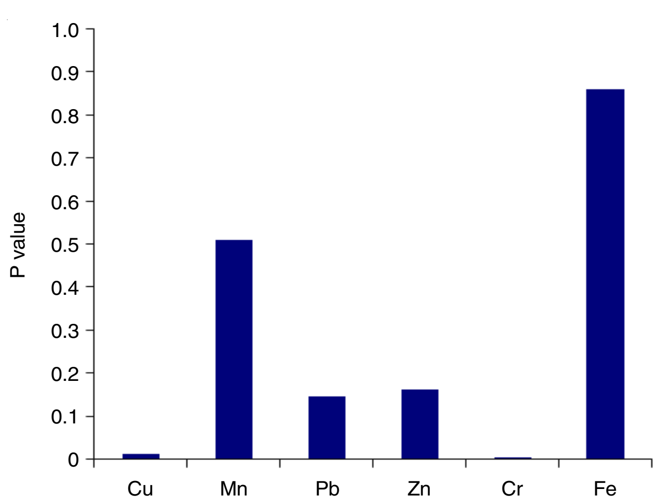

Fig. 2. Spatial variation of heavy metals against P value

Impact of variations in drinking water quality with respect to seasonal and spatial changes in analyzed 6 heavy metals of water samples of 17 sampling sites of Haridwar for both years through ANOVA analysis has been shown in Table-5. Results of ANOVA analysis showed that the significant seasonal variation ($P > 0.05$) was observed only for Cu ($P = 0.53$) and Cr ($P = 0.50$), while, no significant seasonal variation was found for rest other heavy metals as Mn, Pb, Zn and Fe with the $P < 0.05$. Significant spatial variation was depicted in case of Mn ($P = 0.51$), Pb ($P = 0.14$), Zn ($P = 0.16$) and Fe ($P = 0.86$).

TABLE-5
ANAOVA ANALYSIS FOR SEASONAL AND SPATIAL VARIATIONS FOR WATER QUALITY PARAMETERS OF HARIDWAR

Water quality parameters	Seasonal variation		Site variation	
	P value	Statistial significant	P value	Statistial significant
Cu	0.53	S	0.01	NS
Mn	1.98×10^{-16}	NS	0.51	S
Pb	0.01	NS	0.15	S
Zn	0.01	NS	0.16	S
Cr	0.50	S	0.01	NS
Fe	2.78×10^{-6}	NS	0.86	S

NS = Non-significant; S = Significant

Further, assessment of water quality of analyzed water sources of Haridwar in respect of heavy metals for the suitability of drinking purposes have been evaluated in terms of heavy metal pollution index (HPI). Computation of HPI is based on characteristics of the following 6 heavy metals namely copper, manganese, lead, zinc, chromium and iron for evaluation of water quality of selected water sources during the study period. Results of the HPI analysis of 17 drinking water sources of Haridwar of PRM and POM seasons of 2014 and 2015 are summarized in Table-6 and the rating scale for suitability of

TABLE-6
CALCULATED HEAVY METAL POLLUTION INDEX (HPI) OF DRINKING WATER SOURCES OF HARIDWAR DURING PRM AND POM SEASONS OF 2014 AND 2015

Sources/ Site code	PRM 2014	POM 2014	PRM 2015	POM 2015
H1	18.5	24.19	2.31	23.26
H2	20.47	20.03	9.89	17.09
H3	2.84	3.00	2.92	2.73
H4	23.17	10.37	18.73	11.13
H5	34.09	22.57	26.19	42.07
H6	6.03	19.52	1.61	2.03
H7	13.60	16.94	2.20	13.49
H8	23.33	26.75	36.65	54.15
H9	23.49	36.05	26.47	12.1
H10	9.12	4.51	2.92	1.44
H11	15.8	6.25	1.97	0.78
H12	15.71	17.39	1.55	10.37
H13	13.47	0.77	1.81	2.58
H14	9.9	6.63	0.60	1.15
H15	22.91	18.31	11.55	29.23
H16	4.52	7.60	1.62	5.57
H17	30.68	12.19	40.33	20.84
Average	16.92	14.89	11.14	14.71

water sources for drinking purposes in accordance to HPI during the same study period has also been represented in Table-7.

Characterization of water quality of different water sources of Haridwar in terms of heavy metals by using HPI during PRM season 2014 has been depicted that H1, H3, H6, H7, H8, H9, H10, H11, H12, H13, H14, H15 & H16 water sources were found under excellent category and H2, H4, H5 & H17 sources were observed under good category. During POM season 2014, HPI of H1, H2, H3, H4, H5, H6, H7, H10, H11, H12, H13, H14, H15, H16 & H17 sampling sites fall under excellent category and H8 & H9 sites were observed under good class. Variations of HPI during PRM and POM 2014 seasons have been observed from 2.84 to 34.09 and 0.7 to 36.05, respectively.

Further, analysis of heavy metals through HPI technique of water samples of Haridwar during PRM 2015 categorized the water sources as H1, H2, H3, H4, H5, H6, H7, H10, H11, H12, H13, H14, H15 & H16 as excellent and H8, H9 & H17 were observed under good class. While, during POM 2015, H1, H2, H3, H4, H6, H7, H9, H10, H11, H12, H13, H14, H16 & H17 water sources fall under excellent category; H5 & H15 sources belong to good and only H8 was recorded with average rating. During PRM and POM seasons of 2015, range of HPI varied from 0.66 to 40.33 and 0.78 to 54.15, respectively.

A comparative study between the total results of HPI obtained for the PRM and POM seasons of first and second years shows that, in the first year, the average value of HPI of the PRM (16.92) was higher than the POM (14.89). This may be attributed to the excess of lead (0.011 mg/L), which was found more than its standard limit (0.01 mg/L) at H13 drinking water source due to various geographical activities. Whereas, during the second year of the study, the average value of HPI of the POM (14.71) was higher than the PRM (11.14), which is a common characteristic, found after the POM season and the comparative results of the average value of all the four seasons are depicted in Fig. 3.

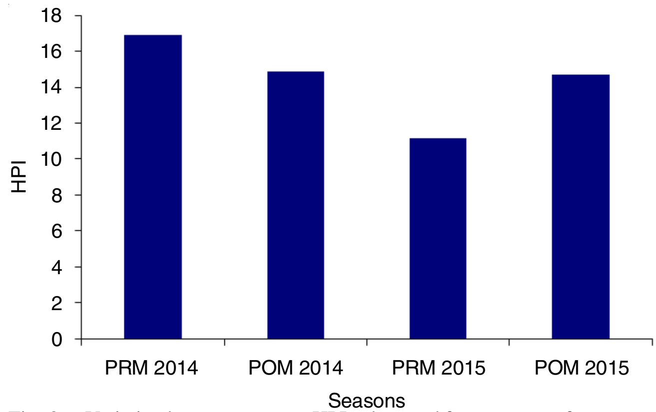

Fig. 3. Variation between average HPI values and four seasons of two years of study

The results also showed the comprehensive correlation of the seasonal variation among these heavy metals. Usually, geogenic activities and some of the times anthropogenic activities are also responsible for the contamination of heavy metals in ground drinking water sources. The presence of heavy metals in the ground water sources is mainly due to various geographical activities such as precipitation, weathering of rocks, soil erosion and dissolution of mineral due to percolation of water through rocks [33-35]. Whereas, many anthropogenic activities such as agricultural effluents enrich with fertilizers and insecticides, seepage of sewage and industrial effluents are also responsible for the contamination of water sources [36].

Conclusion

In this work, the estimation of heavy metals in ground drinking water sources of Haridwar has been done by advanced analytical technique *i.e.* atomic absorption spectroscopy (AAS) with a high degree of accuracy. The characterization of drinking water quality with respect to heavy metals for their suitability of drinking purposes in Haridwar has also been determined in

TABLE-7
SUITABILITY OF DRINKING WATER SOURCES/SITES OF HARIDWAR ON THE BASIS OF HEAVY METAL POLLUTION INDEX (HPI)

PRM 2014		POM 2014		PRM 2015		POM 2015		HPI standard value range	Rating
HPI values obtained	Site (s)	HPI values obtained	Site (s)	HPI values obtained	Site (s)	HPI values obtained	Site (s)		
2.84 to 23.49	H1, H2, H3, H4, H6, H7, H8, H9, H10, H11, H12, H13, H14, H15, H16 (88.23 %)	0.77 to 24.19	H1, H2, H3, H4, H5, H6, H7, H10, H11, H12, H13, H14, H15, H16, H17 (88.23 %)	0.60 to 18.76	H1, H2, H3, H4, H6, H7, H10, H11, H12, H13, H14, H15, H16 (76.47 %)	0.78 to 23.26	H1, H2, H3, H4, H6, H7, H9, H10, H11, H12, H13, H14, H16, H17 (82.23 %)	0- 25	Suitable for drinking
30.68 to 34.09	H5, H17 (11.77 %)	26.75 to 36.05	H8, H9 (11.77 %)	26.19 to 40.33	H5, H8, H9, H17 (23.53 %)	29.23 to 42.07	H5, H15 (11.77 %)	26 - 50	Suitable for drinking
NA	Nil	NA	Nil	NA	Nil	54.15	H8 (5.88 %)	51 - 75	Suitable for drinking
NA	Nil	NA	Nil	NA	Nil	NA	Nil	76 - 100	Suitable for drinking
> 100	Nil	> 100	Nil	> 100	Nil	> 100	Nil	> 100	Unsuitable for drinking

terms of heavy metal pollution index (HPI) and results of the study showed that no site/source has been found with HPI more than its critical limit *i.e.* 100. Results of the quantitative study showed that the concentration of lead (0.011 mg/L) was found more than its standard limit (0.01 mg/L) only at H13 sampling site during PRM 2014 and rest other water quality parameter were found in all the selected ground drinking water sources below their standard limit during the study. ANOVA analysis has been performed to assess the spatial and seasonal variations for selected metals for the period of PRM and POM seasons of both the years. The results of HPI showed that the overall water quality was safe and water of studied ground drinking water sources is suitable for drinking purpose and no serious threat to human consumption with respect to analyzed heavy metals. It is suggested and recommended that a periodic monitoring and evaluation of the analyzed ground drinking water sources must be done for determining the contamination of heavy metals, so that suitable treatment process can be adopted on regular basis.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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