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Assessment of Spatial and Temporal Variation of Water Quality in Mid Hills of North West Himalyas - A Water Quality Index Approach

AJAY KUMAR SINGH* and SATISH KUMAR BHARDWAJ

Department of Environmental Science, YSPUHF, Nauni, Solan, Himachal Pradesh 173230, India.

Abstract

Today, the quality of drinking water across the globe has become an environmental concern because of its degradation due to urbanization, industrialization, transportation etc. Solan, a rapidly developing district and an industrial hub, in the recent past has faced water borne diarrhoeal disease outbreaks. Therefore, the study was undertaken to assess the water quality of disease burden regions of the district during monsoon and post monsoon seasons. pH of the water sources was in the range of 6.92-7.43 and was well within the Bureau of Indian Standards (BIS) normal limits of 6.5-8.5. Electrical conductivity of water ranged from 151.40-414.65 µS cm^{-1}. The water sources of high disease burden regions exhibited higher EC than the prescribed Indian Council of Medical Research (ICMR) standards of 300 µS cm^{-1}. DO (range 7.43-8.56 mg l^{-1}) was above the desired levels of 5 mg l^{-1} in all disease burden regions. BOD (range 12.25- 23.25 mg l^{-1}) was higher than the BIS limits of 5 mg l^{-1} in all regions. The COD, TDS and turbidity (range 75.75- 157.50 mg l^{-1}, 2.24- 81.01 mg l^{-1} and 1.85- 5.05 NTU respectively) were within BIS limits. The concentration (mg l^{-1}) of Ca, Pb, Hg, Zn and Cr was found in the ranges of 37.2-122.9, 0.17-0.51, 0.00-0.03, 0.74-8.99 and 0.04-0.10, respectively. The high disease burden regions exhibited relatively higher contents of Ca, Hg and Cr as compared to lower one and the BIS limits. However, contents of Pb and Zn were above BIS limits in all the regions. The concentration (mg l^{-1}) of Mg, NO3-, Cl- and As was in the ranges of 14.25- 30.61, 5.10- 9.88, 16.42- 74.96, 0.001- 0.014 respectively, which were below prescribed standards. Drinking water sources of all regions were free of Cd contents except Solan region (0.001 mg l^{-1}), however,

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CONTACT Ajay Kumar Singh ajaysingh7279@gmail.com Department of Environmental Science, YSPUHF, Nauni, Solan, Himachal Pradesh 173230, India.

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the contents were within BIS limits of 0.003 mg l^{-1}. Water Quality Index (WQI) computed by using nine parameters varied from 78.58-219.78 (very poor to unsafe drinking water class). Interestingly, water sources of all the high disease burden regions were unsafe for drinking (WQI: 102.02-167.04). Water quality deteriorated more in the monsoons. The study therefore warrants remedial actions of water resource protection and conservation for the provision of the potable water.

Introduction

Water, the most precious resource of the planet earth assumes a vital importance for sustainable environmental health in the present century because of its persistent exploitation across the globe. The deterioration of ground water and surface water quality is alarmingly high.[1] Typically water gets contaminated by various factors such as the population explosion, rapid urbanization and agricultural development, which are continuously contributing in the degradation of the water sources. This environmental resource degradation has been noticed for increased disease morbidity and mortality in various regions (Jain *et al.*, 2007[2] and Adimalla, 2018[3]). The goal seven of Millennium Development Goals set by United Nations, to provide access of safe drinking water to half the population across the world has been met, much before the scheduled time of 2015.[4] Interestingly, about 663 million people across the world still lack access to quality drinking water.[5] The Sustainable Development Goal six, Clean water and Sanitation, aims for providing access to safe and affordable drinking water for all by the year 2030.[6]

Contaminated water sources lead to debilitating water borne diseases afflicting human health. The polluted waters transmit diseases such as cholera, shigellosis, viral hepatitis, campylobacteriosis, various skin diseases, gall bladder and kidney stones, other gastrointestinal diseases and different types of cancers (Smith, 2018).[7] As per World Health Organization (WHO) 2017 estimates, about 1.1 billion people across the globe are drinking unsafe water . Moreover, a vast majority of diarrheal diseases in the world (88%) are attributable to the unsafe water, sanitation and hygiene.[8] Approximately 3.1% of annual deaths (1.7 million) and 3.7% of the annual health burden i.e. disability adjusted life years [DALYs] world- wide (54.2 million) are attributable to unsafe water, sanitation and hygiene (WHO, 2015).[9] Provision of safe water and sanitation services are the topmost priority in many parts of the world and have been the implicit part of policy matter of almost all the countries. However, there still exists a huge challenge for the developing countries especially the lower income group ones, to overcome the hurdles in this provision.

Table 1: Drinking water standards recommending Agencies and unit weights. (All values except pH and electrical conductivity are in mg l^{-1})

Sl. No.	Parameters	Standards	Recommending agency	Unit weight
1	pH	6.5- 8.5	ICMR, BIS	0.219
2	Electrical conductivity	300	ICMR	0.371
3	Total Dissolved Solids	500	ICMR, BIS	0.0037
4	Biological oxygen demand	5	ICMR	0.3723
5	Dissolved oxygen	5	ICMR, BIS	0.3723
6	Calcium	75	ICMR, BIS	0.025
7	Magnesium	30	ICMR, BIS	0.061
8	Chloride	250	ICMR	0.0074
9	Nitrate	45	ICMR, BIS	0.0412

Water Quality Index (WQI) as proposed by National Sanitation Foundation of America is a composite indicator value of quality of water (Brown *et al.*, 1970).[10] Though, WQI is extensively used in most of the countries with slight modification (Hallock, 2002[11]; Veerbhadram, 2005[12]), its use in India is rare. Solan district of Himachal Pradesh, having a mountainous topography in the north western Himalyan region, is urbanizing / industrializing at a fast rate. The high disease burden of Solan has necessitated the monitoring and the surveillance of the water sources of the area. Henceforth, the present research was conducted to assess the seasonal physical-chemical parameters of water as well as to estimate the Water Quality Index (WQI) and also the quality of the water intended for drinking purposes.

Material and Methods

The physical-chemical assessment of drinking water sources falling in all five health blocks namely Arki, Dharampur, Chandi, Nalagarh and Syri was undertaken as per the following methodology:

Complete listing of Public Health Institutes (PHIs) falling under these blocks was made from the records of the office of the Chief Medical Officer, Department of Health and Family Welfare, Solan, HP. Thereafter the incidence of diarrhoea for each PHI was tabulated for five years (2012-2016). In order to select the PHIs further, the commonly used standard stratification method of construction of strata outlined by Singh and Sukhatme (1969)[13] was employed. The frequency of diarrhoeal incidence of each PHI was tabulated. Thereafter, the statistical cumulative cube root method i.e. Cum.3√f, was employed for constructing four strata from the frequency distribution table i.e low, moderate, high and very high. Thereafter the total 49 PHIs were accordingly allocated with optimum stratification under the class intervals of low (0-602), moderate (603-1202), high (1203-2402) and very high (2403 and above) incidence areas strata. The approximation statistics were employed and accordingly 1, 6, 11 and 7 PHIs were found under the strata low, moderate, high and very high category respectively. Out of these categories, a single PHI of low and seven PHIs of very high incidence strata were selected as the regions for the assessment of water quality of the drinking water sources. Accordingly, Primary Health Centre (PHC) Kurgal was selected under the low incidence category and Civil Hospital (CH) Arki, Community Health Centre (CHC) Kunihar, PHC Baddi, CH Kandaghat, Employee's State Insurance (ESI) Hospital Parwanoo, CHC Nalagarh and Regional Hospital (RH) Solan were selected for the study under the high incidence category. Thereafter, a cross-sectional Knowledge, Attitude and Practice survey (KAP) was conducted in these selected PHIs.

Table 2: Water Quality Rating as per Weight Arithmetic Water Quality Index Method

WQI value	Rating of Water Quality	Grading
0 - 25	Excellent water quality	A
26 - 50	Good water quality	B
51 - 75	Poor water quality	C
76 - 100	Very poor water quality	D
> 100	Unsuitable for drinking purpose	E

Sample Size for KAP Survey

A total of 180 diarrhoeal patients (25 per PHI) admitted, were selected randomly for the KAP survey. The sample size was calculated by using the following standard formulae for cross sectional surveys

$$\text{Sample size} = \frac{Z_{1-\alpha/2}{}^2\, p\,(1-p)}{d^2} = 163$$

- Adding 10% non response, sample size = 180
- Per site sample size= 180/8 = 23, rounded off to 25
  here
- $Z_{1-\alpha/2}$ = Standard normal variate {at 5% type 1 error (P< 0.05)}. and is 1.96
- p is expected proportion in population (12.1 %, the probability of diarrhoea in Solan as per the NFHS- 4 report)
- d is absolute error or precision (5 %).

An interviewer administered semi-structured pilot tested questionnaire was used for the patients admitted in the selected PHIs. This was utilized for the identifying all the water sources of the study area. Thereafter on the basis of Selective Random

Sampling technique, a representative number of water bodies i.e. 80 sources (by taking ten water sources from each of the eight sites), were selected.

Water Sampling

The grab samples of the surface and ground water of the selected sources falling in the very high and low incidence area of water borne diseases were collected in acid washed one litre plastic bottles by following the standard procedure (Rice, 2017).[14] In case of dug wells the samples were collected by lowering the bottle at depth of about one foot below the water surface. The temperature was recorded in situ with the help of a mercury thermometer between 11 a.m. and 12 p.m. at all the sites. The collected samples were transported to the laboratory after appropriate labeling and examined for pH, EC, TDS and BOD immediately. The remaining samples were stored in refrigerator in the laboratory at 4˚C for subsequent analysis. The pH of water was determined by microprocessor based pH meter (Model 510 of EIA make). Electrical conductivity (expressed in $\mu S\ cm^{-1}$) and total dissolved solids ($mg\ l^{-1}$) were determined by using microprocessor based conductivity/ TDS meter (Model- 1601 of EIA make). BOD (mg/l^{-1}) was determined by using BOD system Oxi-direct (Aqualytic make). Calcium, magnesium, nitrate were determined photometrically with Spectroquant Pharo 300 (Merk make) and expressed in $mg\ l^{-1}$. Chloride was estimated ($mg\ l^{-1}$) by US standard method (EPA 325.1). The method was analogous to APHA-4500-Cl-E. Heavy metals viz. the trace elements like As, Cd, Cr, Pb, Zn and Hg were determined ($mg\ l^{-1}$) by using Inductively Coupled Plasma model 6300 duo of Thermo make. The physical and chemical parameters of potable water were discussed by comparing with CPCB (Centre Pollution Control Board), WHO, BIS and ICMR standards. Chemical Oxygen Demand (COD), espressed in $mg\ l^{-1}$, was estimated by the method analogous to EPA 410.4 US Standard method 5220 D, and ISO 15705 .

Water Quality Index Calculations

The weighted arithmetic index method (Brown *et al*., 1970) has been used for calculation of WQI of the water bodies. The quality rating or sub index (q_n) calculations were done by employing the following formulae:

$$q_n = 100\ [\ V_n - V_{iv}\ ]\ /\ [\ S_n - V_{iv}\ ]$$

Here, there are n water quality parameters and quality rating or sub index (q_n) corresponding to the n^{th} parameter is a number reflecting the relative value of this parameter in the polluted water with respect to its standard permissible value. The expressions mentioned in the formulae denote the following:

q_n = Quality rating for the n^{th} Water quality parameter

V_n = Estimated value of the n^{th} parameter at a given sampling station

S_n = Standard permissible value of the n^{th} parameter

V_{iv} = Ideal value of n^{th} parameter in pure water (0 for all other parameters except the parameter pH and Dissolved Oxygen which have ideal values of 7.0 and 14.6 $mg\ l^{-1}$ respectively).

Unit weight was calculated by a value inversely proportional to the recommended standard value S_n of the corresponding parameter.

W_n = K/ S_n

W_n = unit weight for the n^{th} parameters

S_n = Standard value for the n^{th} parameters

K = Constant for proportionality

The overall Water Quality Index was calculated by aggregating the quality rating with the unit weight linearly.

$$WQI = \Sigma\ q_n\ Wn\ /\ \Sigma\ Wn$$

The rating of water quality using this method is given in Table 2 (Chatterji and Raziuddin, 2002).[15]

Statistical Analysis

The data emanating from the experiment conducted was subjected to statistical analysis through Factorial Randomized Design (RBD) and the significance of each treatment was calculated (Cochran and Cox, 1964).[16]

Results and Discussion

The perusal of data illustrated in Table 3 shows the mean seasonal variation in the physical parameters of water across the eight selected regions. TDS varied significantly with the seasons, the regions and

Table 3: Seasonal variation in physical parameters of drinking water sources in Solan, 2017

Parameter		pH			Temperature (˚C)			Electrical Conductivity (µS cm^{-1})			Total dissolved solids (mg l^{-1})		
Disease burden area	Season	Monsoon	Post monsoon	Mean	Monsoon	Post monsoon	Mean	Monsoon	Post monsoon	Mean	Monsoon	Post monsoon	Mean
	Arki	7.48	7.39	7.43	28.83	28.83	28.83	233.95	132.06	183	63.21	31.55	47.38
	Baddi	7.18	7.21	7.19	28.77	28.77	28.77	254.17	198.6	226.38	97.56	61.08	79.32
High Incidence	Kandaghat	7.3	7.09	7.19	28.13	28.35	28.24	309.26	146.07	227.66	34.04	15.83	24.93
	Kunihar	7.05	7.18	7.11	27.89	28.42	28.15	378.2	259.5	318.85	84.03	43.08	63.55
	Nalagarh	6.93	7.15	7.04	29.09	29.4	29.24	414.3	210.9	312.6	86.59	41.16	63.87
	Parwanoo	7.05	6.8	6.92	29.4	27.84	28.62	268.76	199.66	234.21	130.71	31.32	81.01
	Solan	7.02	6.83	6.93	27.96	28.59	28.27	542.5	286.8	414.65	0.67	3.81	2.24
Low Incidence	Kurgal	7.37	7.23	7.3	27.84	27.88	27.86	189.01	113.8	151.4	72.6	35.5	54.05
Mean		7.17	7.11	7.14	28.48	28.51	28.46	323.76	193.42	258.59	71.17	32.92	52.04

with the interaction of seasons with the regions of the water sources. Whereas, EC varied significantly with both the seasons and the regions, pH and temperature were affected only by the regions of the water sources. pH: The pH of water sources ranged from 6.92 to 7.43, which was however in the normal range and also within the permissible limits prescribed by BIS. The higher values recorded at Arki may be ascribed to low anthropogenic activities of the region in the terms of industrialization. The comparatively lower values observed for Kunihar, Baddi, Kandaghat, Nalagarh and Solan regions may be explained by the dense population and the presence of industries in these regions releasing more of CO_2 into water and thus decreasing the pH, similarly reported by Kashyap *et al*. (2015).[17] Temperature: The highest values of temperature at high disease burden region Nalagarh may be ascribed to the relatively plain terrain and lesser vegetation of the region. Moreover, larger proportion of pollutants entering in the form of industrial effluents, organic matter from domestic, agricultural waste and sewage may also be increasing the water temperatures.

The lowest values of temperature noticed at Kurgal, the low disease burden region may be ascribed to the presence of hilly terrain enriched with vegetation, the findings which are in line with a study by Sanalkumar *et al*. (2014).[18] Electrical Conductivity (EC): Solan region recorded the highest EC values (286.80 µS cm^{-1}), probably to the developmental activities like construction of roads and buildings, improper disposal of garbage and sewage leading to high amounts of dissolved inorganic substances in ionized form, as also reported by Kerketta *et al*. (2013).[19] The lowest values recorded at Kurgal, the low disease burden region may be ascribed to the relatively low temperatures prevailing in this region, as also reported by Oyem *et al*. (2014).[20] The EC recorded during monsoon (323.76 µS cm^{-1}) exceeded the ICMR standard value of 300 µS cm^{-1} and was significantly higher than the post monsoon status (193.42 µS cm^{-1}), due to more runoff causing greater dissolution of ionic pollutants into the water in the monsoon months.

Total Dissolved Solids

Parwanoo, a high disease burden region, recorded the highest TDS (81.01 mg l^{-1}), along with statistically

Table 4: Seasonal variation in chemical parameters mg l^{-1} of drinking water sources in Solan, 2017

Parameter		Dissolved Oxygen			COD			BOD			Turbidity		
Disease burden area	Season	Monsoon	Post monsoon	Mean	Monsoon	Post monsoon	Mean	Monsoon	Post Monsoon	Mean	Monsoon	Post Monsoon	Mean
	Arki	8.04	8.18	8.11	225.7	78.6	152.15	15.1	9.4	12.25	6.4	2.5	4.45
High Incidence	Baddi	7.68	7.85	7.76	192.8	39.8	116.3	21.4	10.7	16.05	2.6	1.4	2
	Kandaghat	7.46	7.41	7.43	148	167	157.5	25.4	12	18.7	6.3	1.9	4.1
	Kunihar	8.21	8.2	8.2	81	102.5	91.75	18.4	9.5	13.95	8.2	1.9	5.05
	Nalagarh	7.71	7.56	7.64	85.3	66.2	75.75	32	14.5	23.25	2.2	1.5	1.85
	Parwanoo	7.78	7.61	7.7	106.4	91.9	99.15	19	8.9	13.95	5.5	1.4	3.45
	Solan	9.09	8.03	8.56	133.8	100.1	116.95	21.9	11.9	16.9	4.1	1.5	2.8
Low Incidence	Kurgal	7.7	8.33	8.01	499.7	174	336.85	20.6	10.3	15.45	3.3	1.3	2.3
Mean		7.95	7.96	7.95	184.08	102.51	143.29	21.72	10.9	16.31	4.82	1.67	3.24

at par high disease burden regions of Baddi, Nalagarh and Kunihar. Higher TDS may be ascribed to the presence of lots of industries which potentially pollute water sources through their solid and liquid wastes, as also noted in another study by Rana *et al.* (2016).[21] Monsoon months also exerted a significant influence on TDS of water sources (71.17 mg l^{-1}). However, the TDS values observed were well below the BIS prescribed limits of 500 mg l^{-1}.

The data depicted in Table 4 shows the seasonal and area wise variation detected in the chemical parameters. Parameters such as COD, BOD and Turbidity varied significantly across the regions and with the seasons. Moreover, the interaction of the disease burden regions with the seasons of the year also exerted significant influence in the variations in DO and COD.

Dissolved Oxygen

The highest values of DO at Solan and statistically at par region Kunihar may be ascribed to the greater dissolution of oxygen in water, attributed to the low temperatures prevailing in this region. The lowest values of DO noticed at Kandaghat region may be ascribed to the high altitude of the region, similar finding reported by Tareq *et al.* (2013).[22] However, the values observed were well above the BIS desirable limits of 5 mg l^{-1}. Irrespective of the disease burden regions, highest DO was 9.09 mg l^{-1} noticed at Solan in monsoon and the lowest of 7.41 mg l^{-1} at Kandaghat during post monsoon months. However, the values observed were well above the BIS desirable limits of 5 mg l^{-1}. COD: The highest values of COD at Kandaghat (157.50 mg l^{-1}) may be due to the fact that most of the water sources being in the form of open streams have more of organic matter from point and non-point sources getting mixed with them due to runoff. On the contrary, majority of the water sources of Nalagarh region (with lowest COD of 75.75 mg l^{-1}) are either the hand pumps or the bore wells. Henceforth, these are not prone to surface runoff and have less of organic matter and the lowest values of COD thereafter. Mahananda *et al.* (2010)[23] has also reported similar findings. The COD detected in the months of monsoon and post monsoon was 135.50 and 91.54 l^{-1} respectively. However, the values observed in present study were well below the BIS prescribed limits of 250 mg l^{-1}. BOD: The highest values of BOD at Nalagarh may

Table 5: Seasonal variation in chemical parameters (mg l^{-1})of drinking water sources in Solan, 2017

Parameter		Calcium			Magnesium			Nitrate			Chloride		
Disease burden area	**Season**	**M***	**PM****	**Mean**	**M**	**PM**	**Mean**	**M**	**PM**	**Mean**	**M**	**PM**	**Mean**
	Arki	51.6	39.7	45.65	24.21	14.47	19.34	7.48	2.72	5.1	19.84	13.87	16.85
High Incidence	Baddi	69	49.8	59.4	39.34	14.3	26.82	10.36	4.68	7.52	42.55	24.56	33.56
	Kandaghat	77.8	61.3	69.55	22.42	11.49	16.95	11.46	4.9	8.18	21.07	11.76	16.42
	Kunihar	135.5	110.3	122.9	40.49	20.74	30.61	13.14	6.63	9.88	95.33	54.6	74.96
	Nalagarh	93.6	65.8	79.7	18.91	9.69	14.3	12.22	5.11	8.66	42.25	19.56	30.9
	Parwanoo	53.5	40	46.75	24.32	12.34	18.33	7.96	5.77	6.86	27.6	12.29	19.95
	Solan	45.7	32.5	39.1	29.14	19.2	24.17	13.32	5.88	9.6	24.64	17.24	20.94
Low Incidence	Kurgal	43.6	30.8	37.2	19.15	9.36	14.25	10.06	4.26	7.16	38.5	21.67	30.09
Mean		0.01	71.29	53.77	62.53	27.25	13.95	20.6	10.75	4.99	7.87	38.97	21.94
C.D. (0.05)													
Region			15			7.21			NS			18.46	
Season			7.5			3.6			1.93			9.23	
Region X Season			NS			NS			NS			NS	

* Monsoon, **Post monsoon

be ascribed to more growth of weeds etc. in some of the water bodies and lack of cleanliness of these sources, causing more of organic matter after the decay of such vegetative matter, as also being revealed in the KAP survey undertaken in the present study. However, the values observed were well above the ICMR permissible levels of 5 mg l^{-1}.

The data illustrated in Table 5 shows the variations in the concentrations of calcium, magnesium, nitrate, chlorides and lead. The regions and the seasons exerted significant influence on the amounts of calcium, magnesium, chlorides and lead. The interaction of regions with seasons did not affect any of these parameters. Calcium: Ca was detected in the range of 37.2- 122.9 mg l^{-1}. The highest concentration of Ca at Kunihar (122.9 mg l^{-1}) may be ascribed to the presence of large amounts of limestones in the region as also reported by Bacciottini *et al*. (2004).[24] The values observed in high disease burden regions of Kunihar and Nalagarh were above the BIS permissible levels of 75 mg l^{-1}. Whereas, the values observed during monsoon (71.29 mg l^{-1}) and post monsoon (53.77 mg l^{-1}) were below the permissible levels. Magnesium: Mg was detected in the range of 14.25- 30.61 mg l^{-1}. The highest concentration of Mg at Kunihar may be ascribed to the types of rocks in these areas. The values detected were very well below the BIS permissible levels of 100 mg l^{-1}. Nitrate: The highest concentration at Kandaghat may be probably due to use of inorganic nitrogenous fertilizers and manures in the region. However, the values detected were very well below the BIS permissible levels of 45 mg l^{-1}. Higher contents observed during monsoon were due to the point and non-point sources of pollution, hastened further by the runoff phenomenon, as also reported by Mueller *et al*. (2013).[25] Chloride: The highest concentration of chloride at Solan and Kunihar may be ascribed to the mixing of sewage generated from the domestication of milk producing animals such as cows, buffaloes, goats etc in the region, as also reported by Interlandi *et al*. (2003).[26] The land use patterns especially the sewage systems and the livestock management in this region, contributes the high hydrological fluxes of chloride ions, making them pass through the underlying strata into the ground water, as also reported by Chauhan *et al*. (2014).[27] However, the values detected were below the BIS permissible limits of 250 mg l^{-1}.

The data presented in Table 6 elicits the seasonal and temporal variation of the various trace elements of water such as mercury, arsenic, zinc, cadmium and chromium. Whereas, lead concentrations in water significantly varied with the seasons and the regions of the water sources, Hb and Cr concentrations showed variation with respect to the seasons, regions and the interaction of seasons with regions. On the other hand the concentrations of As, Zn and Cd were neither affected by the seasons and the regions and nor by the interaction of these two factors. Lead: The highest concentration of lead at Parwanoo and Solan may be ascribed to large number of cable manufacturing units and plastic stabilizer factories in these regions, as also reported by Cobbina *et al*. (2015).[28] The values detected were higher than the BIS permissible limits of 0.01mg l^{-1}.

Mercury

Irrespective of the regions, the relatively high values of mercury recorded in Arki region (0,09 mg l^{-1}) during the post monsoon season may be probably due to mineral deposits getting leached into the ground strata and eventually finding its way into the water acquifer. The highest concentration of mercury at Baddi and Kandaghat region may be ascribed to the widespread mining activities undertaken in the area as also reported by Kim *et al*. (2015).[29] No mercury was detected in the water sources of Arki, Nalagarh, Parwanoo and Solan. Arsenic: The high contents observed at Parwanoo may be attributed to their geogenic source of origin, probably from the type of rocks present in this region. The study findings are in line with Shankar *et al*. (2014).[30] The values detected were well below the BIS permissible limits of 0.05 mg l^{-1}. Zinc: The highest concentration of lead at Nalagarh region may be ascribed to large number of alloys and steel galvanizing industries and tannery plants in the region, as also has been reported in other studies in Banglasesh (Hasan *et al*., 2017).[31] Excessive use of insecticides in farming practices in this region may also be leading to higher concentrations of zinc in water sources. However, the values detected were below the BIS permissible limits of 15 mg l^{-1}. Cadmium: all the water sources were free

Table 6: Seasonal variation in chemical parameters (mg l^{-1}) of drinking water sources in Solan, 2017

Parameter		Mercury			Arsenic			Zinc			Cadmium			Chromium		
Disease burden area	**Season**	**M***	**PM****	**Mean**	**M**	**PM**	**Mean**	**M**	**PM**	**Mean**	**M**	**PM**	**Mean**	**M**	**PM**	**Mean**
	Arki	0	0.09	0	0.003	0.002	0.002	2.29	0.45	2.29	0.1	0.03	0.1	0.05	0.02	0.05
High Incidence	Baddi	0.03	0.01	0.03	0.003	0.002	0.003	0.77	0.08	0.76	0.06	0.12	0.06	0.08	0.02	0.08
	Kandaghat	0.02	0.01	0.02	0.004	0.007	0.005	0.75	0.06	0.74	0.07	0.03	0.07	0.06	0.02	0.06
	Kunihar	0.01	0.02	0.01	0.001	0.001	0.001	1.17	0.69	1.17	0.09	0.11	0.09	0.05	0.02	0.05
	Nalagarh	0	0.04	0	0.002	0.002	0.002	8.99	0.43	8.99	0.05	0.09	0.05	0.05	0.02	0.05
	Parwanoo	0	0.02	0	0.026	0.001	0.014	1.09	0.53	1.09	0.03	0.04	0.03	0.1	0.03	0.1
	Solan	0.01	0.01	0.01	0.017	0.003	0.01	0.91	0.61	0.91	0.04	0.03	0.04	0.04	0.02	0.04
Low Incidence	Kurgal	0	0	0	0.002	0.002	0.002	0.76	0.13	0.76	0.03	0.09	0.03	0.04	0.02	0.04
Mean		0.01	0.03	0.02	0.007	0.002	0.004	2.09	0.37	1.23	0.06	0.07	0.06	0.06	0.02	0.04
C.D. (0.05)																
Region		0.02			0.003			NS			NS			0.01		
Season		0.01			0.002			NS			NS			0.01		
Region X Season		0.03			NS			NS			NS			0.02		

* Monsoon, **Post monsoon

Table 7: Water Quality Index of drinking water sources in Solan, 2017

Disease burden	Area	Monsoon	Post monsoon	Mean
High incidence	Arki	119.87	84.18	102.02
	Baddi	160.93	94.15	127.54
	Kandaghat	182.52	96.08	139.29
	Kunihar	151.54	94.38	122.96
	Nalagarh	219.78	114.3	167.04
	Parwanoo	142.3	81.22	111.76
	Solan	177.45	102.05	139.75
Low incidence	Kurgal	83.75	78.58	81.17
Mean		154.77	93.12	

C.D. (0.05)
Region 27.92
Season 13.96
Region x Season 39.48

of Cd contents except Solan region which recorded 0.001 mg $l^{-1}$of Cd. However, the values detected were well below the permissible limits. Contents detected may be due to the effluent waste from automobile industries and building construction material, as also reported by Machado *et al*. (2017).[32] Chromium: The highest concentration of chromium at Parwanoo and Solan region may be ascribed to runoff mixed with automobile industry wastes, paints and dyes being used in extensive building materials, and steel works along with Cr-electroplating industries. Kandaghat and Kunihar regions, predominantly rural areas and without industries, also had higher contents. These rural areas exhibit the presence of chemical based agriculture. Use of pesticides and insecticides leads may be leading to higher chromium contents of water, as also reported by Repula *et al*. (2012).[33]

Water Quality Index

The regions of the water sources, the seasons and the interaction of the regions with the seasons had a significant influence on the water quality index of the drinking water sources (Table 6). Nalagarh, the high disease burden region, had the water sources which were unsuitable for drinking purposes (Grade E) with WQI of 167.04 followed by statistically at par region of Solan (139.75) and Kandaghat (139.29). The other high disease burden regions of Baddi, Kunihar, Parwanoo and Arki also had the sources which were unsuitable for drinking purposes. Even the water sources of the low disease burden region Kurgal were having the water of very poor quality with the WQI of 81.17. The deterioration of water quality was significantly more in monsoon with water unsuitable for drinking purposes (WQI- 157.77) as compared to post monsoon season having a very poor quality of water (WQI- 93.12). The unsuitable drinking water quality of the sources in Nalagarh and Solan may be ascribed to the ill effects of industrialization in congested urban areas where rampant discharge of industrial wastes and effluent is not only entering the water sources through run off but probably has also leached down and contaminated the various ground water sources even. Kandaghat region is predominantly a rural area with heavy usage of chemical based farming which may be polluting the water sources, as also reported by Chauhan *et al*. (2015).[27] The region of Kurgal had water sources which were predominantly unprotected and were always prone to external environmental pollutants and contaminants. The runoff phenomenon, more in monsoon further deteriorated the water quality of these sources, as also has been reported by Hasan *et al*. (2017)[31] and Machado *et al*. (2017).[32]

Conclusion

Rampant industrial pollutants deteriorating water quality is a matter of great concern and warrants for utmost public action. The ill effect of urbanization and industrialization on the water quality has been clearly highlighted in the present study. Improper sewage disposal, unchecked industrial effluents entering the water sources, may be sometimes due to runoff phenomenon and the unprotected nature of natural water sources itself, is leading to poor water quality of drinking water sources of the district. This may be leading to the higher diarrhoeal disease burden observed in the region. Last but not the least, poor knowledge, attitude and practice of the people in respect to aspects of the management of water sources needs intervention so as to protect these precious natural resources.

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