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Original Research Article

Assessment of water quality in disease burdened industrializing town of mid hills of North India

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ABSTRACT

Background: Anthropogenic activities associated with rapid urbanization and industrialization have deteriorated the water quality across the world. Rampant industrialization and poor water, sanitation and hygiene in an industrializing town of northern India necessitated the assessment of drinking water in the region.
Methods: The study of physico-chemical parameter of the water and water quality index of the most commonly used ten drinking water sources in 2017-2018 was undertaken. Grab water samples were collected during monsoon, the rainy season (June, July and August) and post monsoon (September, October and November) during the years 2017 and 2018 by following the standard procedures. Weighted arithmetic index method was used for the water quality index (WQI) analysis.
Results: Pooled analysis inferred water pH, temperature, total dissolved solids and carbonated oxygen demand to be within, whereas, electrical conductivity (91.00-431.50 µS/cm), turbidity (1.00-4.30 mg/l), dissolved oxygen (6.53-7.23 mg/l) and biological oxygen demand (6.12-7.62 mg/l), exceeding the Bureau of Indian standards permissible limits. Calcium, nitrate, chlorides and zinc were within limits, magnesium concentrations (9.16-29.35 mg/l) were below whereas lead (0.06-0.62 mg/l), chromium (0.01-0.12 mg/l), cadmium (0.00-0.25 mg/l) and mercury (0.00-0.08 mg/l) were above the standards. WQI was above 50 in all the drinking water sources.
Conclusions: Water was of poor quality and unsuitable for drinking purposes, indicating alarming water pollution. WQI of the various drinking water sources of the region deteriorated more in the monsoon season as compared to the post monsoon season.

Keywords: Assessment, Industrialization, Physico-chemical, Poor quality, Monsoon, Water pollution, Water quality index

INTRODUCTION

Anthropogenic activities such as rapid urbanization, industrialization and chemical-based farming have globally influenced the physical, chemical and biological properties of water.[1] Water quality has been deteriorating due to these activities, especially more in the developing countries such as India.[2]

A Large number of diseases of gastrointestinal system, skin, gall bladder, kidney, heart and blood have generated the demand for the regular monitoring and surveillance of the water sources of an area. Such public health tools further assist in prioritizing the health intervention efforts.[3,4] Keeping a watch on quality of water is critical. This will assist in designing and developing pollution prevention, control and management methodologies.

Solan district in northern India has also witnessed rampant and unchecked industrialization in the recent past and this has led to alarming water pollution.[2] The menace of discharging untreated effluents into the water bodies and surroundings has become a common feature of environmental degradation.

Physical parameters of water such as colour, temperature, odour, taste, conductivity and turbidity therefore warrant assessment in such a scenario. Industrial and agricultural work involve the use of many chemicals that run-off into the water and pollute it, generating the need for chemical property assessment of water. Pesticide contamination of water is also assuming alarming proportions. This is due to adoption of chemical-based farming for monetary gains in the region. Water quality index (WQI) as proposed by National Sanitation Foundation of America is a composite indicator value of quality of water.[5] WQI in India is rarely used, though it is extensively used in most of the countries with slight modification. Eliciting WQI of this region will strengthen the water resource management of this region. Henceforth, the study was undertaken with the objective of eliciting the WQI of drinking water sources and asses the physicochemical status of water.

METHODS

Type of study

A cross-sectional survey of drinking water was conducted followed by descriptive analysis of water quality index. Written informed consent was obtained from the study participants who had volunteered for the knowledge, attitude and practices (KAP) survey.

Study place

In order to select the industrial region of the district for the study, we constructed the water borne disease burden strata of the whole district. The five-year diarrhoeal disease incidence data of 49 Public Health Institutes (PHIs) of the district was procured for the year 2012-2016 from the Health Department. Thereafter, the standard stratification method was employed.[6]

By applying the approximation statistics to the constructed strata, four regions were categorized i.e., very low, low, high and very high disease burden region. PHI Nalagarh of the very high disease burden region, being in the most industry dominated region, was purposively selected for assessment of water quality.

Study period

Grab water samples were collected during monsoon, the rainy season (June, July and August) and post monsoon (September, October and November) seasons during the years 2017 and 2018 by following the standard procedures.[7]

Inclusion and exclusion criteria

Ten most commonly used water bodies/sources for drinking purpose were further selected purposively for the study (Figure 1). The five-year data pertaining to diarrhoea was not collected from the private health institutes of the district.

Statistical analysis

The data obtained from the physico-chemical and microbiological assessment was subjected to statistical analysis under the Factorial Randomized Block Design by following the procedure suggested by Gomez and Gomez (1984) for each year of the study.[8] For the sake of brevity the data of the years 2017 and 2018 was pooled and was statistically analyzed as per the procedure of individual years. The treatment means were compared by the means of critical difference (CD) at 5 per cent level of probability. The WQI data was also analyzed by using the Microsoft Excel 2007 software. The primary data collected from the KAP survey was analyzed in Statistical Package for the Social Sciences (SPSS) software version 21 and was expressed as averages and percentages.

Analytical procedures

The water temperature was measured *in-situ* with a mercury thermometer between 11 am and 12 pm. The samples were transported on the same day to the laboratory. Thereafter, these were analysed for pH, electrical conductivity (EC), total dissolved solids (TDS) and biological oxygen demand (BOD). These samples were also stored at 4°C in refrigerator for further analysis. pH was assessed by Microprocessor based pH meter (Model 510 of EIA make).

Microprocessor-based conductivity/TDS meter (Model 1601 of EIA make) was employed for determining EC (expressed in $\mu S/cm^-$) and TDS (mg/l). BOD (mg/l) was analyzed by BOD system Oxi-direct of Aqualytic make. Pharo300 spectroquant of Merk make was used for determining calcium, magnesium and nitrate (mg/l) photo-metrically. US standard method (EPA 325.1) was used for chloride content (mg/l) assessment. This method was also analogous to APHA-4500-Cl-E method. Inductively coupled plasma model 6300 duo of Thermo make was used for the analysis of trace elements (mg/l) such as cadmium (Cd), chromium (Cr), lead (Pb), zinc (Zn) and mercury (Hg). The chemical oxygen demand (COD) expressed in (mg/l) was assessed by the method analogous to EPA 410.4 US standard method 5220D and ISO 15705.

Water quality index calculation

Weighted arithmetic index method was used for the WQI analysis.[9]

The following formula was used for the quality rating or sub index (q_n) calculations:

$$qn = 100 \times \frac{[Vn - Viv]}{[Sn - Viv]}$$

The formulae illustrated that there were n water quality parameters and quality rating or sub index (q_n) corresponding to the nth parameter is a number which is reflecting the relative value of this parameter in polluted water with respect to its standard permissible value. The expressions used in this formula denote the following:

Where q_n=Quality rating for the nth water quality parameter, V_n=Estimated value of the nth parameter at a given sampling station, S_n = Standard permissible value of the nth parameter, V_{iv} = Ideal value of nth parameter in pure water (0 for all other parameters except the pH and dissolved oxygen which have ideal values of 7.0 and 14.6 mg/l respectively). Unit weight was calculated by a value inversely proportional to the recommended standard value S_n of the corresponding parameter.

$$W_n = K/S_n$$

Where W_n= unit weight for the nth parameter, K = constant for proportionality.

The overall water quality index was calculated by aggregating linearly the quality rating with the unit weight (Table 1).

$$WQI = \frac{\sum q_n W_n}{\sum W_n}$$

RESULTS

Out of the ten different types of drinking water sources majority were the bore-wells (4) followed by hand-pumps and unprotected springs (2 each) and single source each was of a river and a protected spring.

Table 1: 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

Table 2: Temporo-spatial variations in physical parameter of drinking water in Nalagarh.

Water source	pH		Temperature (°C)		EC (µS/cm)		TDS (mg/l)	
	M[a]	PM[b]	M	PM	M	PM	M	PM
S1	7.16	7.21	27.95	28.80	431.50	145.00	94.40	20.40
S2	6.86	7.41	30.40	29.30	417.50	156.00	173.40	86.00
S3	7.14	7.23	27.10	30.05	309.50	234.00	96.20	49.50
S4	6.26	7.60	33.40	29.45	301.50	249.50	78.16	44.55
S5	6.92	7.21	28.20	27.70	328.00	223.00	121.50	78.10
S6	7.12	7.11	29.40	29.05	350.50	149.50	111.00	64.15
S7	7.04	7.00	30.20	29.20	291.50	91.00	121.90	89.60
S8	7.12	6.91	24.10	28.70	272.50	157.50	55.90	39.85
S9	6.82	7.1	28.20	29.20	291.00	173.50	74.00	60.60
S10	6.96	6.81	32.40	30.20	245.00	145.00	119.00	17.05
Mean	6.94	7.16	29.13	29.16	322.85	172.40	104.54	54.98
P value	0.16		0.97		0.000		0.000	

[a] Monsoon, [b] Post monsoon

Physico-chemical properties

It was inferred from (Table 2) that the pH of the water was in the range of 6.26-7.60 (S4-river) whereas the temperature varied between 24.10°C (S8-spring unprotected) and 33.4 °C (S4-river). The pH was within the permissible limits as prescribed by BIS (Bureau of Indian Standards). The water temperature was also observed to be within the permissible limits prescribed by BIS. The EC and TDS (Table 2) showed significant variation with respect to the region of the source and the season of the year with the EC varying between 91.00 (S7-borewell) to 431.50 (S1-handpump). The EC showed a significant fall in post monsoon season. The mean water EC observed during monsoon was above the Indian Council of Medical Research (ICMR) prescribed limits of 300 µS/cm. The TDS values observed were well below the BIS prescribed limits of 500 mg/l. The TDS showed a significant fall in the post monsoon season. It ranged between 17.05 (S10-spring unprotected) and 173.40 (S2-borewell). Dissolved oxygen (Table 3) showed a significant fall during the post monsoon season. Although these were well above the BIS desirable limits of 5mg/l. The biological oxygen demand (BOD) ranged from 9.5 (S8) to 39.5 mg/l (S4) and this was above the permissible limits of 5 mg/l.

Table 3: Temporo-spatial variations in chemical parameter (mg/l) of drinking water in Nalagarh.

Water source	Dissolved oxygen		BOD		COD		Turbidity	
	M	PM	M	PM	M	PM	M	PM
S1	6.62	6.40	24.5	11.5	119	46	2.5	1.5
S2	7.15	6.42	22	13	71	39	2	2.5
S3	7.28	6.30	26.5	11	69.5	29	3	1.5
S4	7.17	7.07	39.5	17	41.5	23	3	2.5
S5	6.67	6.73	30.5	14.5	27	61	3	2
S6	7.17	6.56	27.5	14	135.5	44.5	2.5	1.5
S7	6.84	7.07	20.5	12	112.5	93	2.5	1.5
S8	7.56	6.39	22.5	9.5	59.5	34.5	4.5	1
S9	7.12	6.12	27	12	150	86	3	1.5
S10	7.62	6.37	38.5	14	124	89.5	1.5	1
Mean	7.12	6.54	27.9	12.85	90.95	54.55	2.75	1.65
P value	0.008		0.000		0.009		0.008	

Table 4: Temporo-spatial variations in chemical parameter (mg/l) of drinking water in Nalagarh.

Water source	Calcium		Magnesium		Nitrate		Chloride	
	M	PM	M	PM	M	PM	M	PM
S1	60.50	45.50	20.59	11.66	8.65	5.50	51.05	22.66
S2	84.50	72.00	18.40	12.11	8.55	8.00	29.96	13.71
S3	115.00	55.50	24.99	10.27	20.55	12.56	22.41	14.89
S4	38.00	18.00	16.71	9.56	10.81	6.10	79.56	44.65
S5	92.00	63.00	29.35	15.45	12.21	6.15	72.67	39.50
S6	100.50	57.00	17.61	11.72	5.11	4.10	59.50	39.15
S7	148.50	83.00	16.74	9.16	26.06	14.50	24.13	14.45
S8	129.50	93.00	27.56	14.44	25.56	14.55	22.70	13.73
S9	138.50	101.00	19.05	12.10	10.40	6.66	51.00	20.13
S10	132.50	99.00	21.20	12.51	13.21	6.65	62.00	29.65
Mean	103.95	68.70	21.22	11.90	14.11	8.47	47.50	25.25
P value	0.000		0.000		0.000		0.000	

Table 5: Temporo-spatial variations in chemical parameter (mg/l) of drinking water in Nalagarh.

Water source	Lead		Chromium		Cadmium		Zinc		Mercury	
	M	PM	M	PM	M	PM	M	PM	M	PM
S1	0.33	0.07	0.11	0.01	0.00	0.02	0.15	0.06	0.01	0.01
S2	0.29	0.125	0.03	0.02	0.00	0.02	1.43	0.06	0.01	0.08
S3	0.18	0.065	0.06	0.03	0.02	0.03	38.31	0.06	0.01	0.01
S4	0.625	0.225	0.06	0.03	0.02	0.04	1.95	0.11	0.01	0.05
S5	0.355	0.23	0.06	0.02	0.03	0.04	0.53	0.12	0.01	0.02
S6	0.295	0.21	0.04	0.02	0.04	0.00	1.16	0.70	0.01	0.02
S7	0.335	0.21	0.06	0.04	0.04	0.01	1.56	0.11	0.00	0.01
S8	0.365	0.175	0.12	0.01	0.02	0.00	4.36	0.12	0.01	0.01
S9	0.255	0.155	0.11	0.02	0.04	0.04	0.44	0.7	0.00	0.01
S10	0.3	0.165	0.09	0.01	0.02	0.25	1.37	1.16	0.01	0.01
Mean	0.33	0.16	0.08	0.02	0.03	0.05	5.13	0.32	0.01	0.03
P value	0.00		0.00		0.41		0.23		0.13	

Chemical oxygen demand (COD) was within the permissible limits as prescribed by BIS. The post monsoon season observed a significant fall in the mean value of COD. A significant fall in the amount of turbidity of the drinking water sources was also observed during the post monsoon season. The mean values recorded during monsoon season exceeded the BIS permissible limits of 1.66 mg/l i.e., 5 Nephelometric Turbidity Units (NTU). (Table 4) illustrated the values of calcium, magnesium, chloride and nitrate. However, the values observed were well within the prescribed limits of BIS. The Mg contents of the drinking water sources were detected well below the permissible limits of 100 mg/l. Nitrate levels detected were within the BIS permissible limits of 45 mg/l. The Cl contents were within the BIS permissible limits of 250 mg/l. Perusal of data in (Table 5) inferred the values of lead, chromium, cadmium, zinc and mercury. The contents of Pb detected were higher than the BIS permissible limits of 0.01 mg/l and more during monsoon season. The mean monsoon values of Cr detected was above the BIS permissible limits of 0.05 mg/l. The Cd values detected were above the BIS permissible limits (0.003 mg/l), probably due to effluent from automobile industry polluting water sources. Zn concentration was in the range of 0.06 mg/l (S1, S2 and S3 in post monsoon season) 38.31 mg/l (S3 in monsoon).

Table 6: Water quality index of drinking water sources of Nalagarh.

Water source	Monsoon	Post monsoon	Average
S1	57.55	44.00	50.77
S2	55.33	46.17	50.75
S3	216.35	111.33	163.84
S4	288.21	152.16	220.18
S5	54.12	56.30	55.21
S6	54.55	47.12	50.83
S7	176.07	112.80	144.44
S8	144.88	98.51	121.70
S9	83.49	118.00	100.74
S10	117.67	79.61	98.64
Mean	124.82±81.07	86.60±37.56	p=0.04

Total Zn concentrations observed were well within BIS limits. Mercury concentrations ranged from no traces of Hg observed in sources S7 and S9 in monsoon to 0.08 mg/l in the water source S2 in post monsoon and were more than the BIS permissible limits of 0.001 mg/l. (Table 6) demonstrated the water quality of the drinking water sources of Nalagarh. The average water quality of the handpumps S1 and S5 was of poor quality. The borewells S2 and S6 had the water of poor quality whereas the water of the borewells S3 and S7 was unsuitable for drinking purposes.

The protected spring S9 exhibited water of poor quality. Whereas, the unprotected spring S8 had water of poor quality and the S10 had the water which was unsuitable for drinking purpose. The water of the river was also not found suitable for drinking purposes. There was a significant temporal variation in the water quality with the water of monsoon season found unsuitable for drinking purposes and the water of drinking water sources being of poor quality during the post monsoon season **(**p value = 0.04). The rivers, springs (protected and unprotected) of the study area which were being explored by the native people for drinking water purposes contained water which was unsuitable for drinking purposes. Dumping of untreated sewage and industrial waste, garbage, plastic waste, e-waste, bio- medical waste, municipal solid waste and river bank erosion due to mining activities in the district are on a high and might have led to high grade of water pollution of these rivers. The spring which was of protected nature also had poor water quality (WQI>51). This indicated that the protection of these bodies is also not fool proof.

DISCUSSION

The regional variations of pH observed may be ascribed to different vegetation and soil characteristics across the region. The present study elicited higher pH during post monsoon season as compared to monsoon months. This may probably be due to dilution effect as has similarly been observed by Rana et al.[10] High EC may be attributed to the developmental activities like construction and improper disposal of garbage and sewage. Bouslah et al also reported in a study similar attributing factors of higher EC.[11] TDS values were found below the permissible limits. This may be attributed to the dissolution of industrial wastes and by-products into the water, also reported in a similar study by Kumar et al.[12] Dissolved oxygen was above the desired limits, similarly reported by Sangeeta and Neha.[13]

There was a significant increase in the mean values of BOD in the post monsoon season. This could be ascribed to urbanization and industrialization which could be adding organic materials in water, observations found in a similar study by Yamada et al.[14] Higher values of COD recorded during the monsoon season may be probably due to the dissolution of organic and inorganic matter into the water due to the runoff phenomenon, a feature more predominant in the rainy season Mahananda et al.[15] Borewells and the handpumps which were very less exposed to the rainfall water had comparatively lesser turbidity as compared to spring and river water which were always prone for runoff water, also reported in a similar study by Liao et al.[16]

The significantly high concentration of Ca during monsoon may be ascribed to the presence of large amounts of limestones in the region getting dissolved in the rain water during the monsoons. Sengupta also reported the effect of limestones on Ca concentration in water.[17] The present study also highlighted the significant higher levels of magnesium observed in the monsoon as compared to the post monsoon season, probably due to the types of rocks in these areas, similar to the findings of study by Mohamed et al.[18] The mean values of nitrates observed during the monsoon season were significantly higher than the post monsoon period, may probably be due to the mixing of untreated effluent released by the paper manufacturing and the pharmaceutical industry which dominated the region. Kashyap et al had also reported the effect of untreated effluents on higher values of nitrates.[19]

Significantly higher concentration of chloride concentrations observed in the study during monsoon season may be ascribed to unplanned housing, no sewage lines and domestic sewage removed by the run- off and due to the ice factories. Mathuram et al had also observed higher chloride levels due to housing activities.[20] Pb concentrations were higher than the permissible limits (more in the monsoon season) which may be ascribed to large number of cable manufacturing units and plastic stabilizer factories, similarly reported by Cobbina et al.[21] Significant higher concentration of Cr was observed during monsoon season, may be due to runoff mixed with automobile industry wastes, paints and dyes. Mercury concentrations were above the permissible limits in the present study and this may probably be due to mineral deposits getting leached into the ground strata and eventually finding its way into the water aquifer and the widespread mining activities being undertaken, also reported by Annan et al.[22] The present study also demonstrated that, in general, the water quality index of the various drinking water sources of the region deteriorated more in the monsoon season as compared to the post monsoon season. The hand pumps and the borewells having poor water quality were predominantly located in the industrial regions of Nalagarh. Open discharge of untreated effluents into the adjoining lands and dumps of garbage lying untreated on land surfaces was a common phenomenon in these regions. Further the loose strata of the region might have contaminated the groundwater being drawn by these hand pumps The corrosion of hand pump material (iron casing) was also observed which invite the growth of many pathogenic microorganisms in the corroded area (through bio-film transformations) which eventually leads to higher BOD. Similar observations have been documented in another study by Singh et al.[3] Central Ground Water survey in Nalagarh in 2013 had predicted the high level of pollutants entering the ground water in the region because of rapid industrialization leading to effluents polluting the water sources.[23] Fick et al had also similarly reported the high levels of contaminants in drinking water sources.[24]

Limitations

Limitation of study was that only one industrial region of the study area could be included for analysis due to monetary constraints.

CONCLUSION

The unsuitable drinking water quality of the sources in Nalagarh 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. Public health advisory has been given to the district administration for undertaking similar analysis of water quality at regular intervals, especially during the monsoon and post monsoon seasons.

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