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Quality Characterization of Surface Water Sources Using Water Quality Index in Urban Areas of Solan District of Himachal Pradesh

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Authors' contributions

This work was carried out in collaboration between both authors. Author JP performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author SKB designed the study and managed the analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

The studies of surface water quality of urban areas has become a major environmental challenge. In effect these aquatic ecosystems are increasingly under strong anthropogenic pressure. This fact causes the deteriorations of their quality and biodiversity. That seems the cases of the surface water of Solan District. Known the importance of these ecosystems in socio-economic activities of this district, it is important to lead studies for water qualities assessment. So, the surface water quality of urban areas of Solan District was assessed using the water quality index (WQI).To realize this objective, water samples were collected from five urban areas (Arki, Baddi, Nalagarh, Parwanoo, Solan) during the summer and winter seasons and were analyzed for major physicochemical parameters, viz. pH, EC, turbidity, TDS, BOD, COD, DO,As, Cr, Zn, Pb, Cd, to determine its suitability for drinking and domestic purposes. In surface water pH, EC, turbidity, TDS, BOD, COD, DO were found in the range of 6.74-7.55, 0.294-0.506 dS m^{-1},3.71-7.79 NTU, 105.51-253.26 mg l^{-1}, 1.51-3.14 mg l^{-1},101.79-166.88 mg l^{-1}, 4.16-6.58 mg l^{-1} consequently. Trace elements Pb, Cr, Zn, As, Cd, were found in the range of 0.04-0.28 mg l^{-1}, 0.034-0.063 mg l^{-1}, 0.22-0.46 mg l^{-1}, 0.004-0.020 mg l^{-1} and 0.002-0.008 mg l^{-1} respectively. All water quality parameters except Pb, Cr, Cd

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were within the permissible limits. Out of all urban areas WQI of Arki (33) and Solan (46) was categorized as good. Whereas WQI of Parwanoo, Baddi and Nalagarh was 69, 62, 57 respectively and was categorized as poor, indicating negative impacts o urbanization and industrialization. The study indicated that urbanization in the district has started impacting surface water sources, therefore bregular quality monitoring is required and for sustainable urbanization the implementation of stringent rules and guidelines are needed to enhance health and preserve them for future generations.

Keywords: Surface water quality; urbanization; industrialization; seasonal variation; water quality index.

1. INTRODUCTION

Water is a valuable natural resource and is the basic need without which life does not exist. Also, safe water is a precondition for health and development. However, increasing population, urbanization and modernization in developing countries has created a significant risk on water quality. Rivers due to their function to transport the domestic, industrial wastewater and run-off from cultivated lands in their huge drainage basins are amongst the most susceptible aquatic forms to pollution. The surface water quality of any area is mainly dependent on both the natural processes and anthropogenic influences viz. municipal, industrial and agrarian activities, consequently leading to a huge upsurge in the amount of effluents in the water bodies [1,2]. In the recent times, population explosion and increased human interventions have enforced a huge burden on the river ecosystems negatively affecting their natural productive capacity and ecosystem homeostasis. Surface water pollution rising from point as well as non-point sources is being noticed as a serious and emerging problem. Since, rivers act as a major resource for meeting municipal, industrial and irrigation requirements, therefore it is imperious to avert and regulate their contamination for sustainable management [3]. Rivers Municipal and industrial wastewater discharge constitutes a constant polluting source, whereas surface runoff is a seasonal phenomenon, largely influenced by climate within the basin [4]. Seasonal variations in precipitation, surface runoff, interflow, groundwater flow and pumped in and outflows have a strong effect on river discharge and, subsequently, on the concentration of pollutants in river water [5]. River water pollution is a major global concern and threat to aquatic ecosystems [6]. Though industrialization acted as engines of economic development, it deteriorates the air, water, soil resources and biodiversity [7]. Developing country like India experiences water pollution problems due to changing lifestyles, economic enhancement, urban sprawl and land use pattern [8]. In India, industrial effluents both untreated/partially treated wastewaters often get mixed with domestic sewage contaminated the surface water body affecting homeostasis of riverine ecosystem. Monitoring and conserving water sources is necessary for healthy living and an adequate supply of safe drinking water. One of simple methods that can recount the qualitative conditions of water is the use of WQI [9]. It indicates the quality of water in terms of an index number which represents the overall quality of water in relation to specific standards for specific uses [10]. The first WQI was proposed by Horton [11], and subsequently, there have been improvements to the original technique. Accordingly, numerous WQIs have been formulated and approved around the world [12], which vary in terms of statistical incorporation and translation of parameter values [13]. This index is very popular and considered comprehensive for the qualitative classification of surface water. With its implementation, it is likely to produce an appropriate view regarding water quality of rivers [11]. It is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers as it is an important parameter for the assessment and management of surface/ground waters [14]. Solan district of Himachal Pradesh, having a mountainous topography in the north western Himalayan region, is changing rapidly on account of the forces of urbanization and commercialization. Contamination of water by urban centers mainly occurs via outflow of domestic sewerage systems, which is not only constant and highly polluting, but also deteriorates human health and environment [15]. Thus monitoring and controlling surface waters are necessary and vital to assure the availability of high-quality water for its many uses [16]. Henceforth, the present research was conducted to evaluate the surface water quality of different urban areas of Solan district using WQI.

2. MATERIALS AND METHODS

2.1 Study Area

The Solan District is precisely located between North latitude of 30°44'53" to 31°22'01" and East longitude of 76°36'10" to 77°15'14" of Himachal Pradesh in India. The climate of this district is sub-tropical to sub-temperate type and experience four seasons during the year. The spring season commences from March to April and end in May, summer season falls from June to August, followed by autumn which falls from September to November and winter from December to February. In this region 70% of rains are received during monsoon months i.e. from June to September). The average annual rainfall in the district is about 1140 mm. In order to assess the surface water quality in Solan district five urban areas: Arki, Baddi, Parwanoo, Nalagarh and Solan. The location of these water bodies in this district is given in Fig. 1.

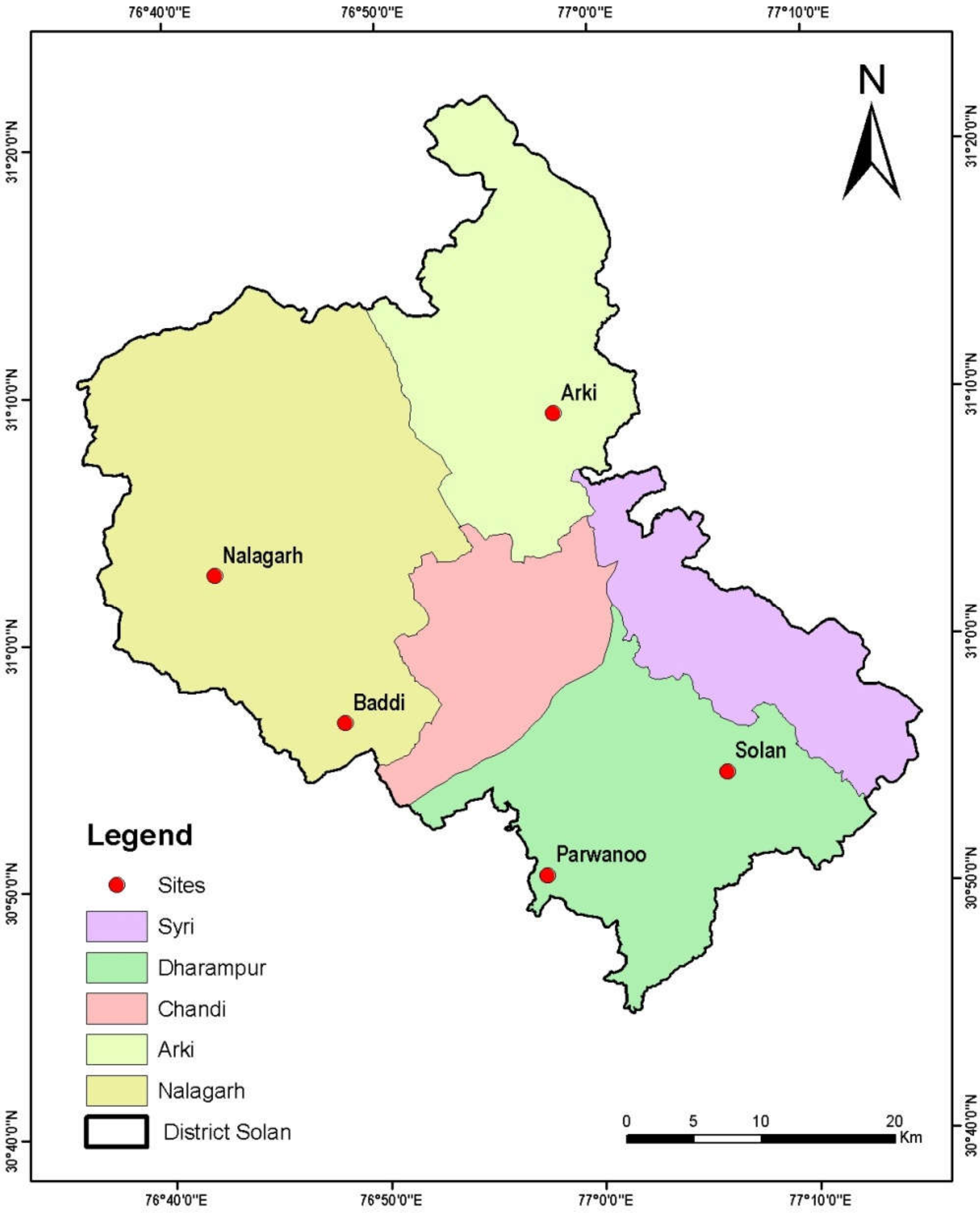

Fig. 1. Location of the five water surfaces studies in Solan district

2.2 Water Sampling and Analysis

This study has been conducted in the Department of Environmental Science, College of Forestry, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni Solan Himachal Pradesh during 2018 and 2019. In order to investigate the surface water quality samples were collected randomly in two different seasons i.e. summer and winter. There were ten treatment combinations (2x5) which were replicated thrice in randomized block design. Water samples were collected in acid washed one liter plastic bottles as per standard procedure recommended by APHA [17]. The surface water samples were collected from 10 to12 cm below the water surface.

After sampling, the samples were transported to the laboratory and refrigerated at 4°C for physicochemical analysis. The collected samples were adequately labeled, taken to laboratory and analyzed for pH, Electrical Conductivity (EC), Total Dissolved Solid (TDS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Turbidity immediately and the remaining samples were stored in refrigerator at 4°C for subsequent analysis. The standard analytical procedures as recommended by the APHA [17] were employed in the present study. The pH of the water samples was determined using microprocessor based pH meter (Model 1013 of EIA make). Electrical conductivity and total dissolved solids were determined by using microprocessor based conductivity/TDS meter (Model- 1601 of EIA make). Turbidity was measured using digital turbidity meter (Model-331 of EIA make). Biological oxygen demand (BOD) was determined by using BOD system Oxi-direct (Aqualytic make) and chemical oxygen demand (COD) with TR320 Spectroquant. Trace elements viz. the trace elements like As, Cd, Cr, Pb, Zn and Hg were determined by using Inductively Coupled Plasma model 6300 duo of Thermo make. The results were compared with BIS and WHO permissible limits (Table 1).

2.3 Water Quality Index Computation

The WQI of all water samples was assessed by applying the weighted arithmetic index method employed by Balan et al. [20]. In essence twelve important parameters were chosen for the WQI calculation. The calculations were done by employing the following formulae:

$$WQI= \Sigma QiW_i / \Sigma W_i$$

The quality rating scale (Q_i) for each parameter is calculated by using this expression:

$$Q_i=100[(V_i-V_0 / S_i-V_0)]$$

Where V_i is estimated concentration of i^{th} parameter in the analyzed water, V_0 is the ideal value of i^{th} parameter in pure water and V_0 is 0 (except pH =7.0 and Dissolved Oxygen = 14.6 mg l^{-1}) while S_i is recommended standard value of i^{th} parameter (Table 1).

The unit weight (W_i) for each water quality parameter is calculated by using the following formula:

$$W_i=K/S_i$$

Where K= proportionality constant and is calculated by using the following equation:

$$K= 1 / \Sigma[1/S_i]$$

The rating of water quality according to this WQI is given in Table 2.

Table 1. Permissible limit of water quality parameters for drinking and domestic purpose

S. no.	Parameters	BIS (2012) [18]	WHO (2011) [19]
1	Ph	6.5-8.5	8.2-8.8
2	EC (µS/cm)	-----------------	1.5
3	TDS (mg/l)	2000	500
4	Turbidity(NTU)	10	<1.5
5	BOD (mg/l)	5	-----------------
6	COD (mg/l)	250	-----------------
7	DO (mg/l)	6	-----------------
8	As (mg/l)	0.05	0.05
9	Cr (mg/l)	0.05	0.05
10	Cd (mg/l)	0.003	0.005
11	Pb (mg/l)	0.001	0.006
12	Zn (mg/l)	0.01	0.05

**BIS = Bureau of Indian Standards; ** WHO=World Health Organization*

Table 2. WQI values suitable for human consumption

WQI value	Rating of water quality
0-25	Excellent water quality
26-50	Good water quality
51-75	Poor water quality
76-100	Very poor water quality
>100	Unfit for human consumption

2.4 Statistical Analysis

The data derived from the experiment conducted was subjected to statistical analysis through Factorial Randomized Design (RBD) and the significance of each treatment was calculated [21].

3. RESULTS AND DISCUSSION

3.1 Quality Characterization of Surface Water

3.1.1 Physical parameters: TDS and turbididy

The different urban areas were found to display noteworthy variations in Turbidity and TDS of these surface water sources (Table 3). The surface water turbidity in different urban areas was within the permissible limit of as prescribed by BIS and followed the trend: Baddi followed Parwanoo, Nalagarh, Solan and Arki. The values of Baddi, Nalagarh and Parwanoo were found to be at par with each other. The seasons of the year also exerted significant influence on turbidity of surface water sources. Highest turbidity was noticed during the summer, whereas lowest during the winter season for all these surface water sources. The highest turbidity was noticed in Baddi in summer and lowest was observed in Arki in winter season. Higher values of turbidity in Parwanoo, Nalagarh and Baddi may be due to unscientific disposal of industrial effluents, domestic waste water, sewage and other waste materials directly into surface water sources. The lowest water turbidity in Arki may be attributed to, natural run off in hills which might have exerted dilution effect and further hastened the microbiological degradation of wastes as reported by Karthikeyani et al. [22] and Dwivedi and Pathak [23]. The results are in consonance with the findings of Joshi et al. [24] who had revealed that the turbidity is higher in summer due to maximum wind velocity, resulting in turbulence in water, favouring the resuspension of the bottom sediment due to stirring.

The surface water TDS in different urban areas was within the permissible limits as prescribed by BIS and WHO. The surface water sources of Parwanoo have registered significantly highest TDS followed by Baddi, Solan, Nalagarh and Arki. The highest values recorded in water sources of Parwanoo may be imputed to dissolution of industrial wastes and by products into the water. These wastes get generated out of the various anthropogenic activities like mining, ill planned construction of buildings and roads and unscientific sewage disposal into the water sources. The results are in congruence with the findings of Rajan and Samuel [25]. The seasons of the year also exerted significant influence on TDS of surface water sources. Highest TDS was noticed during the summer, whereas lowest was registered during the winter season. Highest TDS in summer may be ascribed to stagnation, concentration of salts due to increased evaporation and low level of water, as reported by Agrawal et al. [26] and Kumar et al. [27].

3.1.2 Chemical parameters: pH, EC, BOD, COD and DO

The different urban areas were found to display noteworthy variations in pH, EC, BOD, COD, DO of surface water sources (Table 4). The surface water pH was within the permissible limits as prescribed by BIS (Table 1). The surface water sources of Arki registered highest pH followed by Solan, Nalagarh, Parwanoo and Baddi. The values of Nalagarh, Parwanoo and Baddi were found to be at par with each other. The lowest pH in Baddi may be explained by the presence of industries thereby releasing more of CO_2 into water and thus decreasing the pH, as reported by Singh and Bhardwaj [28]. The seasons of the year also exerted significant influence on pH of surface water sources. The highest pH was observed during the summer, whereas lowest was recorded during the winter season. The results are in line with the findings of Sharma and Capoor [29] and Araoye [30] who had reported high pH in summer season due to decreased volume of water by evaporation and concentration of ions or due to high photosynthesis of micro and macro vegetation resulting in high production of free CO_2, shifting the equilibrium towards alkaline side.

Table 3. Seasonal physical characteristics of surface water in different urban areas of Solan district

Parameters	Turbidity (NTU)			TDS (mg l^{-1})		
Seasons Urban areas	Summer	Winter	Mean	Summer	Winter	Mean
Arki	2.63	4.80	3.71	129.05	81.97	105.51
Baddi	11.21	4.37	7.79	253.09	140.80	196.94
Nalagarh	8.26	5.28	6.77	138.45	113.79	126.12
Parwanoo	7.34	7.84	7.59	254.32	252.20	253.26
Solan	6.34	3.59	4.96	139.22	114.05	126.63
Mean	7.15	5.17		182.82	140.56	
$CD_{0.05}$						
Urban areas			0.46			0.37
Seasons			0.86			0.13
Urban areas x Seasons			1.22			0.52

The surface water EC in different urban areas which was within the permissible limit of as prescribed by WHO (Table 2). Significantly highest electrical conductivity was discerned in the surface water sources of Baddi followed by Nalagarh, Solan, Parwanoo and Arki. The water EC of Solan and Parwanoo was found to be statistically at par with each other. Highest EC in Baddi may be attributed to establishment of excessive industrial units and addition of their waste along-with untreated sewage leading to high amounts of dissolved inorganic substances in ionized form. Similar results were also observed by Kerketta et al. [31] and Bouslah et al. [32]. The seasons of the year also exerted significant influence on EC of surface water sources. Highest EC was noticed during the summer, whereas lowest during the winter season. Higher EC in summer season may be ascribed to less availability of water in the sources. The results are in comparability with the disclosures of Trivedi et al. [33] who had detailed that the relative higher temperature during summer might have induced increase in evaporation, as the water level lowers, the ions present become concentrated contributing to higher conductivity level.

The surface water BOD in different urban areas was within the permissible limit as prescribed by BIS (Table 2). Significantly highest BOD was discerned in the surface water sources of Baddi followed by Nalagarh, Parwanoo, Solan and Arki. The values of Arki and Solan were found to be statistically at par with each other. The highest BOD of surface water sources of Baddi may be due to urbanization and industrialization, which might result in discharge of municipal wastewater and industrial effluents in the water sources as reported by Liyanage and Yamada [34]. The seasons of the year also exerted significant influence on BOD of surface water sources. Highest BOD was noticed during the summer, whereas lowest during the winter season. The outcomes are in similarity with the discoveries of Das and Acharya [35] who have detailed that metabolic activities of various aerobic and anaerobic micro-organisms are accelerated at high temperature eventually depleting dissolved oxygen concentration.

The surface water COD in different urban areas was within the permissible limit as prescribed by BIS. The trend of surface water COD in different urban areas was: Baddi > Parwanoo > Nalagarh > Solan > Arki. Higher estimations of COD in Baddi may be imputed to the unscientific disposal of urban solid and sewage waste as well as industrial effluents as called attention to by Srivastava et al. [36] that disposal of organic and chemical waste is responsible for increase in water COD. The seasons of the year also exerted significant influence on COD of surface water sources. Highest COD was observed in summer, whereas lowest during the winter season. The results are in consonance with the findings of Shiddamallayya [37] and Gayatri et al. [38] who had reported highest COD in summer due to low water level and high decomposition rates

The surface water DO in different urban areas was above the permissible limits as prescribed by BIS. The surface water sources of Arki recorded highest DO followed by Solan, Parwanoo, Nalagarh and Baddi. The highest water DO levels of sources in Arki may be ascribed to minimal anthropogenic activities in terms of industrialization. The lowest surface water DO of Baddi may be due to increase in nutrients and organic materials from industrial wastewater, sewage discharges, and runoff from the land. Similar results were reported by Radwan et al. [39]. The seasons of the year also exerted significant influence on DO of surface water sources. Highest DO was noticed during the winter, whereas lowest in summer season. The results are in congruence with the findings of Abdelmongy et al. [40] and Varol and Sen [41] who outlined higher values of DO during winter because of low temperature and photosynthetic activities and lower estimations in summer due to high temperature and higher rate of oxidation of organic matter.

3.1.3 Trace elements: As, Cr, Zn, Pb, Cd

The different urban areas were found to exhibit significant variations in trace elements (Table 5).

The surface water As in different urban areas was within the permissible limit as prescribed by BIS and WHO. Significantly highest As was noticed in the surface water sources of Baddi followed by Parwanoo, Nalagarh, Solan and Arki. The highest concentration of As in Baddi may be due to release of industrial effluents and dumping of household waste in the urban areas. The seasons of the year also exerted significant influence on As of surface water sources. Highest As was noticed in the summer, whereas lowest of during the winter season. This may be due to intense evaporation in summer, enabling the crystallization of minerals as noticed by Levitt et al. [42]. The interaction between urban areas and seasons also exerted significant influence on surface water as. The highest As was noticed in Baddi in summer and lowest was observed in Arki in winter season.

The surface water Cr in different urban areas extended was above the permissible limit of 0.05 mg l^{-1} as prescribed by BIS and WHO. Notably highest Cr was noticed in the surface water sources of Parwanoo followed by Nalagarh, Baddi, Solan and Arki. The maximum concentration of Cr in Parwanoo may be attributed to runoff mixed with automobile industry wastes, paints and dyes being used in extensive building materials and steel works with Cr electroplating industries. The minimum concentration of Cr in Arki may be due to lower industries in the region. Use of pesticides and insecticides might have led to marginal amounts being detected in water as reported by Repula et al. [43] The seasons of the year also exerted significant influence on Cr of surface water sources. Highest Cr was observed in summer, whereas lowest of during the winter season. The results are in congruence with the findings of Basak and Alagha [44].

The surface water Zn in different urban areas was within permissible limits as prescribed by BIS and WHO. The surface water sources of Nalagarh reported highest Zn concentration followed by Parwanoo, Baddi, Solan and Arki. The highest concentration of Zn in Nalagarh may be ascribed to large number of alloys and steel galvanizing industries and tannery plants in the region as revealed by Hasan et al. [45] and Biswas and Hamada [46]. The seasons of the year also exerted significant influence on Zn of surface water sources. Highest Zn was noticed during the summer, whereas lowest in winter season. The Zn concentration was higher in summer due to less volume of water in surface sources as a result of less rains leading to its greater concentration. The results are in line with the findings of Dev et al. [47] and Rajmohan and Elango [48] who reported higher Zn concentration in summer due to less volume of water in surface sources because of less rains leading to its greater concentration.

The Pb content in surface water in different urban areas was above the permissible limit as prescribed by BIS and WHO. The surface water Pb in different urban areas followed the sequence: Parwanoo > Baddi > Solan > Nalagarh > Arki. The water Pb of Parwanoo and Baddi was found to be statistically at par with each other. The highest concentration of Pb at Baddi and Parwanoo may be attributed to large number of cable manufacturing units and plastic stabilizers factories in these areas. The results are in consonance with the findings of Michael and Johnson [49]. The seasons of the year also exerted significant influence on Pb of surface water sources. Highest Pb was detected during the summer, whereas lowest in winter season. The highest Pb content in summer may be ascribed to reduced water level associated with higher evaporation rate induced by the higher water temperature as reported by Ndeda and Manohar [50].

Table 4. Seasonal chemical characteristics of surface water in different urban areas of Solan district

Parameters	pH		EC (dS m^{-1})				BOD			COD			DO		
Seasons / Urban areas	Summer	Winter	Summer	Summer	Summer	Mean	Summer	Winter	Mean	Summer	Winter	Mean	Summer	Winter	Mean
Arki	7.81	7.49	1.48	1.48	1.48	0.294	1.48	1.54	1.51	109.86	93.72	101.79	5.64	7.52	6.58
Baddi	6.86	6.63	3.51	3.51	3.51	0.506	3.51	2.77	3.14	178.12	155.64	166.88	4.10	4.21	4.16
Nalagarh	7.15	6.77	3.31	3.31	3.31	0.438	3.31	2.29	2.80	142.71	124.53	133.62	3.01	5.42	4.22
Parwanoo	6.92	6.69	2.55	2.55	2.55	0.402	2.55	2.02	2.29	146.56	125.33	135.94	3.98	6.24	5.11
Solan	7.55	6.97	2.20	2.20	2.20	0.413	2.20	1.29	1.74	132.37	119.67	126.02	4.82	6.59	5.70
Mean	7.26	6.91	2.61	2.61	2.61		2.61	1.98		141.92	123.78		4.31	5.99	
CD $_{0.05}$															
Urban areas			0.20			0.016			0.33			0.92			0.39
Seasons			0.15			0.007			0.19			1.07			0.34
Urban areas x Seasons			0.29			0.023			0.46			1.30			0.55

Table 5. Seasonal variation in trace elements of surface water in different urban areas of Solan district

Parameters	Cr			Zn			Pb			Cd			As		
Seasons / Urban areas	Summer	Winter	Mean	Summer	Winter	Mean	Summer	Winter	Mean	Summer	Winter	Mean	Summer	Winter	Mean
Arki	0.036	0.032	0.034	0.35	0.26	0.31	0.06	0.02	0.04	0.002	0.002	0.002	0.006	0.002	0.004
Baddi	0.045	0.038	0.042	0.33	0.24	0.29	0.22	0.29	0.26	0.009	0.006	0.008	0.022	0.017	0.020
Nalagarh	0.046	0.040	0.043	0.53	0.40	0.46	0.22	0.12	0.17	0.008	0.005	0.007	0.013	0.010	0.012
Parwanoo	0.064	0.062	0.063	0.36	0.36	0.36	0.34	0.21	0.28	0.006	0.003	0.005	0.015	0.010	0.013
Solan	0.040	0.038	0.039	0.23	0.22	0.22	0.24	0.17	0.20	0.005	0.002	0.004	0.012	0.008	0.010
Mean	0.046	0.042		0.36	0.30		0.21	0.16		0.006	0.004		0.014	0.009	
CD $_{0.05}$															
Urban areas			0.002			0.063			0.032			0.002			
Seasons			0.000			0.069			0.009			0.001			
Urban areas x Seasons			0.003			0.089			0.046			NS			

Table 6. Seasonal WQI of surface water in different urban areas of Solan district

Seasons / Urban areas	Summer	Winter	Mean
Arki	37	28	33
Baddi	66	58	62
Nalagarh	64	50	57
Parwanoo	73	65	69
Solan	55	37	46
Mean	59	48	

The surface water Cd in different urban areas was above the permissible limit as prescribed by BIS and WHO. The trend of surface water Cd in different urban areas was: Baddi > Nalagarh > Parwanoo > Solan > Arki. The highest concentration of Cd in surface water sources of Baddi may be ascribed to the addition of wastes from different industries, Cd-stabilized plastics, or Ni-Cd batteries, or unprocessed effluents from sewage treatment plants as detailed by Singh et al. [51] and Yu et al. [52] The seasons of the year also exerted significant influence on Cd of surface water sources. Highest Cd was observed during the summer, whereas lowest in winter season. This may be due to accumulation of the metal concentration during low flow condition of the river. The results are in line with the findings of Reza and Singh [53].

3.2 Water Quality Index

The WQI values for surface water samples f each season are presented in Table 6. The mean values of WQI followed the order: Parwanoo > Baddi > Nalagarh > Solan > Arki. WQI was perceived to be maximum in summer season and minimum in winter months which indicates poor water quality in summer and good in winter for all these surface water sources. The surface water quality of Baddi, Nalagarh, Parwanoo was rated as poor and good in case of Solan and Arki. Highest WQI in Baddi may be ascribed to rampant discharge of industrial effluents, sewage disposal by the communities residing nearby and unprotected surface water source. Similar results were outlined by Yisa and Jimoh [54] and Shah and Joshi [55].

4. CONCLUSION

The study deduced that urbanization has begun impacting water quality. The surface water sources have started registering trace elements like Pb, Cr, Cd at undesirable level which makes it unsuitable for drinking and domestic purposes. Urbanization and industrialization in Baddi, Nalagarh and Parwanoo has prompted negative environmental impacts as indicated by poor surface water quality index. 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 surface water sources of the district. This may pose environmental risks and health hazards to the inhabitants of the region. Hence, the investigation revealed that the water sources needs some degree of treatment before usage and it is essential to protect them from the perils of contamination. Moreover, the regulatory standards for emission and discharges from different industries should be strictly followed and regular/proper implementation of clean technology and environmental measures by industries should be employed to achieve sustainable management of water resources.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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