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Studies on groundwater quality index around industrial areas of low hills in Himachal Pradesh

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Abstract

The present study emphasizes on groundwater quality assessment and working out the interrelationship between various physico-chemical parameters and potentially toxic elements in low-hills of Himachal Pradesh. The study was conducted in industrial areas of two districts and a total of 240 groundwater samples were collected during 2020-2022from borewells and handpumps and analyzed 21 parameters such as temperature, turbidity, TDS, EC, pH, DO, BOD, alkalinity, sulphate, nitrate, sodium, calcium, total hardness, chloride, magnesium, manganese, iron, zinc, copper, chromium, and lead. The study area was divided into five locations in both the districts and samples were taken during pre-monsoon and post-monsoon to check the seasonal variation. The estimated values were then compared with drinking water quality standards prescribed by BIS and location-wise WQI value was calculated. The results showed that in both the districts, the physico-chemical parameters under study were within the permissible limits. The WQI values range from 43.85 to 25.85 in district Sirmaur and 39.18 to 25.60 in district Una. In both the districts, the WQI lies under the good to excellent category and were suitable for human consumption. Location-wise, the highest WQI value was found to be highest around the industries followed by samples within the industry > along the main highway > residential areas, and the lowest value was found in the control which was the samples taken from the Department of Irrigation and Public Health supply. Seasonal-wise, the concentration of the physico-chemical parameters as well as the WQI was found to be higher during post-monsoon than pre-monsoon.

1. Introduction

Groundwater quality is one of the most important aspects of any water resource study [1]. The increasing evidence of groundwater contamination in recent years coupled with human health concerns and ecological effects of contaminants such as nitrate, and pesticides have heightened the pressure on public agencies to better groundwater quality [2]. Utilization of land varies from place to place due to rapid urbanization and industrialization, causing a lot of variation in the quality of the groundwater within a short distance, which constrains the developmental activities drastically everywhere [3]. Knowledge about the status of groundwater is as important as its quantity; it helps in determining the suitability of water for various purposes. The groundwater quality variation in any area is a function of physicochemical quality parameters which are greatly influenced by the geological formations and anthropogenic activities of the area [4]. The water quality index (WQI) is one of the most effective tools to assess the quality of water for concerned citizens and policy makers.

A water quality index is defined as a rating reflecting the composite influence of different water quality parameters. WQI is calculated from the point of view of the suitability of groundwater for human consumption [5].

Due to rapid industrialization and urbanization in districts Sirmaur and Una, it was important to study the impacts it could have on groundwater. According to [6], the stage of groundwater development in Kala Amb valley was 564.63% as on 2011 and fell under "*Over Exploited category"* and the net groundwater availability for future irrigation purposes was 0.00-hectare metre. Further, in Una district, due to extensive groundwater development for irrigation and the recently set up industrial units, the water levels were likely to show a depleting trend. As of March 2011, the stage of groundwater development in the Una valleys of the district was 108% and fell under "*Critical category"* of development [7]. A number of studies have been conducted to assess the quality of groundwater but the effect of industries on groundwater quality in low hills is rare, hence the present study was planned. The industrial area particularly lying in the low hills of district Sirmaur and district Una of Himachal Pradesh has been taken for the present study. Thus, it was the need of the hour to monitor the quality of groundwater in these areas. The objective of the present study is to assess the various physico-chemical parameters to obtain Water Quality Index and to find out interrelationships between the various parameters. These studies are the first attempts with respect to groundwater quality assessment in industrial areas lying in low hills of Himachal Pradesh.

2. Material and method

2.1. Study Area

The present study is conducted in industrial areas of districts Sirmaur and Una lying in the low hills of Himachal Pradesh, India. Kala-Amb industrial area in Sirmaur district and Mehatpur industrial areas in Una district have been selected for the current study as there has been a significant increase in the number of industries in the area since 1980 when a large number of industries were established due to tax incentives. A detailed map of the study area has been given in Figure1. The Sirmaur district is the southernmost district of Himachal Pradesh having a geographical area of 2825 $km^2$and lies between North latitude of 31°01'00" to30°22'00" and East longitude of 77°01'00" to 77°50'00". The climate of the Sirmaur district is sub-tropical to temperate depending upon the elevation. The Average annual rainfall in the district is about 1405 mm, out of which 90% occurs during the monsoon season. The mean maximum and minimum temperatures of 30°C and-0°C respectively experienced in the district.

Una district is situated in the southwestern part of the state of Himachal Pradesh. The district Una has a geographical area of 1540 $km^2$and covers 2.8% area of the total area of the State. It lies between 31°18'00" to 31°55'00" N latitude and 75°55'00" to 76°28'00" E longitude and has elevations ranging from 340m to 1041m above mean sea level. The climate of the Una district is

tropical to temperate in nature, as the terrain varies from plains to high hills. Temperature varies from a minimum of 4°C in winter to a maximum of 46°Cin summer. The area receives rainfall during the monsoon period, extending from June to September, and also during the non-monsoon period. The annual average rainfall

in the area is about 1040 mm, with about 55 average rainy days. The winter season starts in November and continues till the middle of March.

1.1. Sampling of groundwater and analysis

The present study was conducted in the Kala-Amb and Mehatpur industrial areas of District Sirmaur and Una respectively during the period 2020-2022. In these districts, five locations were randomly selected and replicated three times each. The groundwater samples were collected in two different seasons (pre-monsoon and post-monsoon) from handpumps and borewells thus making a total of 240 samples during the whole study period. In District Sirmaur, the depth of handpumps was 50-60 m and borewells were 90-120 m while in District Una, handpumps depth was 10-25 m and depth of borewells was 40-70 m. The collected samples were then analysed for various physico-chemical parameters such as temperature, turbidity, total dissolved solids, electrical conductivity, pH, dissolved oxygen, biological oxygen demand, alkalinity, sulphate, nitrate, sodium, calcium, total hardness, chloride, magnesium, manganese and potentially toxic elements such as iron, zinc, copper, chromium, and lead using standard procedures recommended by [8]. The WQI was calculated using the Weighted Arithmetic Water Quality Index Method where each of the parameters was assigned a weight (w_i) according to its relative importance in the overall quality of water for drinking purposes. The water quality index range has been presented in table 1.

Table 1: Water Quality Index range

Water Quality Index Level	Water Quality Status	Water Quality Grading	Possible uses
0-25	Excellent	A	Drinking, irrigation and industrial purpose
26-50	Good	B	Drinking, irrigation and industrial purpose
51-75	Poor	C	Irrigation and industrial purpose
79-100	Very poor	D	For irrigation purpose
>100	Unsuitable for drinking and fish culture	E	Proper treatment required for any kind of usage

1. The relative weight (W_i) was computed from the equation:

$$Wi = \frac{wi}{\sum wi}$$

2. A quality rating scale (q_i) was calculated by

$$qi = (Ci|Si) \times 100$$

where,

C_i is concentration of each parameter in the water sample

S_i is Indian drinking water standard for each parameter

3. Sub-index is then calculated as

$$SIi = Wi \times qi$$

where,

SI_i is sub index of i^{th} parameter

WQI is then calculated as

$$WQI = \sum SIi$$

Table 2: Details of sampling sites under study area

Locations	Code	Area of sample collection	Source	Latitude	Longitude	Elevation (m amsl)
District Sirmaur						
Around industry	S1	Steel industry	Borewell	30º30'39"N	77º13'08"E	353
		Engineering works	Borewell	30º30'35"N	77º12'57"E	351
		Thread factory	Borewell	30º30'26"N	77º13'05"E	359
Within industry	S2	Spinning and weaving industry	Borewell	30º31'31"N	77º12'10"E	352
		Steel industry	Borewell	30º31'13"N	77º12'04"E	353
		Rolling mill	Borewell	30º31'01"N	77º12'03"E	350
Along main highway	S3	Near Chamunda devi temple	Handpump	30º31'25"N	77º11'55"E	342
		Kala-Amb road	Handpump	30º30'32"N	77º12'20"E	339
		Rampur-Jatan road	Borewell	30º30'30"N	77º12'55"E	338
Residential Area	S4	Near School	Borewell	30º30'09"N	77º12"34"E	376
		Moginand	Handpump	30º31'08"N	77º13"43"E	380
		Near Ajgara Samay Mata Madir	Handpump	30º29'52"N	77º12'41"E	385
Control	S5	Johron	Borewell	30º31'05"N	77º12'32"E	346
		Near Kheda Mandir	Borewell	30º30'37"N	77º12'38"E	358
		Near Kheda Mandir	Handpump	30º30'39"N	77º12'40"E	351

District Una						
Around industry	U1	Swiss Park	Borewell	31º24’33”N	76º20’52”E	400
		Roller mills	Borewell	31º24’47”N	76º20’47”E	381
		Textile industry	Borewell	31º24’40”N	76º20’49”E	377
Within industry	U2	Lamination industry	Borewell	31º24’37”N	76º20’53”E	382
		Timber and plywood industry	Borewell	31º24’41”N	76º20’56”E	386
		Steel enterprise	Borewell	31º24’35”N	76º20’49”E	390
Along main highway	U3	Near Auto works	Borewell	31º24’28”N	76º20’33”E	398
		Near Brewery	Borewell	31º24’46”N	76º20’25”E	391
		Near Dental centre, Dehlan	Borewell	31º25’15”N	76º20’12”E	383
Residential Area	U4	Jakheda	Handpump	31º25’10”N	76º21’05”E	388
		Dehlan	Handpump	31º25’29”N	76º20’09”E	398
		Jalgra	Borewell	31º25’09”N	76º20’43”E	410
Control	U5	Near Gurudwara	Borewell	31º24’22”N	76º20’08”E	393
		Near Health Centre	Borewell	31º24’18”N	76º20’09”E	386
		Near Secondary School	Borewell	31º24’22”N	76º20’17”E	384

3.0. Results and discussion

The normal statistics of the groundwater quality parameters in study for districts Sirmaur and Una have been presented in Tables 4 and 5 respectively. All of the physico-chemical parameters in the study area were within the permissible limits given by BIS (Table 3). This indicated that even though a number of industrial as well as anthropogenic activities have been going on in the area, the level of water contamination was confined to surface or sub-surface level and has not yet penetrated to groundwater.

Table 3: Drinking water standards of quality parameters [9].

S No.	Parameters	Desirable	Permissible
1	Colour (Hazen units)	5	25
2	Odour	Essentially free	
3	Taste	Agreeable	
4	Turbidity	5	10
5	pH	6.5	8.5

6	Hardness, mg/l	300	600
7	Iron, mg/l	0.30	1.00
8	Chloride	250	1000
9	Residual chlorine	0.20	
10	Total dissolved solids, mg/l	500	2000
11	Calcium, mg/l	75	200
12	Magnesium, mg/l	30	100
13	Copper, mg/l	0.05	1.50
14	Sulphate, mg/l	200	400
15	Nitrate, mg/l	45	100
16	Fluoride, mg/l	1.00	1.50
17	Cadmium, mg/l	0.01	No relaxation
18	Lead, mg/l	0.05	No relaxation
19	Zinc, mg/l	5	15
20	Chromium, mg/l	0.05	No relaxation
21	Manganese, mg/l	0.10	0.30
22	Alkalinity, mg/l	200	600

3.1. Groundwater quality parameters in district Sirmaur

3.1.1. Physical parameters:

Table 4 revealed that the temperature in district Sirmaur ranged from 21.4ºC to 19.6ºC during pre-monsoon and 21.5ºC to 19.7ºC during post-monsoon and turbidity was very low with an arithmetic mean of 2.07 NTU and 2.2 NTU during pre-monsoon and post-monsoon respectively indicating that the groundwater was quite clear and there was the less suspended matter. The TDS ranged from 589 to 140mg l^{-1} during pre-monsoon and 506 to 139 mg l^{-1}during post-monsoon. The degree of groundwater quality can be classified as fresh if the TDS value is less than 1,000 mg l^{-1} brackish if TDS value lies between 1,000 mg l^{-1} and 10000 mg l^{-1}; saline if TDS value varied from 10,000 mg l^{-1} to 1,000,000 mg l^{-1} and brine if TDS is more than 1,000,000 mg l^{-1} [10]. Thus, the groundwater samples from the current study fall under the fresh category as all the TDS values are under 1,000 mg l^{-1}. The standard deviation of TDS was found to be 88.671 during pre-monsoon and 76.861 during the post-monsoon season which was found to be higher than the other parameters. This indicates that the values of the samples differ widely from the mean.

Table 4: Seasonal groundwater quality parameters in district Sirmaur

S No	Parameters	Pre-monsoon			Post-monsoon		
		Max	Min	Mean±SD	Max	Min	Mean±SD
1	Temperature (ºC)	21.4	19.6	20.4±0.402	21.5	19.7	20.5±0.558
2	Turbidity (NTU)	2.72	1.38	2.07±0.409	2.96	1.56	2.2±0.409
3	TDS(mg l^{-1})	589	140	426±88.671	506	139	360±76.861
4	EC (dS m^{-1})	0.78	0.336	0.522±0.138	0.824	0.345	0.463±0.142

5	pH	8.8	7.1	8.0±0.525	8.9	7.2	8.1±0.518
6	DO (mg l^{-1})	5.7	4.3	5.2±0.414	6.3	4.2	5.2±0.528
7	BOD (mg l^{-1})	3.6	1.45	3.1±0.700	3.8	2.5	3.0±0.309
8	Alkalinity (mg l^{-1})	116	82	98±9.647	146	80	90±16.739
9	Sulphate (mg l^{-1})	96	26	54±18.531	98	25	51±19.818
10	Nitrate (mg l^{-1})	9.8	3.5	5.8±1.958	6.2	3.6	5.1±1.897
11	Sodium (mg l^{-1})	61.2	21.3	39.4±11.791	50.1	27.3	37.6±10.324
12	Calcium (mg l^{-1})	74	15	38±15.318	59	31	37±8.052
13	Total Hardness (mg l^{-1})	188	44	85±40.432	118	45	60±30.780
14	Chloride(mg l^{-1})	78	26	52±14.517	72	20	48±15.773
15	Magnesium(mg l^{-1})	35.6	9.5	17.5±7.755	22.8	6.1	13.8±9.162
16	Manganese(mg l^{-1})	0.46	0.06	0.23±0.101	0.39	0.14	0.23±0.087
17	Iron(mg l^{-1})	0.23	0.10	0.16±0.042	0.22	0.10	0.12±0.039
18	Zinc(mg l^{-1})	0.116	0.017	0.078±0.044	0.089	0.026	0.064±0.038
19	Copper(mg l^{-1})	0.045	0.011	0.026±0.009	0.039	0.013	0.021±0.007
20	Chromium(mg l^{-1})	0.36	0.13	0.24±0.069	0.31	0.13	0.23±0.057
21	Lead(mg l^{-1})	0.015	0.001	0.006±0.004	0.014	0.002	0.005±0.003

3.1.2. **Chemical parameters:**

The pH indicates the strength of the water to react with any acidic or alkaline material present in the water and is controlled by carbon dioxide, carbonate and equilibrium of bicarbonate (Hem, 1985). The pH ranged from 8.8 to 7.1 during pre-monsoon and 8.9 to 7.2 during post-monsoon showing a slightly alkaline range of pH in district Sirmaur. The electric conductivity (EC) indicates the presence of dissolved solids as well as contaminants especially electrolytes [11]. In district Sirmaur, the mean concentration of EC was 0.522±0.138 dS m^{-1} during pre-monsoon and 0.463±0.142 dS m^{-1} during post-monsoon. Alkalinity was found in the range of 116 to 82 mg l^{-1} during pre-monsoon and 146 mg l^{-1} to 80 mg l^{-1} during post-monsoon. Alkaline water may decrease the solubility of metals and varies in accordance with fluctuations in the pollution load [12]. Sulphate concentration on average±SD was 54±18.531 mg l^{-1} during pre-monsoon and 51±19.818 mg l^{-1} during post-monsoon showing a very less seasonal variation. The mean value±SD of nitrate in the groundwater was observed between 5.8±1.958 mg l^{-1} during pre-monsoon and 5.1±1.897 mg l^{-1}during post-monsoon. Epidemiological evidence suggests that nitrate-nitrogen exposure in water is strongly associated with diseases like methemoglobinemia, gastric cancer, thyroid diseases, and diabetes [13]. It was an indication of good water quality as all the samples collected were within the desirable limit of 45 mg l^{-1}as given by BIS. Calcium and magnesium are directly related to the hardness of water and these ions may exist mainly as bicarbonates or in the form of sulphate and chloride to a lesser degree [14]. The concentration of calcium ranged between 74 mg l^{-1} to 15 mg l^{-1} during pre-monsoon and 59 mg l^{-1} to 31 mg l^{-1} during post-monsoon while magnesium concentration ranged from 35.6 mg l^{-1} to 9.5 mg l^{-1} during pre-monsoon and 22.8 mg $l^{-1}$to 6.1 mg l^{-1} during post-monsoon. Total hardness exhibited a fairly high standard deviation with concentrations in the range of 118 mg $l^{-1}$to 44 mg l^{-1}during pre-monsoon (SD = 40.432) and 118 mg $l^{-1}$to 45 mg l^{-1} during post-monsoon (SD = 30.780). Chloride

in groundwater may come from diverse sources such as weathering, leaching of sedimentary rocks and soil as well as domestic and municipal effluents [15]. The mean±SD concentration of chloride was 52±14.517 mg l^{-1}during pre-monsoon and 48±15.773 mg l^{-1}during post-monsoon. Seasonal variations showed that the concentrations of all the physico-chemical parameters in the study area were lower in the post-monsoon season than the pre-monsoon season. Yashoda *et al* [16] also found similar seasonal variations in physico-chemical characteristics of groundwater in industrial areas in Vishakhapatnam.

3.1.3. Potentially toxic elements:

The mean concentration of iron was found to be 0.16±0.042 mg l^{-1}during pre-monsoon and 0.12±0.039 mg l^{-1}during post-monsoon while that of zinc was 0.078±0.044 mg l^{-1}during pre-monsoon and 0.064±0.038 mg l^{-1}during post-monsoon. The concentration of copper was in the range of 0.045 mg $l^{-1}$to 0.011 mg l^{-1}during pre-monsoon and 0.039 mg $l^{-1}$to 0.013 mg l^{-1}during post-monsoon. Chromium showed a mean concentration of 0.24±0.069 mg $l^{-1}$and 0.23±0.057 mg l^{-1}during pre-monsoon and post-monsoon respectively. Lead concentration was in the range of 0.015 mg $l^{-1}$to 0.001 mg l^{-1}during pre-monsoon and 0.014 mg $l^{-1}$to 0.005 mg l^{-1}during post-monsoon. The concentration of toxic elements in the groundwater was within the permissible limits given by BIS.

3.2. Groundwater quality parameters in district Una

3.2.1. Physical parameters:

Table 5 showed the seasonal variation of various physico-chemical parameters in district Una. The temperature of the groundwater samples in district Una ranged from 21.3ºC to 19.6ºC during pre-monsoon and 21.7ºC to 19.4ºC during post-monsoon. Turbidity ranged from 2.98 to 1.04 NTU during pre-monsoon and 2.7 to 1.4 NTU during post-monsoon which also indicates a very less presence of suspended matter. TDS showed a wide range with a standard deviation of 72.318 during pre-monsoon and 62.114 during post-monsoon. The TDS values were also under 1,000mg l^{-1} in district Una thus, the samples can be classified as fresh according to [10].

Table 5: Seasonal groundwater quality parameters in district Una.

S No	Parameters	Pre-monsoon			Post-monsoon		
		Max	Min	Mean±SD	Max	Min	Mean±SD
1	Temperature (ºC)	21.3	19.6	20.4±0.513	21.7	19.4	20.0±0.666
2	Turbidity (NTU)	2.98	1.04	2.1±0.654	2.7	1.4	2.1±0.416
3	TDS (mg l^{-1})	528	291	408±72.318	528	309	392±62.114
4	EC (dS m^{-1})	0.772	0.345	0.526±0.135	0.714	0.339	0.466±0.100
5	pH	8.8	7.2	8.0±0.477	8	7.1	7.6±0.277
6	DO (mg l^{-1})	6.64	4.19	5.3±0.685	3.4	2.7	3.1±0.442
7	BOD (mg l^{-1})	4.2	2.7	3.1±0.359	2.80	1.04	1.8±0.219
8	Alkalinity (mg l^{-1})	111	81	96±8.026	103	82	92±8.951

9	Sulphate (mg l^{-1})	86	35	55±17.427	49	14	36±9.825
10	Nitrate (mg l^{-1})	7.4	4.3	5.3±0.879	2.8	1.1	1.7±0.435
11	Sodium (mg l^{-1})	61.2	21.3	40.6±10.307	46.3	33.8	38.9±3.341
12	Calcium (mg l^{-1})	68	33	44±8.740	47	22	35±7.930
13	Total Hardness (mg l^{-1})	161	42	96±33.448	94	39	65±18.712
14	Chloride (mg l^{-1})	59	25	41±10.723	59	22	39±11.464
15	Magnesium (mg l^{-1})	32.8	17.2	23.6±4.162	34.6	8.5	17.1±6.909
16	Manganese (mg l^{-1})	0.61	0.12	0.33±0.146	0.35	0.14	0.21±0.071
17	Iron (mg l^{-1})	0.31	0.09	0.17±0.056	0.29	0.08	0.14±0.052
18	Zinc (mg l^{-1})	0.096	0.033	0.070±0.017	0.088	0.023	0.055±0.018
19	Copper (mg l^{-1})	0.046	0.012	0.027±0.010	0.033	0.011	0.022±0.007
20	Chromium (mg l^{-1})	0.36	0.15	0.27±0.057	0.37	0.05	0.23±0.092
21	Lead (mg l^{-1})	0.015	0.002	0.007±0.004	0.014	0.001	0.006±0.003

3.2.2. Chemical parameters:

Similarly, the pH in district Una was slightly alkaline and its value ranged from 8.8 to 7.2 during pre-monsoon and 8 to 7.1 during post-monsoon. EC ranged from 0.722 dS m^{-1} to 0.345 dS m^{-1} during pre-monsoon and 0.714 dS m^{-1} to 0.339 dS m^{-1} during post-monsoon. Alkalinity ranged from 111 mg l^{-1} to 81 mg l^{-1} during pre-monsoon and 103 mg l^{-1} to 82 mg l^{-1} during post-monsoon which indicated that the concentrations were below the desirable limit prescribed by BIS. Sulphate showed a wide seasonal variation with an arithmetic mean of 55±17.427 mg l^{-1} during pre-monsoon and 36±9.825 mg l^{-1} during post-monsoon. Nitrate concentration ranged from 7.4 to 4.3 mg l^{-1} during pre-monsoon to 2.8 to 1.1mg l^{-1} during post-monsoon. Calcium concentration ranged between 68mg l^{-1} to 33mg l^{-1} during pre-monsoon and 47 mg $l^{-1}$to 22mg l^{-1} during post-monsoon and magnesium concentration was between 32.8 to17.2 during pre-monsoon and 34.6 mg $l^{-1}$to 8.5 mg l^{-1}during post-monsoon. The concentration of total hardness lies between 161 mg l^{-1} to 42 mg l^{-1} during pre-monsoon (SD = 33.448) and 94 mg l^{-1} to 39 mg l^{-1} during post-monsoon (SD = 18.712). The mean chloride concentration was 41±10.723 mg $l^{-1}$for pre-monsoon and 39±11.464 mg $l^{-1}$for the post-monsoon season.

3.2.3. Potentially toxic elements:

The concentration of iron varied from 0.31 mg l^{-1} to 0.09 mg l^{-1} during pre-monsoon and 0.29 mg l^{-1} to 0.08 mg l^{-1} during post-monsoon. The mean value of zinc was 0.070±0.017 mg l^{-1} during pre and 0.055±0.018 mg l^{-1} during post-monsoon while copper showed a mean value of 0.027±0.010 mg l^{-1}during pre-monsoon and 0.022±0.007 mg l^{-1} during post-monsoon. Chromium and lead also exhibited a concentration lower than the permissible limit prescribed by BIS.

Table 6: Seasonal variation in WQI of groundwater in low hills of Himachal Pradesh

Seasons / Locations	Pre-monsoon	Post-monsoon	Category	Suitability for drinking
District Sirmaur				
S1	43.85	40.76	Good	Suitable
S2	42.18	40.78	Good	Suitable
S3	39.02	38.27	Good	Suitable
S4	38.14	37.02	Good	Suitable
S5	26.91	25.85	Excellent	Suitable
District Una				
U1	39.18	38.47	Good	Suitable
U2	38.40	38.08	Good	Suitable
U3	37.97	37.75	Good	Suitable
U4	37.58	37.55	Good	Suitable
U5	26.89	25.60	Excellent	Suitable

3.0. Water Quality Index (WQI) of groundwater

Table 6 revealed that in district Sirmaur, the WQI ranged from 43.85 to 25.85 and comes under good and excellent categories. Similarly, in district Una, the groundwater WQI comes under good and excellent categories with values ranging from 39.18 to 25.60. Seasonal variations in both the districts showed that the WQI was found to be higher during the pre-monsoon season than the post-monsoon season. All the groundwater samples taken from different locations were suitable for drinking purposes. Location-wise, the highest WQI in both the districts was found in S1 (around the industries) followed by S2 (within the industries), S3 (along the main highway), S4 (residential areas) and the lowest value was found in the control which was the IPH (Irrigation and Public Health) supply. However, during the post-monsoon season in district Sirmaur, the highest WQI value was found in S2 which was within the industries followed by S1 which was around the industries.

4. Conclusions

The present study provides insights into the groundwater quality status around the industrial area in the low hills of Himachal Pradesh. The groundwater quality of these areas was assessed by considering important physico-chemical parameters. The concentrations of these parameters in comparison with the standard values of BIS are

well within the permissible limits. This indicated that pollution occurring from industrial activities as well as anthropogenic sources have not yet entered into great depths as the groundwater samples were collected from handpumps and borewells of more than 10 m in depth. WQI was computed using these parameters and it has been found that the WQI in both the districts comes under the good to excellent category and its value ranges from 43.85 to 25.85 in district Sirmaur and 39.18 to 25.60 in district Una. Seasonal variation indicated that the concentration of the parameters as well as WQI was higher during pre-monsoon as compared to post-monsoon. This may be attributed to the inflow of freshwater of good quality during the monsoon season

This study demonstrated that the groundwater quality in the study area in general was good and fit for human consumption. All the parameters were within permissible limits by BIS. However, with increasing industrial and human activities, continuous monitoring of groundwater is required to check any possible contamination and to know the quality status. It is recommended that safe disposal of waste should be practiced in order to prevent groundwater contamination in these areas.

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