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Geospatial mapping and drinking water quality status of fluoride endemic hilly District Doda (J&K), India

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Abstract
In the present study, an attempt has been made to investigate the drinking water quality status of various surface and ground water sources and the supplied water from two water filtration plants supplying drinking water to Doda town and its adjoining areas by using Arithmetic Water Quality Index (WQI) and geospatial mapping techniques. Doda is fluoride endemic district of Jammu and Kashmir State where groundwater fluoride concentration upto 7.0 mg/L is recorded. Water samples collected from about twenty two drinking water sources from two blocks of Doda district (Bhagwah and Doda blocks) were analyzed at pre-determined locations marked using handheld GPS(Montana 650). These locations formed the attribute database for the study based on which fluoride distribution maps have been derived and integrated with Arithmetic WQI through Inverse distance weighted (IDW) interpolation technique. Prepared thematic maps have confirmed the vulnerability of the drinking water sources and water supply systems in the study area, thus, posing a serious public health concern. Based on the WQI, water quality status of Beoli filtration plant (WQI=43.26) falls under the category of good water whereas that of Moochan filtration plant (WQI=157.41) has been classified as unfit for drinking. The geochemical evolution of the water studied using Piper's diagram has shown mixed type of hydrochemical facies. Coefficient of correlation(r) between different parameters has indicated significant correlation between several parameters. The study urges the concerned government authorities to make provisions for providing safe drinking water to public which is free of turbidity and low in fluoride concentration.

Keywords: Doda, fluoride, Ground water quality, Thematic map, Water quality index

INTRODUCTION

Accessibility to quality drinking water is a basic right of all the human beings and has been included as sixth goal among the seventeen sustainable development goals of United Nations (Sustainable Development Goals, 2016). Achieving this goal is very challenging as water is a universal solvent and due to increased pollution of water bodies, contains a range of contaminants that make it unsafe for drinking. Water pollution has become a major problem world over and regular monitoring of the drinking water sources is required for the welfare of the society. Several approaches have been introduced to assess the water chemistry and status of water quality. WQI is one of the most effective expressions which reflects a composite influence of contributing factors on the quality of water of any water system. It is widely used to rate the overall water quality as it can be represented as a meaningful single number and can easily determine the suitability of water for human consumption and other uses (Singh *et al.,* 2013a; Tiwari and Singh, 2014; Tiwari *et al.,* 2014; Rabeiy, 2017). WQI converts raw water quality information into comprehensible data which can be easily understood by general public and policy makers. Kannel *et al.* (2007) used WQI to evaluate spatial and seasonal changes in the water quality in the Bagmati river basin. Dhar and Slathia (2018) evaluated the drinking water quality of Lake Mansar, J&K by calculating arithmetic water quality index using thirteen water quality parameters. Naveen *et al.* (2018) investigated water quality index of Lake Vengaihnakere and Varthur and found unsuitability of water from both lakes for drinking purposes and suitability for irrigation and industrial purposes. The use of a WQI was initially proposed by Horton (1965) and numerous water quality indices have been formulated all over the world since then. A commonly-used WQI known as NSFWQI was developed for the US National Sanitation Foundation (NSF) by Brown *et al.* (1970) to provide a standardized method for comparing the water quality of various bodies of water. Other WQI methods include Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), British Columbia Water Quality Index (BCWQI) and Oregon Water Quality Index (OWQI). These indices are based on the comparison of the water quality parameters to regulatory standards and give a single value to the water quality of a source (Abbasi 2002, 2012; Debels *et al*. 2005; Kannel *et al.* 2007). Details on computation of WQI using relative weight and quality rating scale as has been used in the present study have been presented in the studies by Babiker *et al.* (2006), Boateng *et al.* (2016), Jhariya *et al.* (2017) and Dhar and Slathia(2018). Geographical Information System (GIS) based techniques are widely used for collecting diverse spatial data and for overlay analysis in spatial register domain to represent spatially variable phenomena (Bonham-Carter1996). GIS is defined as a technique to capture, store, retrieve, analyze and predict the information (Gajbhiye *et al.* 2016). In water related studies, geo-informatics technologies encompassing the modern tools of remote sensing (RS), GIS, and Global positioning system (GPS) help in finding out water potential areas, mapping water availability, its contamination and other details (Magesh *et al.*, 2012; Huchhe and Bandela, 2016; Rabeiy, 2018). Water quality maps indicate potential areas vulnerable to contaminants and are very helpful for evaluating potability of surface and groundwater as these can be visually interpreted easily by anyone (Chatterjee and Raziuddin, 2002; Rabeiy, 2018). GIS and water quality integration yields the comprehensive and reliable information quickly for decision makers to implement or adopt strategies related to water pollution and scarcity in time (Singh *et al.*, 2013b). Keeping in view the importance of WQI and geospatial mapping, the present study has been conducted to assess the suitability of water quality for drinking purposes by computing arithmetic WQI using thirteen water quality parameters from 22 sampling locations and to generate fluoride distribution and water quality Index maps for the Doda and Bhagwah areas of Doda District, J&K. GIS-based, simple, and robust fluoride distribution and WQI maps would be essential and easy tools for rapid transfer of information to water resource managers for water resource planning and to the public for meeting their water requirements from safe water sources in the area.

MATERIALS AND METHODS

Study area: District Doda, the present area of study, falls between 32^0 53' and 34^0 21' N and 75^0 14' and 76^0 47' E with altitudinal variation from 600m to 4700m (Fig. 1). Doda is a town and a notified area committee in Doda district in the Indian state of Jammu and Kashmir. The Doda Municipal Committee has population of 21,605 of which 12,506 are males while 9,099 are females as per report released by Census of India (2011). Doda Municipal Committee has total administration over 4,597 houses to which it provides basic amenities like water and sewerage. Public Health Engineering (PHE) department in Doda operates two filtration plants to supply clean drinking water to residents in the area. One is in Moochan area of the town which gets its supply from nearby Koti nullah and other comparatively newer one is Beoli filtration plant (Doda-Dessa gravity water supply) which gets it supply from remote Dessa nullah further north of Bhagwah area. Both of these filtration plants remain in news due to supply of contaminated filthy water causing diseases like Hepatitis, Jaundice, Diarrhea etc. (PHE…, 2016). Therefore, people prefer use of water from springs and handpumps for drinking and domestic purposes. Also, Doda district has been reported to be endemic to fluoride contamination and number of dental fluorosis cases have been reported from the area (Khandare, 2017). According to Gupta (2006), 90% population in Doda area and 100% population in Malwas area of district Doda (J&K) is suffering from dental fluorosis. The whole district has been declared as drought prone as it receives average rainfall of 926 mm per annum (Central Ground Water Board, 2014).

Methodology: Twenty two water samples comprising of eight surface (nullahs, streams), ten groundwater(springs, hand pumps etc.) and four samples from functional filtration units supplying water to the Doda town(two from inlets supplying raw water to the treatment unit and two supply water samples) were collected from two blocks of Doda District divided into three regions (Bhagwah, Malwas and Doda town) based on fluoride concentration (low, high and very high fluoride areas). The samples were analyzed for their physico-chemical properties during pre-monsoon and post-monsoon seasons during the year 2017. Water samples were collected in properly cleaned polypropylene bottles and the physico-chemical analysis of water samples was done using standard techniques (APHA, 2005). Air and water temperature were measured using mercury bulb thermometer (^{0}C); electrical conductivity, TDS, turbidity and pH with standardized Multi-parameter water analysis kit (Horiba U-52), free carbon dioxide, carbonate, bicarbonate, DO, chloride, calcium, magnesium by titration method; sodium and potassium by flame photometry and phosphate, silicate, sulphate and nitrate by double beam spectrophotometer. Determination of fluoride was done by SPADNS method and cross checked using IC (Model: Metrohm IC 850 D) in duplicates.

Water Quality Index (WQI): Water quality index is a numerical value that expresses overall water quality at a certain location and time based on several water quality parameters. Dhakad *et al.* (2008) suggested the application of water quality index in estimating the quality of ground water. Akkaraboyina and Raju (2012) transformed complex water quality data into simpler and useful form with water quality index. To determine the variations in drinking water quality of surface and ground water sources, arithmetic water quality index (WQI) was calculated using thirteen water quality parameters viz. pH, turbidity, TDS, total alkalinity, chloride, calcium, magnesium, total hardness, DO, fluoride, sodium, potassium and nitrate) using the formula as given by Brown *et al.* (1970).

$$WQI = \sum_{n=1}^{13}(qn.Wn) / \sum_{n=1}^{13}(Wn) \quad \text{………..Eq. 1}$$

Where, n=number of variables; W_n is the relative weight of the n^{th} parameter; q_n is the water quality rating of n^{th} parameter

Computed arithmetic water quality index values were categorized using water suitability classification:

Water Quality Index		Water Quality status
0-25	:	Excellent
26-50	:	Good
51-75	:	Poor
76-100	:	Very Poor
>100	:	Unsuitable for drinking

Source: Brown *et al.* 1972; Mishra & Patel, 2001

Geospatial analysis: GIS is a tool which helps us in representing cause and effect relationship visually besides it can be used to develop solutions for assessing water quality and managing water resources at regional scale (Collet, 1996). Out of the number of spatial modeling techniques available for spatial interpolation GIS, Inverse Distance Weighted (IDW) approach has been applied in the present study to represent and delineate water quality under different constituents. Piper plot was drawn with the help of AQUACHEM 2011.1 software.

RESULTS AND DISCUSSION

The Site ID, site name, location coordinates, and the water types (extracted using AQUACHEM software) of various surface and ground water samples are shown in the Table 1. The mean values of the water quality parameters studied at surface and groundwater Sites in District Doda (J&K) are tabulated in the Tables 2 and 3. Table 4 depicts results of water analysis of filtration plants and Table 5 depicts comparison of different water sources with national and international standards. Table 6 and 7 represents correlation matrix between different water quality parameters obtained for surface and ground water in the study area.

Air and water temperature: Atmospheric temperature near surface and ground water sources observed similar variation trend. However, groundwater showed thermostatic nature and observed narrow fluctuations (1.3^{0}C) at similar altitude with slight low temperature at high altitude (GW7-15^{0}C) as compared to surface water which observed wide fluctuations (8.33^{0}C) with well-marked altitudinal variations. Among various groundwater sources, water temperature of handpumps showed narrow variation as compared to springs. Mallam spring (GW7) was limnocrene in nature

Table 1. Site ID, site name, coordinates and the water types of surface and ground water samples of the study area in District Doda (J&K).

Source	Site ID	Site name	Latitude	Longitude	Water type
Surface Water	SW1	Malwas nullah (Downstream)	33° 9' 1.1988"	75° 30' 40.7982"	Ca-Mg-HCO3
	SW2	Mothli downstream	33° 8' 53.3004"	75° 31' 29.0994"	Ca-Mg-Na-HCO3
	SW3	Nagri nullah	33° 9' 9.1002"	75° 32' 51.5004"	Ca-Mg-HCO3
	SW4	Golibagh nullah	33° 9' 13.5"	75° 30' 44.499"	Ca-HCO3
	SW5	Malwas nullah (Upstream)	33° 9' 21.2004"	75° 30' 16.8006"	Ca-HCO3
	SW6	Koti nullah	33° 9' 33.1986"	75° 32' 36.3012"	Mg-Ca-HCO3
	SW7	Gadi nallah	33° 11' 47.2986"	75° 28' 47.8992"	Ca-Mg-HCO3-Cl
	SW8	Dessa nullah	33° 14' 19.8306"	75° 27' 52.7934"	HCO3
Ground water	GW1	Malwas Spring Village	33° 8' 51.9"	75° 30' 20.0988"	Ca-HCO3
	GW2	Near Malwas Spring	33° 8' 58.8978"	75° 30' 58.7016"	Ca-HCO3
	GW3	Nagri Spring	33° 9' 9.1002"	75° 32' 51.5004"	Ca-Mg-Na-HCO3
	GW4	Golibag Spring near LFS	33° 9' 15.0012"	75° 31' 2.1"	Ca-Na-HCO3
	GW5	Srikhand spring	33° 10' 40.7994"	75° 28' 31.7994"	Ca-Mg-Na-HCO3
	GW6	Nagni Spring	33° 10' 40.5978"	75° 28' 31.6986"	Ca-Na-HCO3
	GW7	Mallam Spring	33° 11' 0.8016"	75° 28' 25.3986"	Ca-Na-HCO3-NO3
	GW8	HP Stadium Doda	33° 8' 46.2006"	75° 32' 31.8978"	Ca-Na-HCO3
	GW9	Dangrota HP	33° 9' 4.8996"	75° 29' 49.3008"	Ca-Mg-HCO3
	GW10	Shaloth HP	33° 9' 56.9982"	75° 28' 33.3978"	Ca-Mg-HCO3
Supply Water	MI	Moochen Inlet	33° 9' 33.1986"	75° 32' 36.3012"	Mg-Ca-HCO3
	MS	Moochan Supply	33° 9' 33.1986"	75° 32' 36.3012"	Ca-HCO3
	BI	Beoli FP Inlet	33° 14' 19.8306"	75° 27' 52.7934"	HCO3
	BS	Beoli Supply	33° 9' 9.201"	75° 32' 24.2982"	HCO3

Table 2. Water quality of surface water sources of the study area in District Doda (J&K).

Parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	Mean
Elevation	**964m**	**1068m**	**1110m**	**1172m**	**1178m**	**1360m**	**1588m**	**1704m**	**1268m**
Air temp. °C	24	24	25.8	25	18.13	23.2	19	26.1	23.15
Water temp. °C	20.7	21.4	20.7	22.25	18.11	16.9	13.1	13.92	18.39
EC µS/cm	0.34	0.3	0.42	0.3	0.24	0.15	0.05	0.15	0.24
TDS ppm	224	192	245	195	156	960	30	96	262.25
Turb. NTU	0	0	0.3	2.3	12.9	52.3	12.3	5	10.64
Sal. Ppt	0.2	0.1	0.2	0.1	0.1	0.1	0	0.1	0.11
pH	8.45	7.87	8.11	8.77	8.72	7.98	7.63	7.27	8.10
FCO_2 mg/L	0	6.61	6.61	0	0	6.61	6.61	4.41	3.86
DO mg/L	6.83	7.41	5.27	4.88	6.44	6.83	5.85	3.32	5.85
CO_3^{2-} mg/L	11.58	0	0	15.44	11.58	0	0	0	4.83
HCO_3^- mg/L	196.2	145.2	121.6	160.9	137.3	109.9	51.03	380.7	162.85
Ca^{2+} mg/L	45.33	37.48	26.15	46.2	33.13	17.43	5.23	12.2	27.89
Mg^{+2} mg/L	11.09	10.04	7.4	6.34	7.92	15.85	3.17	6.34	8.52
TH	158.79	134.86	95.72	141.49	115.30	108.56	26.07	56.49	104.66
Na^+ mg/L	16.9	17.9	10.1	13.4	13.6	11.3	3.2	2.8	11.15
K^+ mg/L	5.2	8.4	6.4	8.5	8.2	4.3	2.5	2.9	5.80
$\mathbf{F^-}$ mg/L	3.82	3.51	2.81	5.09	2.27	0.12	0.1	BDL	2.22
Cl^- mg/L	19	9	13	9	11	6	8	5	10.00
NO_3^- mg/L	22.61	22.05	21.16	31.28	12.94	16.07	11.31	26.08	20.44
PO_4^{3-} mg/L	BDL	BDL	0.044	BDL	BDL	0.062	BDL	0.163	0.03
SO_4^{2-}mg/L	16.88	26.27	17.54	12.47	11.53	17.82	8.34	21.95	16.60
SiO_2 mg/L	14.83	17.55	16.83	18.1	15.72	17.99	7.72	11.27	15.00

whose temperature coincided with atmospheric temperature. However, other rheocrene springs were static in nature. Temperature showed more or less similar trends in the supply water.

Electrical conductivity (EC) and Total dissolved solids (TDS): Electrical conductivity is the capability of water to transmit electric current and depends on a variety of factors like valence, relative concentrations, presence of ions their total concentration and mobility (Ganesh *et al.* 2015). The electrical conductivity showed decreasing trend with increase in elevation in surface and groundwater sources (springs) with minor variations. Highest electrical conductivity (1.04 µS/cm) in GW8 (hand pump near Cricket Stadium Doda) was due to location of landfill site near this point. EC was low in BS (Beoli supply water) and MI (Moochan supply water) as compared to all other sources. EC showed significant correlation with various ions (potassium, calcium, magnesium and fluoride) in various surface and ground water sources. TDS is directly associated with the purity and quality of water and is roughly related to sum of the cations and anions concentration (Bansal and Dwivedi, 2018). TDS showed similar altitudinal fluctuation pattern as that of EC with decreasing trend in various water sources. Direct relation between EC and TDS is already on record (Wetzel, 2001). Most of the surface water samples are well within the WHO (2008) allowable drinking water limit for TDS (500 ppm) except MI sample (960 ppm) where TDS exceeded the limit. However, TDS in BS and MS was efficiently reduced to 48ppm and 98ppm, respectively. In case of groundwater samples only GW8 (668ppm) has higher TDS than the permissible limit. TDS was found to be strongly correlated (positive) with turbidity in ground water($r=0.99$, $p< 0.01$).

Turbidity: Turbidity ranged from 0 to 52.30 NTU in water samples. Among groundwater samples, turbidity was absent in all the samples except GW8 (4.3 NTU). Turbidity was high in both the filtration plants (BS - 7.10 NTU; MS - 45.60 NTU), above the desirable limits of drinking water quality (Bureau of Indian Standards, 1991).

Salinity: Salinity represents all the salts dissolved in water. It showed a mean value of 0.10 ppt in surface water to 0.16 ppt in springs and 0.33 ppt in hand pumps. Salinity showed positive correlation with EC($r=0.98$), TDS($r=0.98$), free carbon dioxide($r=0.80$), bicarbonate($r=0.96$), calcium ($r=0.97$), hardness($r=0.98$), sodium($r=0.98$), potassium($r=0.91$) and chloride($r=0.89$) in groundwater samples.

pH and free CO_2: pH of surface water (7.27-8.77) was higher as compared to ground water sources

Table 3. Water quality of groundwater sources of the study area in district Doda (J&K).

Site	**Springs**								**Handpumps**			
Parameter	**GW1**	**GW2**	**GW3**	**GW4**	**GW5**	**GW6**	**GW7**	**Mean**	**GW8**	**GW9**	**GW10**	Mean
Elevation	930	1013	1110	1208	1458	1501	1518	1248	1149	1180	1380	1236
Air temp.°C	24	24	25.6	28	27.4	22	18.5	24.21	24	18.2	27.2	23.13
Wat temp.°C	20.2	19.2	19.8	19	19.5	19.09	15	18.83	19.2	20.3	20.1	19.87
EC µS/cm	0.52	0.44	0.35	0.31	0.28	0.25	0.22	0.34	1.04	0.42	0.63	0.70
TDS ppm	335	286	257	199	184	163	144	224	668	274	405	449
Turb. NTU	0	0	0	0	0	0	0	0	0	0	4.3	1.43
Salinity ppt	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.16	0.5	0.2	0.3	0.33
pH	7.16	6.76	7.1	8.23	7.01	7.14	6.57	7.14	7.57	7.49	7.57	7.54
FCO_2 mg/L	15.42	13.2	19	13.22	15.4	6.61	17.62	14.35	46.26	22.0	15.4	27.89
DO mg/L	5.85	3.32	3.9	6.24	6.05	6.05	4.88	5.18	0.98	2.15	0.1	1.08
CO_3^{2-} mg/L	0	0	0	4.5	0	0	0	0	0	0	0	0
HCO_3^- mg/L	259.0	235	180	184.4	145	125.6	125.6	179.23	431.7	243	290	321.6
Ca^{2+} mg/L	88.92	65.3	43	43.59	31.3	33.13	27.9	47.59	126.4	54.0	71.4	83.93
Mg^{+2} mg/L	4.23	9.51	13	6.87	12.1	6.34	4.75	8.11	7.92	13.7	17.4	13.01
TH mg/L	239.64	202.24	160.8	137.14	127.8	108.82	89.23	152.25	348.47	191.2	249.8	263.5
Na^+ mg/L	27.4	21.2	21	20	19.6	16.2	15.9	20.19	60	20.7	24.3	35
K^+ mg/L	10	11.9	8.4	6.9	9.4	8.5	7.1	8.89	26	11.9	16.2	18.03
F^- mg/L	3.47	3.7	2.6	7.4	0.98	0.26	0.2	2.66	3.39	0.36	BDL	1.88
Cl^- mg/L	17	11	18	10	13	13	13	13.57	33	16	16	21.67
NO_3^- mg/L	34.69	10.7	4.32	52.31	25.1	21.88	43.19	27.46	76.19	BDL	1.02	38.61
PO_4^{3-} mg/L	BDL	BDL	BDL	BDL	0.01	0.008	0.299	0.11	0.003	BDL	BDL	0.00
SO_4^{2-}mg/l	37.54	17.3	21	9.28	16.1	16.32	15.94	19.07	19.51	18.9	21.3	19.90
SiO_2 mg/l	15.11	16.3	13	12.39	17.0	12.61	20.94	15.34	19.6	10.6	12.0	14.07

Table 4. Water quality of supply water/ filtration plants of the study area in district Doda (J&K).

Parameters	MI	MS	BI	BS	Mean
Air temp.°C	23.2	25.2	26.1	26.3	25.20
Wat temp°C	16.9	13.31	13.92	15.4	14.88
EC µS/cm	0.15	0.15	0.15	0.07	0.13
TDS ppm	960	98	96	48	300.5
Turb. NTU	52.3	45.6	5	7.1	27.5
Sal. ppt	0.1	0.1	0.1	0	0.075
pH	7.98	7.5	7.27	7.6	7.59
FCO_2 mg/L	6.61	4.41	4.41	4.41	4.96
DO mg/L	6.83	7.41	3.32	5.27	5.71
CO_3^{2-} mg/L	0	0	0	0	0
HCO_3^- mg/L	109.9	314.0	380.7	451.4	314
Ca^{2+} mg/L	17.43	17.43	12.2	8.72	13.95
Mg^{2+} mg/L	15.85	7.4	6.34	7.4	9.25
TH mg/L	69.57	34.78	29.13	32.61	41.52
Na^+ mg/L	11.3	10.8	2.8	2.4	6.83
K^+ mg/L	4.3	6.4	2.9	2.3	3.98
F^- mg/L	0.12	0.22	BDL	BDL	0.17
Cl^- mg/L	6	5	5	3	4.75
$NO3^-$ mg/L	16.07	15.34	26.08	26.81	21.08
PO_4^{3-} mg/L	0.062	BDL	0.163	BDL	0.11
SO_4^{2-}mg/L	17.82	12.56	21.95	10.69	15.76
SiO_2 mg/L	17.99	14.11	11.27	6.17	12.39

(6.57-8.23) and showed less variation as compared to groundwater. SW4 (Golibagh nullah) with pH 8.77 exceeded the desirable limits for drinking water quality. Mean free carbon dioxide values were observed to be higher in handpumps (27.89 mg/L) followed by springs (14.35 mg/L) and surface water (3.86 mg/L). Free CO_2 is of ecological importance as it influences the pH of water and significant negative correlation of pH with free CO_2 in surface water (r= -0.75; $p<0.05$) indicated their inverse relationship which is already on record (Wetzel, 2001). pH was observed to be near neutral whereas free carbon dioxide was 4.96 mg/L in both the filtration plants.

Dissolved oxygen (DO): The amount of dissolved oxygen of surface water samples in study area ranged between 3.32 to 7.41 mg/L whereas in groundwater it ranged between 0.1 to 6.05 mg/L. DO was observed to be very low for handpumps (0.1-2.15mg/L) among groundwater sources. DO showed strong negative correlation with potassium(r=-0.77), bicarbonate(r=-0.74), total hardness(r=-0.71) in groundwater. DO was sufficiently high in MS (7.41mg/L) and BS (5.27mg/L).

Carbonate (CO_3^{2-}) and Bicarbonate (HCO_3^-): Total alkalinity signifies ability of the water to neutralize acids. Hydroxide, carbonate and bicarbonate are the constituents of alkalinity in natural systems. Microbial decomposition of organic matter contributes to CO_3^{2-} and HCO_3^- (Wotchoko *et*

Table 5. Comparison of mean of physico-chemical parameters of drinking water sources with various national and International standards.

Parameters	Ground water					WHO (2008)		BIS (1991)	
	Surface	Springs	Hand-pumps	MS	BS	Desirable limits	Permisible limit	Desirable limits	Permisible limit
Air temp°C p.	23.15	24.21	23.13	25.2	26.3	-	-	-	-
Wat temp°C	18.39	18.83	19.87	13.31	15.4	-	-	-	-
EC µS/cm	0.24	0.34	0.70	0.15	0.07	-	1500*	-	3000
TDS ppt	262.25	224.00	449.00	98	48	600	1000	500	2000
Turb. NTU	10.64	0.00	1.43	45.6	7.1	5	10	5	10
Sal. Ppt	0.11	0.16	0.33	0.1	0	-	-	-	-
pH	8.10	7.14	7.54	7.5	7.6	6.5-8.5	No relaxation	6.5- 85	No relaxation
FCO_2 mg/L	3.86	14.35	27.89	4.41	4.41	-	-	-	-
DO mg/L	5.85	5.18	1.04	7.41	5.27	-	5 to 7**	-	-
CO_3^{2-} mg/L	4.83	0.00	0.00	0	0	-	-	-	-
HCO_3- mg/L	162.85	179.23	321.57	314.03	451.42	300*	600*	300	600
Ca^{2+} mg/L	27.89	47.59	83.93	17.43	8.72	100	300	75	200
Mg^{2+} mg/L	8.52	8.11	13.01	7.4	7.4	30*	150*	30	100
TH mg/l	42.01	45.75	74.57	34.78	32.61	100	500	300	600
Na^+ mg/L	11.15	20.19	35.00	10.8	2.4	50	200	-	-
K^+ mg/L	5.80	8.89	18.03	6.4	2.3	10*	12*	-	-
F^- mg/L	2.22	2.66	1.88	0.22	BDL	1	1.5	1	1.5
Cl^- mg/L	10.00	13.57	21.67	5	3	250	600	250	1000
NO_3^- mg/L	20.44	27.46	38.61	15.34	26.81	50	-	45	100
PO_4^{3-} mg/L	0.03	0.11	0.00	BDL	BDL	-	0.1	-	-
SO_4^{2-}mg/L	16.60	19.07	19.90	12.56	10.69	250	400	200	400
SiO_4^- mg/L	15.00	15.34	14.07	14.11	6.17	-	-	-	-

WHO* (1997)

Table 6. Coefficient of correlation (r) matrix of physico-chemical parameters of surface water samples of the study area in district Doda (J&K).

	AT	WT	EC	TDS	Turb.	Sal.	pH	FCO_2	DO	CO_3^{2-}	HCO_3^-	Ca^{2+}	Mg^{2+}	TH	Na^+	K^+	F^-	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	SiO_2
AT	1																					
WT	0.38	1																				
EC	0.49	0.88**	1																			
TDS	0.13	0.05	-0.08	1																		
Turb.	-0.25	-0.37	-0.51	0.87**	1																	
Sal.	0.57	0.63	0.86**	0.14	-0.29	1																
pH	-0.20	0.70	0.54	0.05	-0.10	0.35	1															
FCO_2	0.13	-0.37	-0.28	0.26	0.30	-0.26	-0.75*	1														
DO	-0.41	0.36	0.15	0.36	0.26	0.07	0.34	0.06	1													
CO_3^{2-}	-0.14	0.51	0.34	-0.20	-0.27	0.22	0.87**	-0.96**	0.05	1												
HCO_3^-	0.55	-0.16	0.01	-0.22	-0.28	0.24	-0.34	-0.23	-0.65	0.01	1											
Ca^{2+}	0.23	0.91**	0.76*	-0.08	-0.42	0.56	0.79*	-0.67	0.34	0.75*	0.00	1										
Mg^{2+}	0.19	0.29	0.18	0.87**	0.62	0.40	0.15	0.07	0.56	-0.06	-0.05	0.24	1									
TH	0.26	0.88**	0.71	0.24	-0.14	0.62	0.73*	-0.55	0.49	0.62	-0.02	0.94**	0.56	1								
Na^+	0.07	0.86**	0.67	0.20	-0.14	0.50	0.68	-0.39	0.71*	0.48	-0.23	0.88**	0.54	0.94**	1							
K^+	0.03	0.84**	0.67	-0.08	-0.32	0.30	0.74*	-0.42	0.34	0.54	-0.20	0.81*	0.11	0.73*	0.78*	1						
F^-	0.27	0.93**	0.79*	-0.24	-0.58	0.49	0.74*	-0.56	0.22	0.69	-0.10	0.94**	0.00	0.81*	0.76*	0.81*	1					
Cl^-	0.01	0.55	0.67	-0.21	-0.45	0.70*	0.55	-0.48	0.38	0.48	-0.16	0.62	0.10	0.57	0.56	0.27	0.59	1				
NO_3^-	0.83*	0.52	0.48	-0.15	-0.46	0.40	0.13	-0.32	-0.47	0.33	0.58	0.52	-0.04	0.43	0.20	0.30	0.57	0.04	1			
PO_4^{3-}	0.49	-0.51	-0.27	0.13	0.17	0.04	-0.67	0.29	-0.70	-0.48	0.77*	-0.53	0.03	-0.44	-0.61	-0.54	-0.59	-0.52	0.25	1		
SO_4^{2-}	0.65	0.25	0.31	0.17	-0.12	0.36	-0.41	0.35	0.06	-0.43	0.50	0.14	0.44	0.27	0.28	0.12	0.06	-0.11	0.40	0.42	1	
SiO_2	0.36	0.82*	0.67	0.52	0.14	0.54	0.59	-0.19	0.36	0.31	-0.12	0.69	0.64	0.81*	0.77*	0.76*	0.60	0.18	0.38	-0.23	0.36	1

*Significant at 0.05 level; **Significant at 0.01 level; AT=Air temperature WT= Water temperature

Table 7. Coefficient of correlation (r) matrix of physico-chemical parameters of studied groundwater samples of the study area in district Doda (J&K).

	AT	WT	EC	TDS	Turb.	Sal.	pH	FCO_2	DO	CO_3^{2-}	HCO_3^-	Ca^{2+}	Mg^{2+}	TH	Na^+	K^+	F^-	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	SiO_2
AT	1																					
WT	0.44	1																				
EC	0.15	0.33	1																			
TDS	0.15	0.34	0.99**	1																		
Turb.	0.34	0.22	0.26	0.26	1																	
Sal.	0.08	0.35	0.98**	0.98**	0.25	1																
pH	0.44	0.46	0.32	0.31	0.23	0.22	1															
FCO_2	-0.10	0.02	0.83**	0.84**	-0.10	0.80**	0.20	1														
DO	0.07	-0.24	-0.72*	-0.72*	-0.60	-0.70*	-0.17	-0.58	1													
CO_3^{2-}	0.42	-0.03	-0.20	-0.21	-0.11	-0.30	0.72*	-0.17	0.36	1												
HCO_3^-	0.12	0.39	0.98**	0.98**	0.26	0.96**	0.37	0.80**	-0.74**	-0.14	1											
Ca^{2+}	0.11	0.36	0.96**	0.95**	0.15	0.97**	0.28	0.74**	-0.58	-0.17	0.96**	1										
Mg^{2+}	0.28	0.51	0.14	0.16	0.63*	0.11	0.18	0.03	-0.63*	-0.22	0.17	-0.04	1									
TH	0.17	0.47	0.97**	0.97**	0.29	0.98**	0.31	0.74**	-0.71*	-0.22	0.99**	0.97**	0.19	1								
Na^+	0.11	0.19	0.94**	0.94**	-0.01	0.91**	0.29	0.92**	-0.52	-0.13	0.90**	0.90**	-0.07	0.87**	1							
K^+	0.07	0.26	0.96**	0.96**	0.28	0.91**	0.24	0.84**	-0.77**	-0.29	0.93**	0.87**	0.22	0.90**	0.92**	1						
F^-	0.49	0.15	0.14	0.14	-0.33	0.09	0.53	0.10	0.27	0.77**	0.20	0.26	-0.37	0.17	0.23	-0.03	1					
Cl^-	-0.04	0.17	0.88**	0.89**	0.01	0.89**	0.17	0.93**	-0.56	-0.32	0.82**	0.81**	0.03	0.80**	0.94**	0.87**	-0.01	1				
NO_3^-	0.07	-0.38	0.40	0.38	-0.37	0.33	0.25	0.56	0.17	0.36	0.34	0.42	-0.67*	0.26	0.63*	0.36	0.48	0.48	1			
PO_4^{3-}	-0.54	-0.95**	-0.33	-0.34	-0.12	-0.31	-0.52	-0.03	0.16	-0.12	-0.38	-0.36	-0.40	-0.44	-0.24	-0.28	-0.32	-0.16	0.23	1		
SO_4^{2-}	-0.07	0.36	0.31	0.32	0.10	0.48	-0.22	0.08	-0.07	-0.49	0.33	0.48	-0.12	0.45	0.21	0.15	-0.12	0.29	-0.11	-0.17	1	
SiO_2	-0.18	-0.68*	0.22	0.21	-0.30	0.20	-0.52	0.44	0.06	-0.26	0.13	0.21	-0.49	0.09	0.39	0.26	-0.02	0.33	0.63	0.62	0.01	1

*Significant at 0.05 level; **Significant at 0.01 level; AT=Air temperature WT= Water temperature

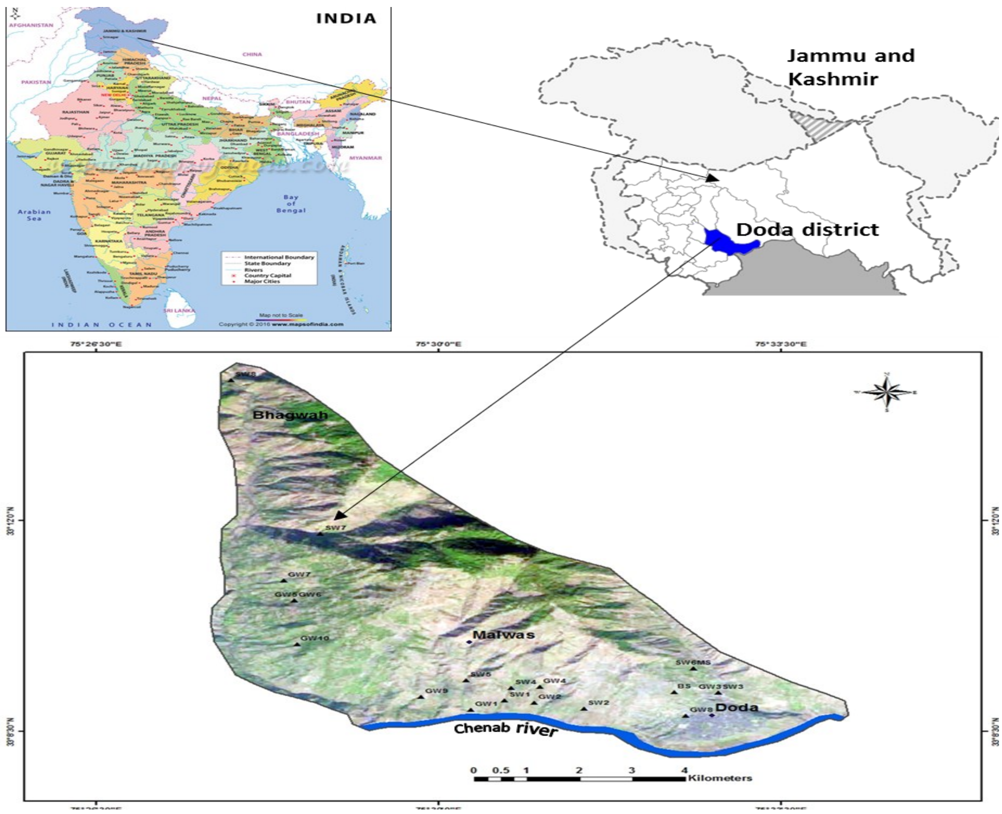

Fig. 1. *Satellite imagery showing the study areas and the study sites in Doda district (J&K).*

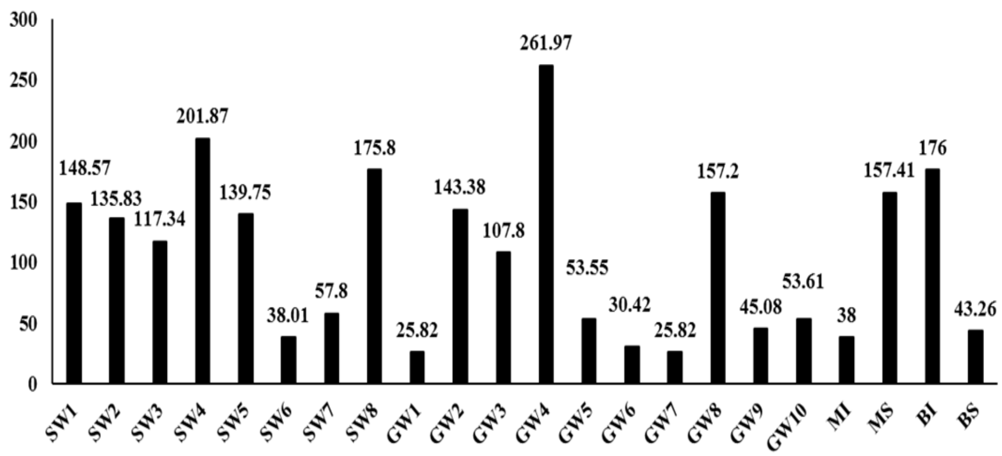

Fig. 2. *WQI of surface, ground and supply water sources of the study area in district Doda (J&K).*

al., 2016). The present value of bicarbonate in both ground as well as surface water is within the permissible limit of bicarbonate in drinking water given by WHO (2008). Carbonate was absent from most of the samples in surface and groundwater sample. Carbonate showed strong positive correlation with pH(r=0.87) and strong negative correlation with free carbon dioxide(r=-0.96) in surface water samples which is already on record (Nag and Gupta, 2014). In the supply water, carbonate was absent whereas bicarbonate was higher than desirable limit but not more than the permissible limit given by WHO (2008) for drinking water quality. Higher HCO_3^- promotes mineral dissolution from rocks (Stumm and Morgan, 1996).

Cations

Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Total Hardness (TH): Calcium and magnesium content in groundwater was observed more in handpumps as compared to springs, among groundwater

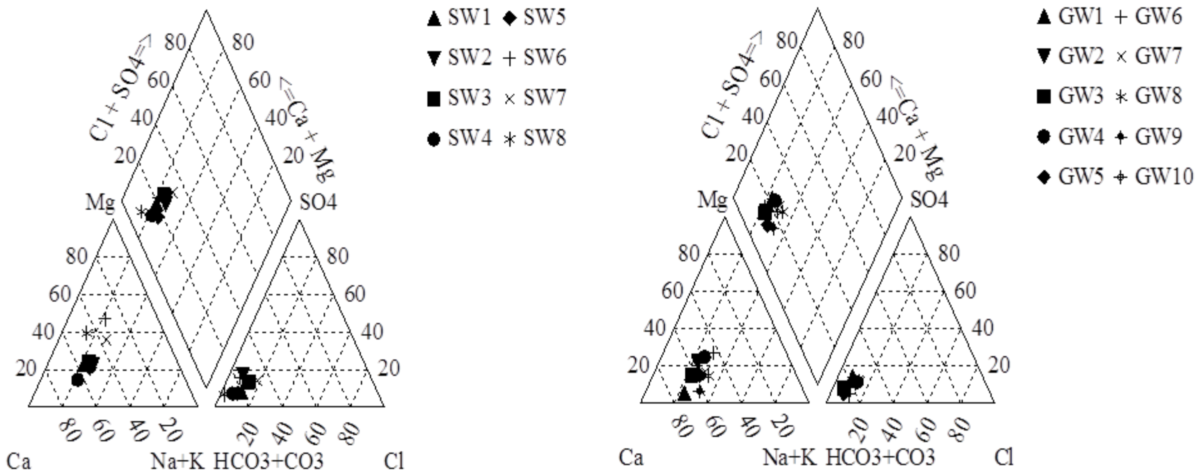

Fig 3(a-b). *Piper diagram showing the chemical character of surface and groundwater in the study area.*

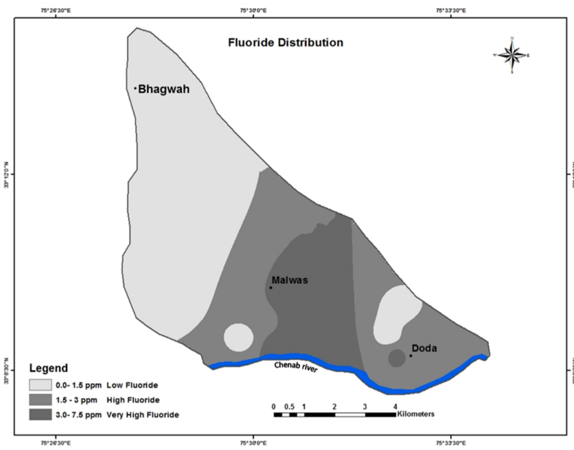

Fig 4. *Showing low, high and very high fluoride areas in the study area in district Doda (J&K).*

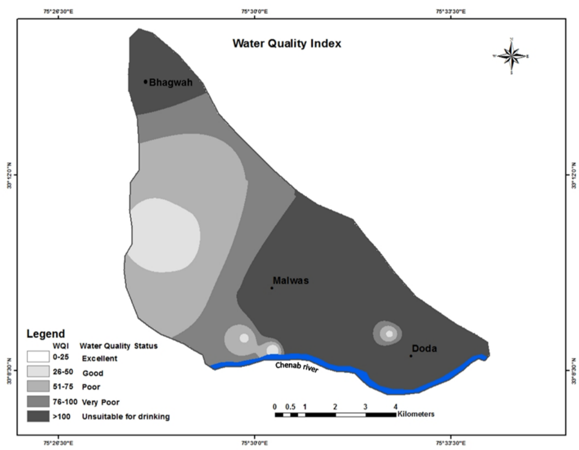

Fig 5. *Showing Water Quality Index(WQI) map of the study area in district Doda (J&K).*

sources. For surface water sources, calcium was observed to be low in SW7 (5.23 mg/L) whereas SW4 had maximum calcium content (46.2 mg/L). Total hardness is one of the important factors of water quality. Dissolved calcium and magnesium salts are the main contributors of hardness in natural waters (Kumar and Nath, 2013). Hardness was observed to be higher in handpumps (191.17 to 348.47 mg/L) as compared to springs (89.23 to 239.64 mg/L). In surface water sources, hardness was observed maximum in SW5 (158.79mg/L) with all the parameters within optimum range. The maximum allowable limit of TH for drinking purpose is 500 mg/L and the desirable limit is 100 mg/L as per the WHO (2008) international standards. Hence all the samples were within the permissible limit for drinking water. Hardness was observed to be acceptable for drinking in MS and BS samples also. Hardness was found positively correlated with pH(r=0.73), calcium(r=0.94), sodium(r=0.94), potassium(r=0.73), fluoride(r=0.81) and silicate(r=0.81) in surface water samples, and with EC(r=0.97), TDS(r=0.97), bicarbonate (r=0.99), calcium(r=0.97), sodium(r=0.87), potassium(r=0.90) and chloride(r=0.80) in groundwater samples.

Sodium (Na^+) and Potassium (K^+): Sodium and potassium occur naturally as well as from human sources. The concentration of sodium in the studied groundwater varied from 20.19 mg/L (springs) to 35mg/L (handpumps) whereas it varied between 2.8 to 17.19 mg/L in surface waters. Sodium in supply water ranged from 2.40 mg/L (BS) to 10.80 mg/L (MS). The sodium content has been found to be well within WHO (2008) permissible limit (50 mg/L) at all the studied locations. The potassium content ranged from 2.30 to 26 mg/L in all water sources with handpumps showing highest mean values (18.03 mg/L) followed by springs (8.89 mg/L), surface sources (5.80 mg/L) and supplies (BS- 2.30mg/L to MS- 6.40 mg/L).

Anions

Fluoride (F^-): Fluoride is a potent ground water pollutant as it affects people drinking such contaminated water significantly (Choubisa, 2011). In groundwater, leaching of fluoride minerals (fluorite, apatite and mica) from rocks is the main contributor of fluoride (Singh and Maheshwari, 2001). Fluoride concentration in the study area varied from BDL to 5.09 mg/L in surface water samples whereas it ranged from BDL to 7.4 mg/L in groundwater. Among different groundwater sources, springs (0.2-7.4 mg/L) showed higher fluoride concentration than handpumps (BDL-3.39 mg/L). Fluoride in surface waters can be attributed to springs which feed water to these streams. WHO (1984) has set 1.5 mg/L as the upper limit of fluoride concentration in drinking water and water having higher concentration is unfit for drinking. Over exposure to fluoride can cause a number of health affects varying from mild dental fluorosis to debilitating skeletal fluorosis, depending upon exposure (Khandare, 2013). Fluoride showed significant correlation with water temperature, EC, pH, calcium, hardness, sodium and potassium in surface water (Table 6). In ground water, it was positively correlated with carbonate. Fluoride in supply water was well under the permissible limit set by WHO (2008).

Chloride (Cl^-): Water quality assessment is incomplete without chloride determination. Amount of chloride varies in different waters and its concentration is high due to human activities (Bansal and Dwivedi, 2018). The chloride content in the groundwater ranged from 13.57 mg/L to 21.67 mg/L in springs and handpumps, respectively. Comparison of water samples from filtration plants revealed that both the supplies had low chloride values. In surface water sources, chloride values varied from 5 mg/L (SW8) to 19 mg/L (SW1). Chloride level in present study is within the permissible limit of WHO, 2008 (250 ppm). Chloride showed a strong positive correlation with Na (r=0.94), K(r=0.87), total hardness(r=0.80), bicarbonate(r=0.82), TDS(r=0.89), Ca(r=0.81) and EC (r=0.88) in groundwater. No significant correlation was observed in surface waters. Highest chloride values were observed in GW8(21.67mg/L) but it was also well below the desirable limit for drinking water. High chloride content and municipal contamination around this site relates with work of Huchhe and Bandela (2016) who contributed high chlorides in groundwater to dissolution of rocks and soils having natural salt formations or due to sewage contamination while studying water quality of Dr. Babashaeb Ambedkar Marathwada University, Aurangabad.

Nitrate (NO_3^-): Nitrate ion in groundwater occurs naturally and can be contributed by anthropogenic activities like industrial and municipal waste, septic system drainage and fertilizers (Reda, 2015). The amount of nitrate recorded in the water of study area ranged from 11.31 to 26.08 mg/L in surface water and BDL to 76.19 mg/L in ground water. The highest amount of nitrate was observed in GW4 (52.31 mg/L) and GW8 (76.19 mg/L) which is more than the maximum permissible limit of 45 mg/L as has been set by WHO (2008) and BIS (1991) for drinking water supplies. It can be attributed to municipal contamination and septic tanks in the vicinity of the study area as this area is thickly populated area besides there is a landfill site nearby. Brindha *et al.* (2012) also attributed high nitrate concentration in groundwater to leaching from indiscriminate dumping of animal waste. Nitrate showed strong negative correlation with magnesium (r=-0.67) in groundwater. Nitrates were well within permissible limits prescribed by WHO (2008) both in MS (15.34 mg/L) and BS (26.81mg/L) water supply samples.

Phosphate (PO_4^{3-}): Phosphates cause excessive growth of algae and affect water quality. Many aquatic plants absorb and store phosphorous many times than their actual immediate need as a result phosphates are found in low quantities in natural waters (Wotchoko *et al*., 2016). Phosphate was absent in supply water and majority of the other water sources in the study area were well below the permissible limit for drinking water but few values have exceeded the limit (WHO, 1993) like SW8 (0.163 mg/L) and GW7(0.299 mg/L). It may be related with agricultural activities in Bhagwah area of Doda district as has been attributed by Fadiran *et al.* (2008).

Sulphate (SO_4^{2-}): Sulphate, an important constituent of hardness with calcium and magnesium is a naturally occurring anion in all natural waters. Sulphate in the supply water was observed to be 12.56 mg/L in MS and 10.69 mg/L in BS supply water. Overall sulphate content ranged between 8.34 to 26.27 mg/L (surface water) and 9.28 to 37.54 mg/L (groundwater). Among different groundwater sources sulphate concentration was more or less similar.

Silicate (SiO_2): Silicate in the surface water ranged from 7.72 to 18.10 mg/L. In the groundwater silicates ranged from 14.07 mg/L in handpumps to 15.34 mg/L in springs. In supply water, silicate varied from 6.17 to 14.11 mg/L in BS and MS supply water. In surface waters, silicate showed strong significant positive correlation with water temperature(r=-0.68).

Water Quality Index (WQI|): Figure 2 represents water quality index of water samples from the study area. WQI index observations revealed that eleven water sources (including MS) fall under the category of unsuitable for drinking with GW4 (261.97) showing highest values followed by SW4 (201.87) and SW8(175.8). The findings reveal that fluoride contamination and high turbidity are the main contributory factors to deteriorating water quality and hence high WQI. WQI of supply water from Moochan filtration plant (157.41) showed water deterioration as compared to its source

SW6 (38.01). This may be due to high agitation resulting in turbidity from already settled material in the sedimentation tank which is not removed periodically.

Hydrochemical facies: Figure 3 (a and b) represent the hydrochemical facies of water sources evaluated by plotting the major cations and anions such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO^{3-},CO_3^{2}-, SO_4^{2-} and Cl^{-} on Piper's trilinear diagram (Piper, 1944,1953). On the diamond-shaped Piper diagram, the plot shows the total dominance of alkaline earth metals(Ca^{2+}, Mg^{2+}) over the alkalies (Na^{+}, K^{+}) and dominance of weak acid(HCO^{3-},CO_3^{2-}) over strong acids(SO_4^{2-}, Cl^{-}). Evaluation of the chemistry of the water samples revealed that these belonged to mixed type of hydrochemical facies (Table 1).

Geospatial analysis: The spatial distribution map of Fluoride and WQI are have been prepared and presented in the Figures 4 and 5. From the spatial maps, it can be easily visualized that Bhagwah area is having least fluoride concentration and can be classified as low fluoride area, whereas Doda town showed high fluoride and Malwas showed very high fluoride concentration. The area in between Doda and Malwas has shown some very high fluoride areas. In Doda town area, low fluoride points depict supply waters having sources piped from Dessa and Koti nullah from Bhagwah block which are having low fluoride concentration. WQI maps of the study area also followed the similar trend as that of Bhagwah area having better water quality compared to Malwas and Doda town. However, unsuitability of water for drinking based on WQI in some areas of Bhagwah block may be attributed to high nitrate concentration in this area.

Comparison of water quality of two filtration plants: Comparison of water quality of Moochan and Beoli filteration units has shown that water from both the filtration plant had high turbidity content and the treatment processes were unable to remove it before supplying water to the town. According to WHO (2012) disinfectants are rendered useless in presence of high turbidity. Bicarbonate also showed similar trends with high values in both the supply waters. All other parameters were within limits of drinking water quality. The supply of clean drinking water by PHE in the area with respect to fluoride is highly appreciated as other water sources in the area are highly contaminated with fluoride.

Conclusion

The results of the present analysis revealed that some of the parameters like fluoride(SW1, SW2, SW3, SW4, SW5, GW1, GW2, GW3, GW4), bicarbonate(SW8,GW8) and nitrate(GW4,GW8) in some of the surface and ground water sources were above the drinking water limits as prescribed by WHO and BIS, whereas in supply water, most of the parameters except turbidity (MI,MS,BI,BS) were within the desirable limits. WQI also indicated that water supplied from Beoli filtration plant (having source from Bhagwah area/Dessa nullah) has better quality than that of Moochan filtration plant (as observed with WQI) and most of the other sources in the study area. It was also noticed that people in this area avoid using supply water from Moochan filtration plant for drinking purposes due to high turbidity content and instead rely on springs due to general notion of their purity and medicinal properties. The spatial distribution maps of fluoride and WQI have illustrated that water sources in Malwas and Doda town fall under unfit for drinking category but Bhagwah area has good quality water. The spatial distribution maps have depicted the fluoride distribution and WQI variations in various surface and groundwater sources of the area. Based on the present findings, the study recommends that the government should increase the capacity of supply water and look into the proper functioning of these water filtration plants besides educating people about the ill effects of drinking fluoride rich water. The prepared spatial distribution maps and present findings can be utilized in preparing drinking water management plan in the area.

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