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Evaluating the source and Quality of River and Groundwater using hydrochemistry and stable isotopes in Tawi Watershed, Jammu District, Jammu and Kashmir, India

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Abstract

Hydrogeochemical and isotopic composition of river and groundwater in Kandi and Sirowal belts of Jammu District in the Union Territory of Jammu and Kashmir was carried out to understand the recharge source and chemical nature of these waters for drinking water quality criteria. Physical parameters (temperature, pH, Total dissolved solids, total hardness and electrical conductivity), major cations and anions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-) and stable isotopes ($\delta^{18}O$ and $\delta^{2}H$) inTawi river and groundwater samples from hand pumps and tube wells were measured. The dominant cation is Ca^{2+} and the dominant anion HCO_3^- implying$CaHCO_3$type water in both river and groundwater. To assess the quality of water for drinking purposes, Groundwater Quality Index (GWQI) has been calculated. The GWQI indicates that Kandi and Sirowal belts are showing "Excellent" to "Good" category for drinking purposes. The stable isotopic composition of river water and groundwater is indicative of meteoric origin and enrichment before groundwater recharge. The stable isotopes in water suggest that the active canals in Sirowal belt,and rainfall and river water near the banks in Kandi belt contribute to ground water recharge.

Keywords: Kandi, Sirowal, Tawi river, Isotope hydrology, Hydrogeochemical.

Introduction

Groundwater is an important natural resource which is recharged by direct infiltration of precipitation and surface water or by subsurface flow. These surface water bodies such as streams, rivers, springs etc. are connected to groundwater in most types of landscapes, being integral part of groundwater flow systems (Romanelli et al., 2011). During the last four decades, environmental isotope techniques have been commonly and largely used in the overall domain of water resource development and management (Fritz and Fontes, 1980). Oxygen and hydrogen isotopic ratios in water have been used to determine the origin and recharge of local ground waters (Burgman et al., 1979; Weyer et al., 1979). These ratios are usually reported relative to an international standard reference such as Standard Mean Ocean Water (SMOW) (Craig, 1961). In the Indian context, there are numerous studies dealing with isotope application in groundwater as summarized by Gupta and Deshpande (2005) and Deshpande et al. (2012). Studies using hydrochemistry and stable isotopes have to understand the interaction between lake water and groundwater in Dal Lake (Saleem and Jeelani, 2017), stable isotopes to identify the sources of groundwater recharge in a karstified landscape of Western Himalaya (Jeelani et al., 2018), quantification of groundwater-surface water interactions using environmental isotopes in Bringi watershed of Kashmir Himalayas (Bhat and Jeelani, 2018).

Jammu district is the highly populated area in the Union Territory of Jammu and Kashmir where geographic factors play dominant role in the development of groundwater and surface water. The Jammu district is drained by Tawi River in addition to Ranbir canal and its distributaries (Fig. 1). The River Tawi gets bifurcated into Nikki Tawi and Wadi Tawi near Jammu city. The socio-economic activities of the region predominantly depend on the groundwater and surface water (River Tawi and canal system) and these are the only water sources which sustain the irrigational as well as domestic needs. The increase in population and urbanisation is severely affecting the water resources of the district. Continuous extraction of groundwater, deforestation and degradation of soil and agricultural resources has affected the recharging of water resources resulting in depletion of groundwater. The quality of water also degrades due to the dumping of garbage and sewage along Tawi River.

Kumar (2013) in a study around Kandi belt, Jammu district suggested that the groundwater is recharged by rain as well as river passing through the area. Kanwar et al. (2014) studied the groundwater levels and water quality in the Kandi and Sirowal belts in Jammu region. However, no study has been carried out to understand the role of surface water in recharging the groundwater in Kandi and Sirowal belts of Tawi watershed in the Jammu district.

The present study has been carried out in part of Tawi watershed in the Jammu district to understand the hydrogeochemistry and isotope hydrology of the river water and groundwater to enhance the understanding of the hydrogeochemical and isotopic characteristics of the river and ground water. This study helps in locating various suitable sites for groundwater development and management in the study area.

STUDY AREA

Physiography and Meteorology

The Jammu District can be divided into two physiographic units namely northern hilly terrain and outer plain area. The hilly terrain constitutes the rocks of Siwalik Group where the terrain is mostly showing rugged topography. The outer plain area comprises of Kandi and Sirowal belts (CGWB, 2013) (Fig. 1). The Kandi belt is dry semi-hilly tract, prone to soil erosion due to high runoff which results in sizeable loss of soil and nutrients (Gupta et al., 2010). The Kandi area is highly porous and capable of allowing in-situ percolation of large quantities of rain and surface water, but is deprived of the water because of substantial runoff due to steep topographic gradient (Thakur et al., 2014). This area shows an undulating topography with irregular steep slope and badly dissected terrain having number of gullies which comprise of boulder beds, gravels and pebbles with ferruginous clay matrix. The outer plain area shows well graded pattern from north to south direction with sediments becoming finer downwards.

The transition zone of Kandi and Sirowal belt lies near Jammu-Pathankot National Highway, Ranbir canal and then along the Pratap canal to the line of actual control on the Munawar Tawi (Kumar et al., 2004). Swampy conditions prevail at places because of immense auto flow of groundwater along the spring line marking the contact between the Kandi in north and the Sirowal in the south (CGWB, 2013).

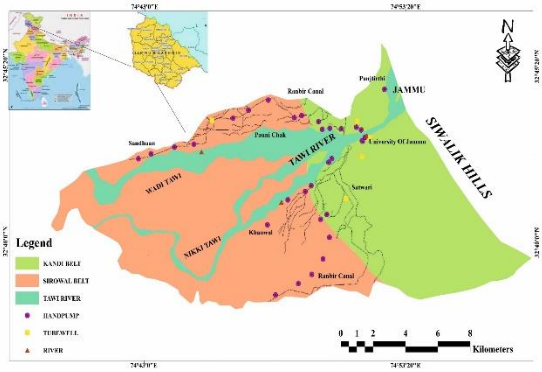

Figure 1: Location map and Physiography of the study area in Tawi watershed in Jammu District (modified after Kanwar et al., 2014).

In Jammu district, the climate is described as sub-humid to sub-tropical type. The months of July and August show maximum rainfall due to south-west monsoon. The district receives annual rainfall of 1246mm. The temperature ranges from 4°C (January) to 41°C (June), June being the hottest month while January is the coldest (CGWB, 2013).

Geology and hydrogeology

The Siwalik Group of rocks consists of conglomerate, sandstone, siltstone and shale and is divided into three subgroups namely lower, middle and upper. The outer plain area comprises of Kandi and Sirowal belts (CGWB, 2013) (Fig. 1). The Kandi belt runs along the foothills and is comprised of unconsolidated to semi-indurated conglomerate, sandstone and clay. Towards the south, the Kandi belt grades into low lying Sirowal belt. Stratigraphically the Sirowal belt is comprised of unconsolidated sand and clay in the upper part and conglomerate, sand and clay at depth. The form and condition of groundwater in the Kandi belt reveal unconfined and deeper ground water table whereas, in the Sirowal belt, the water table is in shallow and confined conditions. The direction of groundwater flow is broadly from north-east to south-west viz from Kandi to Sirowal belt and corresponds roughly with the topographic slope (Kanwar et al., 2014). Due to deeper water table, there are few tube wells and dug wells in the Kandi belt and people mostly rely on the surface water and precipitation.

Materials and Methods

In the present study, 3 and 37 number of samples were collected from Tawi river water and groundwater (hand pumps and tube wells) respectively during Pre-monsoon season corresponding with the month of May and June in 2015. Samples were collected from different locations covering urban and rural areas in the Tawi watershed in Jammu district (Fig. 1). Groundwater sampling sites were mostly located near the Tawi river and were selected based on their frequent use for drinking and domestic purposes. During the collection of samples, global positioning system was used to map the well locations. Field parameters such as temperature using water mercury thermometer, pH using handheld HANNA PH meter HI 96107 water tester while TDS and EC using HM Digital EC/TDS hydrotester were measured at the time of collection of samples. The samples were collected in 250 ml bottles of PVC (Polyvinyl chloride) for measuring the chemical constituents while for stable isotopes, 60 ml capacity bottles were used. The major cations and anions were measured by using Metrohm Ion Chromatograph (IC) model 850 integrated with Compact Autosampler (model 863). This facility was provided by Department of Environmental Sciences, University of Jammu. HCO_3^- was measured in the laboratory using volumetric titration method.

The isotopic (δD and $\delta^{18}O$) results were measured using Isotope Ratio Mass Spectrometer (IRMS) at Physical Research Laboratory, Ahmedabad by adopting the standard equilibration method in which water samples were equilibrated with CO_2 (or H_2) and the equilibrated CO_2 (or H_2) gas was analysed by Delta V Plus isotope ratio mass spectrometer (IRMS) in continuous flow mode using a Gas bench II preparation and introduction system (Maurya et al., 2009).

Groundwater Quality Index

In order to assess the chemical data for water quality, Groundwater Quality Index (GWQI), is used and compared with the drinking water quality standards of Bureau of Indian Standards (BIS, 2012). The steps which are important to calculate GWQI (Horton, 1965) are:

- **Step: 1** To assign weight (wi)- The weight is assigned to the parameter considered for the study. The weight of each parameter depicts their harmfulness when present in water.
- **Step: 2** To calculate relative weight (Wi)- The relative weight has been calculated using the following equation:

  $$Wi = wi / \sum_{i}^{n} wi$$

  Where "Wi" is the relative weight, "wi" is the weight assigned to each parameter, and "n" is the number of parameters.

- **Step: 3**Quality rating (Qi)- The quality rating of each parameter has been computed with its concentration in the groundwater sample by its respective BIS standard and then multiplied by 100. The equation is

  $$Qi = (Ci/ Si)*100$$

  Where Ci= concentration of each groundwater quality parameter
  Qi= quality rating
  Si= recommended value for each parameter.

- **Step: 4** Sub-index (SIi) and GWQI- The sub index and GWQI have been computed using the following equation:

  $$SIi = Wi \times Qi$$
  $$GWQI = \sum_{i=0}^{n} SIi$$

Where SIi is the sub-index of the i^{th} parameter and Qi is the quality rating based on the i^{th} parameter and 'n' is the total number of parameters.

The parameters selected for the assessment of water quality are based on their competence towards deteriorating the water quality. Nine quality parameters were selected to infer the GWQI which includes pH, TDS, Calcium, Magnesium, Sodium, Potassium, Sulphate, Chloride and Nitrate. The GWQI and the water quality status and the usage for drinking purposes are summarized in table 1. The standard values of selected parameters recommended by BIS (2012), their ideal values and the unit weights are presented in table 2.

Table 1: Recommended Ground Water Quality Index (GWQI) (Ramakrishna et al., 2009) and observed water quality status in the study area.
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S. No	Ground Water Quality Index (GWQI)	Water Quality Status	Number of samples	% of samples
1	< 50	Excellent	12 (Kandi) and 13 (Sirowal)	66.6 % (Kandi) and 68.4 % (Sirowal)
2	50-100	Good	6 (Kandi) and 6 (Sirowal)	33.3 % (Kandi) and 31.5 % (Sirowal)
3	100-200	Poor	-	-
4	200-300	Very Poor	-	-
5	> 300	Unsuitable for drinking	-	-

Table 2: Groundwater quality parameters, the assigned weights and computed relative weights with BIS standards in the study area.

S. No	Parameters	BIS standard value	Weight (wi)	Relative weight (Wi)
1	pH	8.5	4	0.129032
2	Total dissolved solids	1500	5	0.161290
3	Calcium	200	3	0.096774
4	Magnesium	150	4	0.129032
5	Sodium	200	5	0.161290
6	Potassium	12	3	0.096774
7	Sulphate	400	3	0.096774
8	Chloride	600	2	0.064516
9	Nitrate	45	2	0.064516
		Total	31	1

Table: 3Chemical composition (mg/L) of groundwater and river water in the study area

Physio-graphic division	S. No.	Latitude	Longitude	Type	Ca	Mg	Na	K	HCO3	Cl	SO4	NO3
GROUNDWATER												
Kandi	MS1	32°43'29.1"	74°51'22.9"	H/P	87.7	14.3	8.3	3.2	120	5.0	2.6	5.2
Kandi	MS2	32°43'24.5"	74°51'34.4"	H/P	76.8	23.2	14.0	2.1	102	11.9	10.2	1.8
Kandi	MS3	32°43'04.7"	74°51'36.6"	H/P	65.4	13.4	24.4	0.9	106	1.5	11.2	1.9
Kandi	MS4	32°43'03.6"	74°51'38.0"	H/P	74.5	27.1	14.5	1.9	119	11.8	9.0	1.8
Kandi	MS5	32°43'11.3"	74°51'44.1"	H/P	94.1	3.3	4.2	0.7	105	1.4	0.9	1.0
Kandi	MS8	32°43'39.3"	74°49'53.0"	H/P	100.5	29.2	29.4	2.0	116	24.3	21.7	25.3
Kandi	MS9	32°43'25.4"	74°50'02.1"	H/P	97.8	5.3	8.5	2.5	105	7.8	7.0	2.3
Kandi	MS10	32°43'27.3"	74°50'20.2"	H/P	91.3	11.0	27.1	3.3	111	12.4	18.6	17.5
Kandi	MS11	32°42'32.0"	74°50'24.6"	H/P	62.6	15.5	16.8	2.7	111	2.8	3.1	0.5
Kandi	MS12	32°42'25.3"	74°50'17.2"	H/P	99.8	4.8	8.9	1.5	107	3.5	1.8	2.0
Kandi	MS13	32°41'42.8"	74°49'36.0"	H/P	80.7	17.9	11.1	1.6	123	5.3	3.2	2.4
Kandi	MS20	32°40'50.7"	74°50'13.2"	H/P	97.7	13.4	23.0	10.1	107	16.5	20.8	8.1
Kandi	MS25	32°44'38.3"	74°52'29.7"	H/P	99.3	7.8	11.3	3.3	114	6.5	19.6	3.5
Kandi	MS47	32°43'26.2"	74°50'47.2"	H/P	78.9	12.3	13.1	3.9	103	6.0	9.6	2.2
Kandi	MS7	32°43'10.9"	74°51'56.0"	T/W	65.5	23.2	14.6	2.4	112	2.8	3.8	2.9
Kandi	MS58	32°41'19.2"	74°50'58.3"	T/W	77.0	30.7	25.6	2.2	82	19.8	2.9	34.6
Kandi	MS61	32°42'35.7"	74°51'36.1"	T/W	83.2	24.6	11.4	3.0	109	7.9	11.9	12.2
Kandi	MS62	32°43'40.4"	74°51'24.4"	T/W	88.2	16.5	32.6	16.4	128	11.5	12.6	19.0
Average value					84.5	16.3	16.6	3.5	110	8.8	9.5	8.0
Sirowal	MS14	32°41'32.2"	74°49'21.8"	H/P	78.2	18.3	20.9	11.0	101	10.9	16.5	4.9
Sirowal	MS16	32°40'31.5"	74°47'52.2"	H/P	85.2	21.6	11.0	1.7	106	4.0	12.2	0.4
Sirowal	MS17	32°41'17.1"	74°48'40.5"	H/P	71.2	9.7	23.6	2.6	96	3.1	9.9	12.5
Sirowal	MS18	32°40'08.9"	74°50'19.2"	H/P	91.7	11.9	12.1	2.2	99	14.0	15.9	10.7
Sirowal	MS19	32°40'41.7"	74°49'58.7"	H/P	58.8	24.5	21.6	2.6	103	5.9	6.4	8.9
Sirowal	MS21	32°39'29.6"	74°50'04.1"	H/P	71.6	7.2	19.4	1.5	98	8.5	10.9	3.8
Sirowal	MS22	32°39'01.7"	74°49'37.6"	H/P	60.7	15.2	15.4	11.0	90	6.5	8.9	5.1
Sirowal	MS23	32°38'44.8"	74°49'05.8"	H/P	81.3	7.0	17.3	1.1	106	7.9	9.1	4.8
Sirowal	MS24	32°38'24.1"	74°48'11.6"	H/P	69.7	10.0	12.3	10.9	98	4.5	5.8	6.2
Sirowal	MS48	32°43'50.3"	74°49'13.0"	H/P	75.3	21.1	6.1	1.4	98	8.3	2.8	12.0
Sirowal	MS49	32°43'46.4"	74°48'55.7"	H/P	68.0	23.9	10.0	1.6	103	6.6	3.6	9.9
Sirowal	MS50	32°44'18.3"	74°47'53.6"	H/P	78.4	15.7	19.6	5.2	119	9.4	2.2	4.0
Sirowal	MS51	32°43'59.6"	74°47'06.8"	H/P	70.7	13.6	11.9	7.4	108	5.6	4.1	7.1
Sirowal	MS52	32°43'45.3"	74°46'29.8"	H/P	67.1	18.2	22.0	1.8	117	7.3	4.0	3.4
Sirowal	MS53	32°42'57.6"	74°44'57.4"	H/P	50.5	21.0	7.9	10.4	99	3.7	7.8	1.0
Sirowal	MS54	32°42'52.4"	74°44'11.1"	H/P	55.5	20.0	26.8	1.7	109	5.0	3.8	8.5
Sirowal	MS55	32°42'40.2"	74°43'15.6"	H/P	72.1	23.1	8.5	2.1	107	5.6	2.2	11.2
Sirowal	MS57	32°42'31.1"	74°42'45.7"	H/P	86.9	16.0	11.5	1.4	97	4.0	20.9	2.9
Sirowal	MS60	32°43'41.0"	74°45'40.2"	T/W	90.4	18.6	9.0	1.2	102	3.7	2.5	4.0
Average value					72.8	16.7	15.1	4.2	102.9	6.6	7.9	6.4
RIVER												
Kandi	MS6	32°43'13.9"	74°51'48.1"	R/W	45.6	27.1	26.8	12.0	105	3.5	8.1	3.6
Sirowal (NT)	MS15	32°41'12.3"	74°48'25.4"	R/W	63.0	15.7	18.4	7.7	104	2.1	1.7	2.8
Sirowal (WT)	MS59	32°42'43.2"	74°45'15.5"	R/W	102.8	6.7	12.6	2.1	115	2.3	12.3	5.3

* NT- Nikki Tawi, WT- Wadi Tawi

Table 4: Chemical composition (mg/L) and isotopic composition of river water and groundwater in Kandi and Sirowal belts in the study area

Physio-graphic division	S.No.	Latitude	Longitude	Type	Temp (°C)	pH	EC (µS)	TDS (mg/L)	TH (mg/L)	SAR	% Na	Mg^{2+}/Ca^{2+}	CAI-1=bei	d ^{18}O (‰)	d ^{2}H (‰)	d-excess
GROUNDWATER																
Kandi	MS1	32°43'29.1"	74°51'22.9"	H/P	24	7.6	381	240	278.39	0.85	10.11	0.16	-0.26	-6.12	-39.64	9.3
Kandi	MS2	32°43'24.5"	74°51'34.4"	H/P	20	7.8	253	158	287.65	1.49	13.85	0.30	-0.03	-5.96	-33.48	14.2
Kandi	MS3	32°43'04.7"	74°51'36.6"	H/P	19	7.8	249	156	218.49	2.87	24.31	0.20	-10.23	-5.81	-36.14	10.3
Kandi	MS4	32°43'03.6"	74°51'38.0"	H/P	20	7.8	245	154	297.70	1.54	13.83	0.36	-0.03	-5.38	-32.21	10.8
Kandi	MS5	32°43'11.3"	74°51'44.1"	H/P	25	8.1	260	135	248.83	0.43	4.82	0.03	-1.81	-5.90	-33.94	13.3
Kandi	MS8	32°43'39.3"	74°49'53.0"	H/P	24	7.1	850	534	371.62	2.74	19.49	0.29	-0.01	-6.46	-38.55	13.1
Kandi	MS9	32°43'25.4"	74°50'02.1"	H/P	26	7.4	442	277	266.19	0.85	9.68	0.05	-0.05	-5.70	-37.66	7.9
Kandi	MS10	32°43'27.3"	74°50'20.2"	H/P	24	7.1	735	463	273.27	2.76	22.95	0.12	-0.12	-5.46	-36.56	7.1
Kandi	MS11	32°42'32.0"	74°50'24.6"	H/P	26	8.0	234	147	220.35	2.01	20.00	0.25	-2.18	-6.24	-36.62	13.3
Kandi	MS12	32°42'25.3"	74°50'17.2"	H/P	25	7.7	327	206	269.04	0.88	9.03	0.05	-0.55	-5.24	-32.33	9.6
Kandi	MS13	32°41'42.8"	74°49'36.0"	H/P	23	7.2	502	316	275.59	1.17	11.39	0.22	-0.26	-7.53	-46.91	13.3
Kandi	MS20	32°40'50.7"	74°50'13.2"	H/P	25	6.9	741	467	299.40	2.25	22.92	0.14	-0.06	-6.39	-37.98	13.1
Kandi	MS25	32°44'38.3"	74°52'29.7"	H/P	22	7.8	405	255	280.28	1.11	12.01	0.08	-0.19	-5.98	-34.78	13.1
Kandi	MS47	32°43'26.2"	74°50'47.2"	H/P	24	7.4	444	277	247.73	1.42	15.73	0.16	-0.30	-6.69	-38.81	14.7
Kandi	MS7	32°43'10.9"	74°51'56.0"	T/W	24	7.5	279	175	259.17	1.66	16.08	0.35	-1.75	-5.14	-30.27	10.9
Kandi	MS58	32°41'19.2"	74°50'58.3"	T/W	26	7.1	766	484	318.76	2.67	20.56	0.40	-0.02	-8.13	-32.86	32.2
Kandi	MS61	32°42'35.7"	74°51'36.1"	T/W	27	7.4	675	425	309.38	1.16	11.76	0.30	-0.11	-5.68	-30.33	15.1
Kandi	MS62	32°43'40.4"	74°51'24.4"	T/W	23	7.4	553	349	288.39	3.32	31.88	0.19	-0.28	-3.55	-31.96	-3.6
Average value					24	7.5	463	290	278.35	1.73	16.13	0.20	-1.01	-6.0	-35.6	12.1
Sirowal	MS14	32°41'32.2"	74°49'21.8"	H/P	23	7.2	462	290	270.89	2.23	24.81	0.23	-0.18	-7.90	-46.40	16.8
Sirowal	MS16	32°40'31.5"	74°47'52.2"	H/P	24	7.3	318	201	301.97	1.12	10.63	0.25	-0.54	-6.23	-35.17	14.7
Sirowal	MS17	32°41'17.1"	74°48'40.5"	H/P	25	6.9	576	364	218.02	2.71	24.50	0.14	-2.36	-8.71	-59.30	10.4
Sirowal	MS18	32°40'08.9"	74°50'19.2"	H/P	24	6.9	635	400	277.97	1.22	12.13	0.13	0.00	-8.12	-51.96	13.0
Sirowal	MS19	32°40'41.7"	74°49'58.7"	H/P	25	6.8	764	481	247.98	2.57	22.52	0.42	-0.52	-5.65	-38.20	7.0
Sirowal	MS21	32°39'29.6"	74°50'04.1"	H/P	24	6.8	623	392	208.51	2.23	20.95	0.10	-0.17	-6.83	-44.55	10.1
Sirowal	MS22	32°39'01.7"	74°49'37.6"	H/P	26	6.9	537	338	214.24	1.86	25.81	0.25	-0.46	-8.46	-53.41	14.3
Sirowal	MS23	32°38'44.8"	74°49'05.8"	H/P	25	6.9	632	398	232.06	1.88	17.26	0.09	-0.17	-6.56	-43.20	9.3
Sirowal	MS24	32°38'24.1"	74°48'11.6"	H/P	27	6.8	621	391	215.40	1.43	22.57	0.14	-0.94	-7.59	-50.05	10.7
Sirowal	MS48	32°43'50.3"	74°49'13.0"	H/P	23	7.2	633	398	274.95	0.66	7.20	0.28	0.01	-8.39	-50.21	16.9
Sirowal	MS49	32°43'46.4"	74°48'55.7"	H/P	23	7.0	718	452	268.32	1.12	11.26	0.35	-0.11	-8.10	-50.30	14.5
Sirowal	MS50	32°44'18.3"	74°47'53.6"	H/P	23	6.7	572	360	260.60	2.11	20.83	0.20	-0.18	-9.06	-56.71	15.8
Sirowal	MS51	32°43'59.6"	74°47'06.8"	H/P	22	6.8	447	281	232.78	1.35	18.66	0.19	-0.43	-9.57	-58.41	18.1
Sirowal	MS52	32°43'45.3"	74°46'29.8"	H/P	22	7.4	477	300	242.63	2.51	21.77	0.27	-0.31	-8.87	-55.83	15.1
Sirowal	MS53	32°42'57.6"	74°44'57.4"	H/P	23	7.4	491	308	212.62	1.02	20.42	0.42	-1.06	-8.66	-54.82	14.5
Sirowal	MS54	32°42'52.4"	74°44'11.1"	H/P	23	7.4	484	304	221.08	3.31	27.36	0.36	-0.92	-8.64	-50.87	18.3
Sirowal	MS55	32°42'40.2"	74°43'15.6"	H/P	23	7.2	527	333	275.47	0.93	10.07	0.32	-0.16	-5.17	-47.32	-6.0
Sirowal	MS57	32°42'31.1"	74°42'45.7"	H/P	22	7.5	375	235	283.27	1.18	11.13	0.18	-0.55	-6.02	-39.20	9.0
Sirowal	MS60	32°43'41.0"	74°45'40.2"	T/W	24	7.5	497	313	302.45	0.90	8.54	0.21	-0.46	-6.75	-54.87	-0.9
Average value					24	7.1	547	344	250.59	1.70	17.81	0.24	-0.50	-7.6	-49.5	11.7
RIVER																
Kandi	MS6	32°43'13.9"	74°51'48.1"	R/W	24	8.2	147	93	225.42	3.48	34.80	0.59	-2.90	-4.46	-18.24	17.4
Sirowal (NT)	MS15	32°41'12.3"	74°48'25.4"	R/W	24	7.9	208	131	221.87	2.18	24.88	0.25	-5.55	-4.50	-27.10	8.9
Sirowal (WT)	MS59	32°42'43.2"	74°45'15.5"	R/W	23	8.0	210	134	284.48	1.22	11.83	0.07	-2.30	-6.00	-30.30	17.7

* H/P= Handpump, T/W= Tubewell, R/W= River water, EC= Electrical conductivity, TDS= Total dissolved solids, TH= Total hardness, SAR= Sodium absorption ratio, CAI= Chloro alkaline indice, WT- Wadi Tawi, NT- Nikki Tawi.

RESULTS AND DISCUSSION

Physico-chemical parameters

The chemical composition of river and groundwater is presented in Table 3, analytical calculations of physico-chemical parameters of groundwater and river are presented in Table 4 and statistical calculations of major ions (mg/L) are presented in table 5. These chemical parameters have been assessed for the Ground Water Quality Index (GWQI) and the computed results are presented in Table 6.

Table 5: Statistical summary of major ions (mg/L) of the river and groundwater samples in the Kandi and Sirowal Belts in the study area

Parameter	Groundwater Kandi Belt			Groundwater Sirowal Belt			River Water		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Ca^{2+}	62.6	100.5	84.5	50.5	91.7	72.8	45.6	102.8	70.4
Mg^{2+}	3.3	30.7	16.3	7.0	24.5	16.7	6.7	27.1	16.5
Na^{+}	4.2	32.6	16.6	6.1	26.8	15.1	12.6	26.8	19.2
K^{+}	0.7	16.4	3.5	1.1	11.0	4.2	2.1	12.0	7.3
HCO_3^-	82.0	128.0	110.0	90.0	119.0	102.9	104.0	115.0	108.0
Cl^-	1.4	24.3	8.8	3.1	14.0	6.6	2.1	3.5	2.6
SO_4^{2-}	0.9	21.7	9.5	2.2	20.9	7.9	1.7	12.3	7.3
NO_3^-	0.5	34.6	8.0	0.4	12.5	6.4	2.8	5.3	3.9

The pH value of groundwater and river water ranges from 6.7-8.1 and 7.9-8.2 respectively, which show slightly acidic to slightly alkaline nature. Total dissolved solids (TDS) in groundwater and river water ranges from 135-534 mg/L and 93-134 mg/L respectively. The TDS concentration of river and groundwater of Kandi and Sirowal belts indicates fresh water (0-1000 mg/L) category (Davis, 1966; Freeze and Cherry, 1979).

Electrical Conductivity (EC) is an index which represents the total concentration of dissolved salts present in water (Purandara, 2003). The EC of groundwater and river water ranges from 234-850 µS and 147-210 µS respectively. The low value of EC in river water may be due to recent infiltration of water which had little time to interact with rocks for mineral dissolution (Olea et al., 2019).

Sources of major ions

Various chemical ions show their presence in river and groundwater due to rock-water interaction in the study area. Calcium and sodium concentration in the groundwater ranges from 50.5 to 100.5 mg/L and 4.2 to 32.6 mg/L respectively. Calcium and sodium concentration in groundwater may be due to weathering of minerals such as pyroxene, epidote, tourmaline and feldspar found in the Siwalik sediments (Abid et al., 1983). The calcium and sodium concentration in river water ranges from 45.6 to 102.8 mg/L and 12.6 to 26.8 mg/L respectively. The magnesium concentration in groundwater and river water ranges from 3.3 to30.7 mg/L and 6.7to 27.1 mg/L respectively. Both calcium and magnesium concentration result from the weathering of carbonate bearing rocks found in the Siwaliks (Sinha et al., 2007; Hossain et al., 2008; Ullah et al., 2009) and are also contributed by river water coming from Trikuta Limestone through Jhajjar stream. Low potassium concentration in groundwater (0.7 to16.4 mg/L) and river (2.1 to 12.0 mg/L) is likely due to less dissolution of potassium salts. The concentration of Ca and Mg (alkaline earth metals) is more than that of Na and K (alkali metals) in the study area and is also reported by Kanwar and Bhatti (2014) which might be due to the presence of clay and silt in the outer plain area.

Table 6: Results of Ground Water Quality Index (GWQI) values in the study area

KANDI BELT			SIROWAL BELT		
Sample	GWQI Values	Status of Water	Sample	GWQI Values	Status of Water
			Along Ranbir Canal		
MS1	44	Excellent	MS14	53	Good
MS2	43	Excellent	MS16	42	Excellent
MS3	38	Excellent	MS17	48	Excellent
MS4	44	Excellent	MS18	51	Good
MS5	35	Excellent	MS19	53	Good
MS8	70	Good	MS21	44	Excellent
MS9	42	Excellent	MS22	49	Excellent
MS10	58	Good	MS23	45	Excellent

MS11	38	Excellent	MS24	50	Good
MS12	39	Excellent	MS48	50	Good
MS13	44	Excellent	MS49	51	Good
MS20	60	Good	MS50	48	Excellent
MS25	45	Excellent	MS51	45	Excellent
MS47	44	Excellent	MS52	45	Excellent
MS7	41	Excellent	MS53	47	Excellent
MS58	68	Good	MS54	46	Excellent
MS61	56	Good	MS55	49	Excellent
MS62	65	Good	MS57	44	Excellent
			MS60	46	Excellent

Based on the hardness classification of water by Sawyer and McCarty's (1967), the river water (221.87 to284.4 mg/L) belongs to hard class and groundwater (208.51 to 371.62 mg/L) belongs to hard and very hard categories. Stuyfzand (1989) classified the groundwater into eight categories on the basis of chloride concentration showing the source and the time length of groundwater interaction with the geological units. In the present study, the river water with chloride concentration of 2.1 to3.5 mg/L groups into Very Oligohaline (<5) and groundwater (1.4to24.3 mg/L) belongs to Very Oligohaline (<5) and Oligohaline (5-30) categories.

Sulphate concentration of groundwater and river water ranges from 0.9to 21.7 mg/L and 1.7 to 12.3 mg/L respectively whereas, the Nitrate concentration of groundwater and river water ranges from 0.4to34.6 mg/L and 2.8to5.3 mg/L. High level of nitrate concentration in groundwater might be due to application of nitrogenous fertilizers, irrigation practices and cattle population in the area (Kanwar et al., 2014).

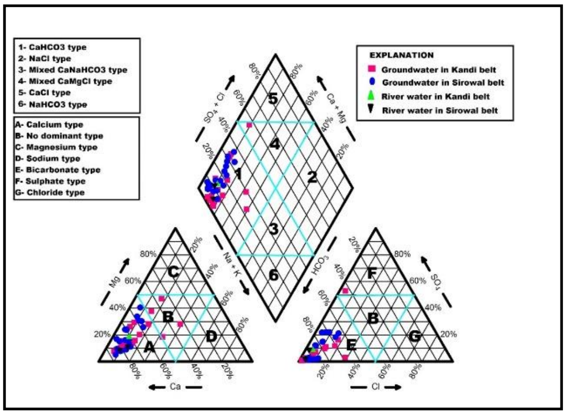

Figure 2: Piper-Trilinear plot for river water and groundwater in Kandi and Sirowal belts.

Calculation of Ground Water Quality Index (GWQI)

GWQI is divided into five categories (Ramakrishnalah et al., 2009) and the status of water quality is given in Table 1. GWQI calculated for groundwater samples are presented in Table 6. The ground water samples of Kandi and Sirowal belts show GWQI ranging from 35 to 70. In Kandi belt, 66.6% ground water samples fall in the Excellent and 33.3% in the Good category whereas, in the Sirowal belt, 68.4% ground water samples fall in Excellent and 31.5% in Good category. The GWQI suggests that the water is suitable for drinking purposes in both Kandi and Sirowal belts.

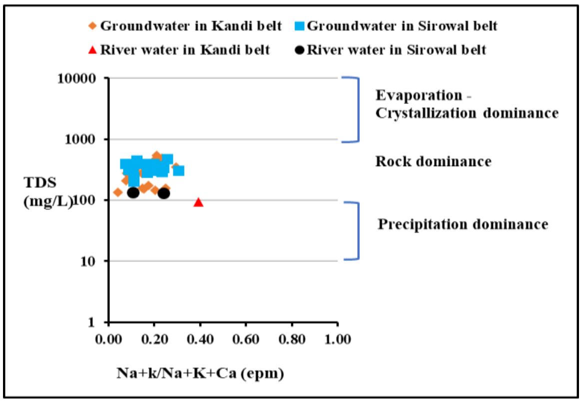

Figure 3: Gibbs diagram showing dominance of rocks for cation composition in study area

Hydrogeochemical characteristics

Piper diagram

The variation in the chemical composition of river water and groundwater was illustrated using the Piper Trilinear diagram (Piper, 1953).

The Piper Trilinear plot (Fig. 2) shows that the hydrochemical facies of groundwater in Sirowal and Kandi belts is $CaHCO_3$ water type (Zone 1). The river water of Kandi and Sirowal belts indicate that the $CaHCO_3$ water type (Zone 1) hydrochemical facies. The $CaHCO_3$ water type reflects that the rain water acts as the primary source for the groundwater recharge (Yang et al., 2019. This means that alkaline earths exceed alkalis and weak acids exceed strong acids. Dominance of HCO_3^- anion suggests bicarbonate class of groundwater (Chebotarev, 1955) in the study area indicating initial stage of groundwater evolution and presence of groundwater near the surface of earth which can be explained in the following sequence.

$HCO_3 \rightarrow HCO_3 + Cl \rightarrow Cl + HCO_3 \rightarrow (Cl + SO_4)$ or $(SO_4 + Cl) \rightarrow Cl$

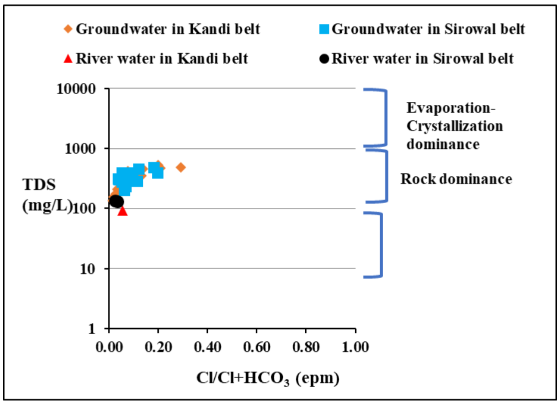

Figure 4: Gibbs diagram showing dominance of rocks for anion composition in study area.

Gibbs diagram

The Gibbs diagrams for the groundwater and river water of Kandi and Sirowal belts are shown in figures 3 and 4. Both the Kandi and Sirowal groundwater samples indicate that the ionic composition was controlled mainly by the rock-dominance. The Gibbs diagram enlightened the fact that weathering of rocks act as the major dominant process which controls the ionic composition in the groundwater of Kandi and Sirowal belts of Tawi watershed. This dominant process confirms that the rock-water interaction acts as the source for the chemical constituents in the groundwater of Kandi and Sirowal belts.

The ionic composition of river water in Sirowal belt is controlled by rock-dominance whereas, the data for river water of the Kandi belt plots at the boundary line between rock dominance and precipitation dominance.

Index of Base Exchange (between groundwater and surrounding rocks)

The "Index of Base Exchange" is used to describe the geochemical reactions taking place in groundwater and was given by Schoeller (1965). The Chloro-alkaline indices (CAI-1) is used to measure the base-exchange during the water-rock interaction. There are minerals in the rocks such as clay etc. which absorb and exchange the ions with the groundwater.

Chloro-alkaline indices (CAI-1)

The ion exchange between groundwater and the surrounding environment has been illustrated by the (CAI-1= bei) indices using ionic concentration expressed in mg/L. The equation used to infer the base-exchange is as:

$$CAI\text{-}1 = \frac{[Cl - (Na + K)] / Cl}{Cl}$$

The calculated CAI-1 values of both river water and groundwater are presented in Table 4. The negative CAI-1 values indicate normal ion exchange of Ca^{2+} or Mg^{2+} ions in the groundwater with that of Na^{+} and K^{+} in the weathered materials whereas the positive value of index represents the reverse ion exchange (Schoeller, 1965). In this study, 95% water samples show negative CAI-1 values and 5% water samples show positive values suggesting that the normal ion exchange is the dominant process.

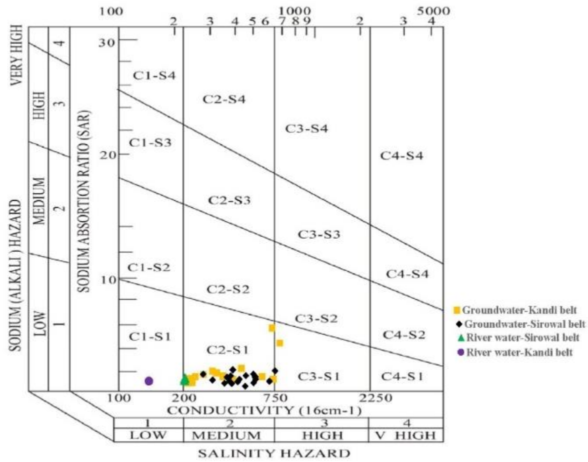

Figure 5: U.S Salinity diagram for the classification of water for irrigational use in the study area

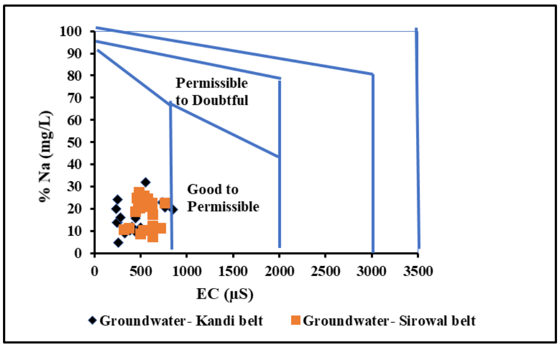

Figure 6: Ratings of groundwater samples based on electrical conductivity and sodium percentage (Wilcox, 1955) in the study area.

Suitability for Irrigational purpose

As the Kandi and Sirowal belts show steep slope and variation in topographic gradient, the study area comes under irrigation land use for the Kharif as well as Rabi crops. The Tawi River, canals as well as groundwater play major role for the irrigation pattern in agricultural land. Two parameters – Sodium absorption ratio (SAR) (Richards, 1954) and Sodium percentage (%Na) (Wilcox, 1955) were used to determine the suitability of water for irrigational use. The calculated SAR and % Na values of river and groundwater (mg/L) are presented in Table 4. Diagrams used to illustrate the groundwater suitability for irrigational use are as under:

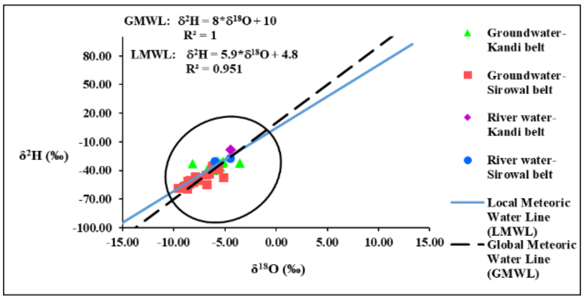

Figure 7: Regression line for LMWL, GMWL, river water and groundwater in Kandi and Sirowal belts in the study area.

A) Richard Diagram- The plot between SAR and EC in the U.S Salinity Diagram (USSL) shows that the majority of groundwater samples of Kandi and Sirowal belt fall in the category of C2S1 (Fig. 5). One groundwater sample of Kandi belt fall in the category of C3S1. The field of C2S1 represents medium salinity and low sodium water which indicates that the quality of water is good and favourable for all types of crops except least salt tolerant crops such as dry beans, soya beans, corn and field peas. C3S1 represents high salinity and low sodium water which can be used on clayey soil but the type of crop depends on the salt tolerant range prior to the cultivation (AL-Alhamdi and EL-Fiky, 2009). The SAR values of river and groundwater in the Kandi and Sirowal belts show the suitability of water for the irrigation use.
B) Wilcox Diagram- The plot between % Na and EC describe Wilcox diagram (Fig.6). High value of these parameters affects the crop growth. The groundwater samples of Kandi and Sirowal belts fall in the category of "Excellent to Good". One groundwater sample of Kandi belt falls in the category of "Good to Permissible". Thus, the groundwater of Kandi and Sirowal belts with respect to percentage Na and EC show favourable conditions for irrigational use.

Isotopic analysis

The isotopic composition of $\delta^{18}O$ and $\delta^{2}H$ of groundwater (hand pumps & tube wells) and river water in Kandi and Sirowal belts is presented in Table 4. These isotopic measurements are plotted in (Fig. 7).

The Global Meteoric Water Line was developed by Craig (1961) using the following equation:

$\delta^2H = 8\times\delta^{18}O + 10.$ (eq.1)

Jeelani et al (2017) developed the Local Meteroic Water Line (LMWL) based on the precipitation data for Jammu which is represented by the equation:

$\delta^2H = 5.9\times\delta^{18}O + 4.8$ (March-April-May). (eq. 2)

Isotopic composition of river water- The $\delta^{18}O$ values of river water (n=3) range from -6.00‰ to -4.46‰ and δ^2H range from -30.30‰ to -18.24‰ respectively. The $\delta^{18}O$ and δ^2H values of river water samples fall on the LMWL which indicates modern precipitation act as primary source of Tawi River (Fig. 7).

Isotopic composition of groundwater- The $\delta^{18}O$ values of groundwater in Kandi belt (n=18) range from -8.13‰ to -3.55‰ (average= -6.0‰) and δ^2H from -46.91‰ to -30.27‰ (average= -35.6‰). The $\delta^{18}O$ values of groundwater in Sirowal belt (n=19) range from -9.57‰ to -5.17‰ (average= -7.6‰) and δ^2H range from -59.30‰ to -35.17‰ (average= -49.5‰).

The isotopic composition of river water is slightly enriched than that of the groundwater in study area in equation 3 and 4 respectively:

Groundwater (*Kandi* and *Sirowal*):
$\delta^2H = 5.3\times\delta^{18}O - 6.6$ (May-June) (eq.3)

River water (*Kandi* and *Sirowal*):
$\delta^2H = 5.1\times\delta^{18}O + 0.38$ (May-June) (eq.4)

The slope and intercept of groundwater of Kandi and Sirowal belts are lower than that of the LMWL which indicates the evaporative enrichment effect on groundwater samples. It is being observed that the slope of groundwater samples is similar to LMWL as given by Jeelani et al. (2017). Contrary to the expectations, groundwater samples are not exclusively recharged by rain water but by river and canal also. Similar slope (Fig. 7) is mere a coincidence because the isotopic values of groundwater is depleted with an average of -6.8‰ and rainfall recharge process cannot cause isotopic depletion.

The groundwater locations along the Ranbir canal show depleted isotopic signatures compared to the river (Nikki and Wadi Tawi) and rain (eq. 1) isotopic signatures except groundwater sample MS19 and MS55. In the Kandi belt, the groundwater locations on both the banks of Tawi River show isotopic signatures similar to rain (eq. 1) except MS1, MS8, MS11, MS13, MS20, MS47 and MS58. Out of these exceptions, MS11, 13, 20, 47 and 58 are groundwater locations along the canal. The highly depleted $\delta^{18}O$ values of groundwater are observed in the Sirowal belt than that of the Kandi belt and might be due to Ranbir canal carrying snow melt cold water of Chenab River into the area and recharging the groundwater. Similar conclusions have been drawn by Ahmad et al. (2012) in the Indus basin in Pakistan.

"Deuterium excess", d-excess = $\delta^2H - 8*\delta^{18}O$ has been defined to identify the relative magnitude of kinetic fractionation in different water masses (Dansgaard, 1964). The values of d-excess for river water in Kandi belt is 17.4‰ and in Sirowal belt, the d-excess value is 8.9‰ (Nikki Tawi) and 17.7‰ (Wadi Tawi). About 72.2% of groundwater samples in Kandi belt and 73.7% in Sirowal belt have d-excess > 10‰ whereas 27.7% in Kandi and 26.3% in Sirowal belt have d-excess < 10‰. These values are close to and more than 10‰. The higher d-excess values (> 10‰) show precipitation due to Western Disturbance (Rozanski et al., 1993) and also indicate the existence of the recycled water derived from local evaporated vapour (Bowen et al., 2012; Gat et al., 1994).

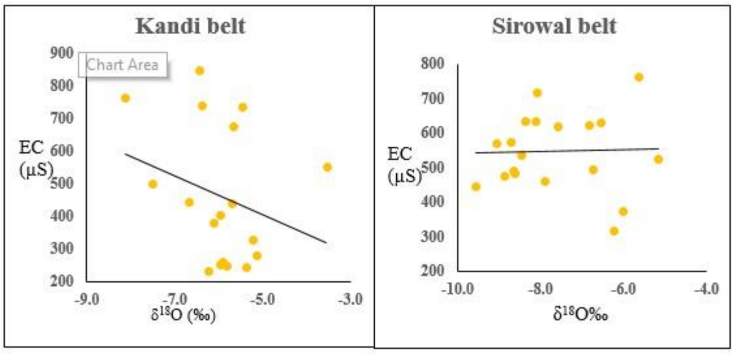

Figure 8: Scatter plot of Electrical Conductivity and $\delta^{18}O$ isotopes of groundwater in the study area.

The plot of $\delta^{18}O$ and conductivity of Kandi belt indicate negative correlation while Sirowal belt do not show any correlation which gives clear picture of no evaporation effect (Fig. 8). It has been reported that the evaporation process in water is associated with low d-excess values (Dansgaard, 1964). However, in Kandi and Sirowal belts, the groundwater has high d-excess values which may be due to the recharging by rainfall and canal water (Jeelani et al., 2017; Ahmad et al., 2012).

Groundwater recharge

In the Sirowal belt, the depleted groundwater $\delta^{18}O$ values compared to river water isotopic values suggest that there is highly depleted source present in the area. The Ranbir Canal traversing from the left bank of Chenab River drains the Sirowal belt and some parts of Kandi belt. This canal carries the snow melt cold water of Chenab River from the glaciated higher reaches and irrigates the Sirowal belt. Thus, there are two sources- highly active canal and precipitation that dominate the groundwater recharge in the study area. In the case of Kandi belt, the $\delta^{18}O$ values of groundwater are enriched and show close isotopic signatures to the river water in scatter plot (Fig. 7). Near the banks, the groundwater $\delta^{18}O$ values might get recharged due to river water. In this zone, precipitation and Tawi river water act as predominant source for the groundwater replenishment. Hence, the sources of groundwater recharge in the study area are modern local precipitation, river and canal water. At this stage, we do not give any quantification of recharge source to groundwater.

Groundwater development involves the management and sustainable use of resources for future use. In the study area, the groundwater recharge occurs mainly along the canal area and through the natural infiltration of rain and river water. The development of sites along the Ranbir canal in Sirowal belt and natural infiltration of rainwater in the Kandi belt can serve as the potential sites for groundwater development. The quantification of recharge sources can further give clear picture about the potential sites for development and sustainable use in future.

CONCLUSIONS

The conclusions drawn from the current study of hydrochemistry and isotope hydrology of river water (Tawi river) and groundwater (Hand pumps & Tube wells) in the Kandi and Sirowal belts of Tawi watershed in the Jammu district are as follow:

- The quality of river water and groundwater is good in the study area with respect to drinking and irrigational purposes.
- The river water shows alkaline nature while groundwater in Kandi belt shows slight acidic to basic nature and Sirowal belt shows acidic nature.
- The hydrochemical facies determined using the Piper-Trilinear plot revealed that both the river water and groundwater were of $CaHCO_3$ type.
- GWQI observation indicates that the quality of water mostly falls in the Excellent and Good categories in the study area.
- The stable isotopic composition ($\delta^{18}O$ and $\delta^{2}H$) of river water and groundwater is indicative of meteoric origin and enrichment before groundwater recharge. Ranbir canal is the active recharge source for ground recharge in Sirowal belt while river water contributes to ground recharge near the banks in the Kandi belts.

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