Hydrological behaviour of natural springs/streams in mid-hills of Chakrata Himalayas, India

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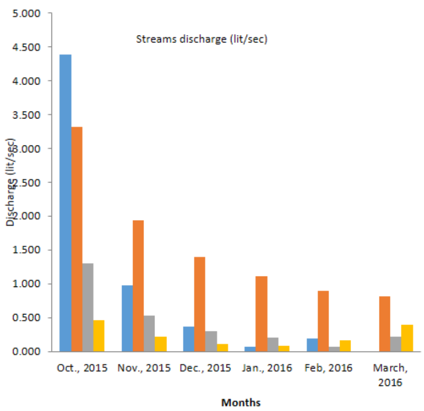
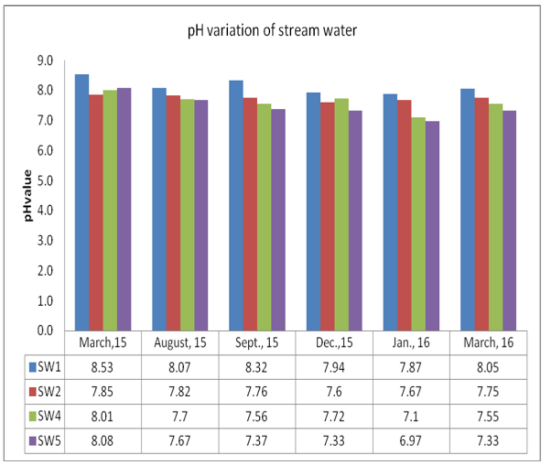
GRAPHICAL ABSTRACT





Abstract

The present study was carried out to understand the hydrological behavior of natural springs/streams in Semalta watershed, Kalsi block, Dehradun. The surface catchment areas of springs/streams were delineated using Survey of India Toposheet (1:50,000 scale) whereas drainage, slope, and land use maps of the watershed were prepared using open source ILWIS GIS software. The drainage map of the watershed indicated the ephemeral, intermittent and perennial nature of streams and the slope map of the watershed indicated that the majority of the area falls under scrubland. The discharge trend at different gauging sites from October 2015 to March 2016 indicated that the flow rate of the stream gradually decreased from post-monsoon to pre-monsoon period. The geohydrological and geomorphological study indicated that most of the springs/streamflow were controlled by fracture/joints with slate/phyllite/limestone/quartzite as country rock. The pH of most of the stream water was mildly alkaline (7.85-8.82) whereas EC was non-saline (0.087-0.425) and temperature varied from 14-23°C. Results on major ions indicated that a higher percentage of NH4+ together with NO3- was possible because of anthropogenic influence. In addition, the higher percentage of SO4- and F- was due to lithological pyrite whereas the higher percentage of HCO3- was due to pyrite weathering of slate. Results on the isotopic variation of δ18O showed that samples were collected with a total height difference of 700 m with a variation of -0.21‰ per 100 m for stream water and -0.5‰ for rainwater. On higher altitudes mainly narrow subsurface pathways are found and therefore only small size of structures are required for recharging and vice versa for the recharge of springs located in lower altitudes. The present study discusses various sampling techniques to ascertain the altitude of recharge of springs which would form the basis for taking appropriate on field activities for spring/stream rejuvenation.

Keywords: Watershed, Chakrata Himalayas, Natural springs, Hydrogeochemical behavior, isotopic variation

1 Introduction

$\delta^{18}O$ and $\delta^{2}H$ are highly useful indicators of hydrological patterns and processes (Zhao *et al.*, 2017). Improved understanding and better inferences of spring and stream water responses in headwaters of the Indian Lesser Himalayas using stable isotopes, conductivity, and temperature as tracers was carried out by Tarafdar *et al.*, (2019). In many of the watersheds of the Himalayan region, springs get dried up in the summer due to poor recharge. Previous studies indicated that grazing and trampling by livestock, deforestation, erosion of top fertile soils, forest fires, and development activities have reduced the *"sponge action"* of land and have created a hydrological imbalance in the fragile watersheds of Garhwal Himalayas (Negi, 2007; Qazi *et al*., 2020; Valdiya and Bartarya, 1991). Springs are drying up or becoming seasonal. The difference in the volume of water flowing in the rivers during dry and rainy seasons is commonly more than 1000 times, thus resulting in too little and too-much water syndrome - a common feature of drought and flood (Valdiya and Bartarya, 1989) and therefore, it becomes essential to delineate recharge zones of springs using environmental isotopes to support climate-resilient interventions (Matheswaran *et al*., 2019). It has been estimated that less than 15% of the rainwater can percolate down through deforested slopes to recharge the springs, and the remaining water runs off causing floods (Joshi *et al*., 2018; Negi, 2002). Thirty percent of springs have almost dried up and an additional 45% of the springs are on the verge of drying or becoming seasonal, thus affecting approximately 60% of the population (Negi and Joshi, 1996 & 2004). Different discharge rates have been observed with lineament, fault-controlled springs, colluvial and fluvial related springs, fracture-joint and karsts related springs (Bhat and Jeelani, 2015; Valdiya and Bartarya, 1991). The stable isotopic composition of water (δ^2H and $\delta^{18}O$) is modified by the process of evaporation and condensation, and it has been observed that recharge water has a characteristic isotopic signature for a particular environment and acts as a natural tracer for water movement (Chinnasamy and Prathapar, 2016; Clark and Fritz, 1997; Iacurto *et al*., 2020; Kendall and McDonnell, 1998; Tarafdar *et al*. 2019). Isotope techniques have been used for the establishment of the source and mechanism of recharge (Dhakal *et al*., 2014; Shivanna *et al*., 2004; Sukhija *et al*., 1996), groundwater circulation, and its renewability (Navada *et al*., 1993; Rao and Kulkarni, 1997), recharge areas and transit times of aquifer (Agarwal *et al*., 2006; Sukhija *et al*., 1998), and characterizing stream/spring water for estimation of the altitude effect in precipitation (Shivanna *et al*., 2008; Wen *et al*., 2012). The study also indicated that recharge zones of drying springs can be identified using environmental isotopes (δ^D & $\delta^{18}O$) from rainwater (Kumar *et al*., 2012; Bartarya *et al*., 1995). Many previous studies (Kumar et al., 2012; Murlidharan and Khatti, 2011; Shivanna *et al*., 2008) have observed that with the intervention of water conservation measures (subsurface dykes, check bunds, and contour trenches), the springs discharge rate increased significantly. Studies on ionic sources and water quality in the mountainous reservoirs and groundwater in Doon valley and the impact on major ion behavior during chemical weathering in plains and peninsular sub-basins of the Ganga has been carried out by Bickle *et al*., 2018; Divya *et al*., 2013; Dudeja *et al.*, 2011 and Rai *et al*., 2010. The real crux of the problem was how to increase the water retention capacity of the fragile watersheds to augment a sustained discharge of water during summer. Therefore, the present study discusses various sampling techniques to ascertain the altitude of recharge of springs which would form the basis for taking appropriate measures for springs/streams rejuvenation.

2 Study area description

2.1 Location and Extent

Semalta watershed lies between Longitude 77°53′00″E and Latitude 30°38′00″N in the NNE of Sahiya in the Kalsi Block of Dehradun District of Uttarakhand. The study area comes under the mid-hills of Chakrata Himalaya and can be accessible by road from Dehradun. Stream water sampling was done along the stream beds which are 150-300 m below the road heads at different altitudes whereas rainwater was collected from a rain gauge installed at an altitude of 1400-1800 m above mean sea level. Location of stream sampling, discharge measuring, and rain gauging sites are marked on the maps shown in Figure 1.

2.2 Geology and Geohydrology

The study area is a part of Chakrata Himalaya. The dominant rocks found are slates, phyllites, limestones, arenaceous quartzite, and granites. The rocks of the area are highly fractured and folded and belong to the Chakrata formation.

2.3 Drainage

The drainage map indicates four orders (1^{st}, 2^{nd}, 3^{rd}, and 4^{th}) of the stream where the 1^{st} order stream is dominantly ephemeral whereas the 2^{nd} order is intermittent while the 3^{rd} and 4^{th} orders are perennial. The first order stream has the maximum length, followed by the second, fourth and third order. Based on the above observations, the watershed of the area has been divided into 17 sub-watersheds (SWS1-17) (Figure 2) with SWS2 being the largest and occupying nearly 278.09 ha. The flow path within the sub-watershed on the micro-scale indicated micro-streams/channels joining the different orders of streams within the sub-watershed. 3D imagery of watershed indicated the relationship of stream order and their topography that forms the basis of delineation of micro-catchment of sub-watershed. Based on the stream orders (1^{st}-3^{rd}), SWS2 was selected to demonstrate the activities relating to time series sampling and discharge measurement.

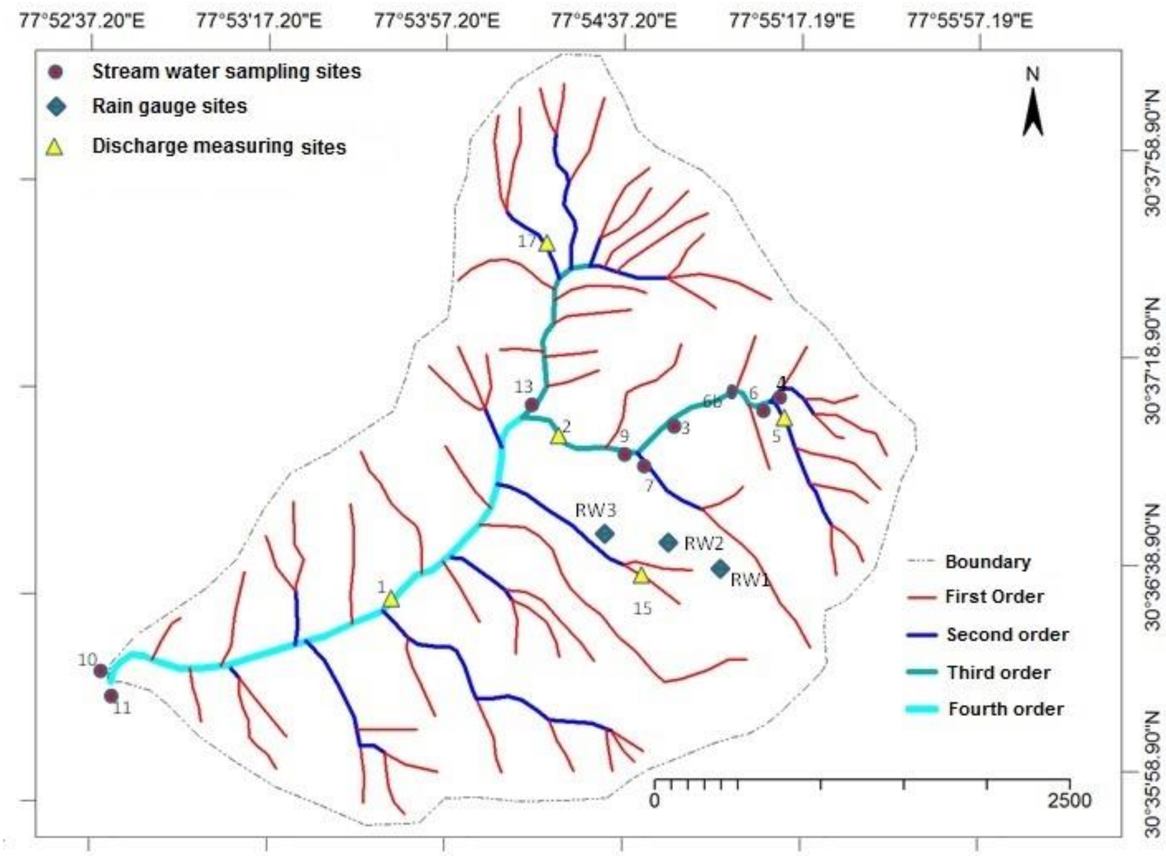


Figure 1. Sample location and stream order in the Semalta watershed

2.4 Slope and Land use map of the watershed

The slope map of the Semalta watershed has been categorized into 10 classes from A (0-1%) - J (100-300%) (Figure 3a). The figure indicated dominant slope of the watershed has steep to very steep sloping for 1st to 3rd order streams, whereas, it has moderate to moderately steep sloping for the 4th order stream. It has been observed that the watershed has two very clearly defined slope directions divided by the 4th order stream (Semalta Gad). On one side, the stream watershed is dominantly north, northwest, and west-facing with a small area facing the south and southwestern direction of the slope. On the other side, it is facing towards the south, southeast, southwest, and east direction. Land use map of watershed indicated four major divisions viz. scrubland with plants, barren land or degraded land, agricultural land, forest land, and stream channels (Figure 3b).

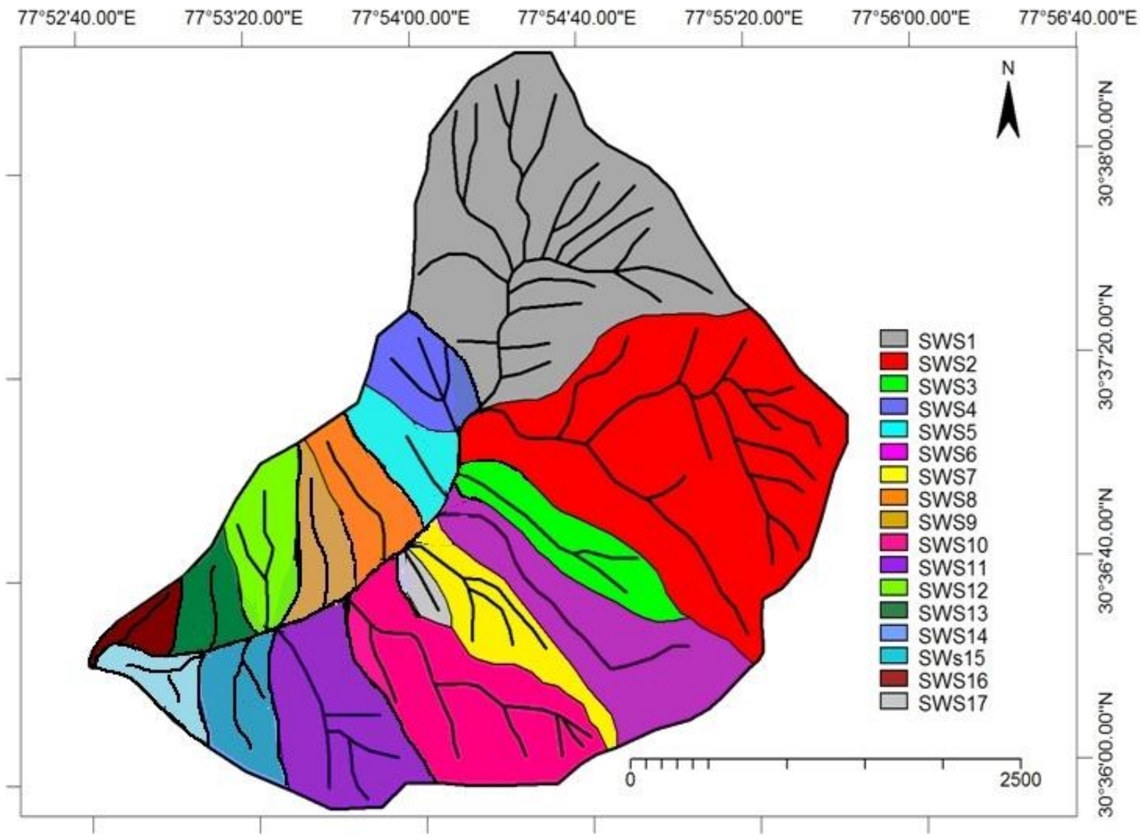


Figure 2. Delineation of sub-watersheds

3 Materials and methods

The surface catchment area of the springs/streams has been delineated from the Survey of India Toposheet. ILWIS open source software was used to prepare the thematic maps of drainage, slope, and land use of the watershed. Based on different drainage, slope, land use, altitude, and geological settings, four sites viz., with degraded land; with degraded cum forest land and only forested land (two) were selected and masonry V- notch was constructed for discharge measurement (Figure 4). Water samples were collected from the different stream sites during March 2015-16.

The pH (Orion pH meter, Thermofisher), EC, and temperature were measured at the sites whereas, altitude was measured by GPS. Samples were filtered using a 0.22 μm nylon membrane filter (Millipore®), kept in polypropylene bottles, and pre-cleaned with milli Q water. Two separate aliquots of filtered water were stored in 60 ml bottles for determining the major ions and stable isotopes. Another aliquot of unfiltered water was collected and kept in a 60 ml bottle for alkalinity measurement.

a]
b]

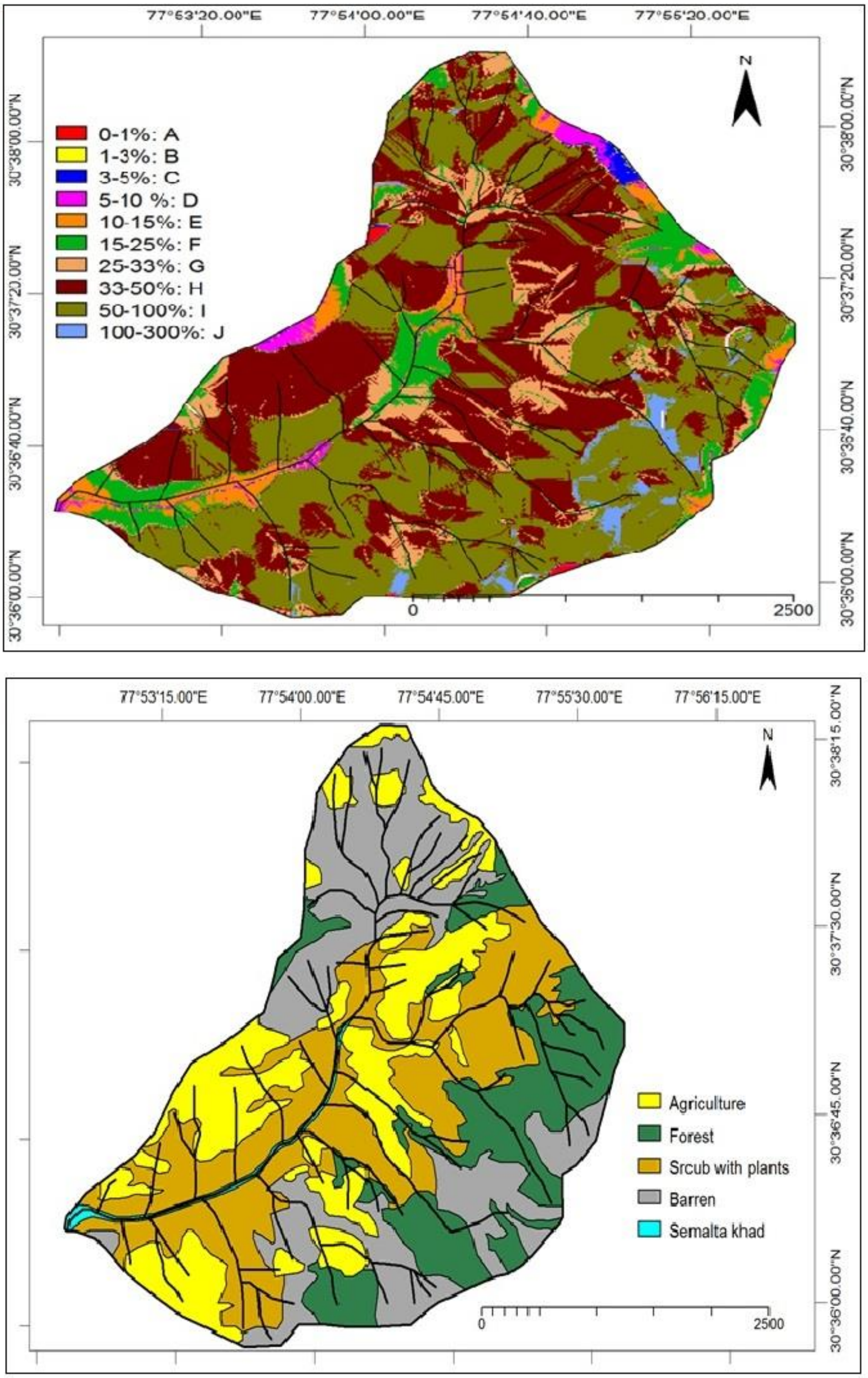


Figure 3a, **b** Slope map and Land use map of Semalta watershed

Water samples were transported to the laboratory for alkalinity, major ions, and isotopic analysis following the procedures of Dalai *et al*. (2002) and Das *et al*. (2005). $\delta^{18}O$ of water were analyzed using Isotope Ratio Mass Spectrometer (IRMS) at Wadia Institute of Himalayan Geology (WIHG), Dehradun, following the standard procedure (Deshpande *et al*., 2010). The reproducibility of results was better than 0.1% (1SD) for $\delta^{18}O$. Alkalinity (HCO_3^-) and major ions of water samples (Cl^-, F^-, SO_4^{2-}, NO^{3-}, Na^+, K^+, Mg^{2+}, Ca^{2+}) were measured on Metrohm auto-titrator (pH-based) and Ion Chromatograph (Dionex ICS-5000), respectively for characterizing the stream water.

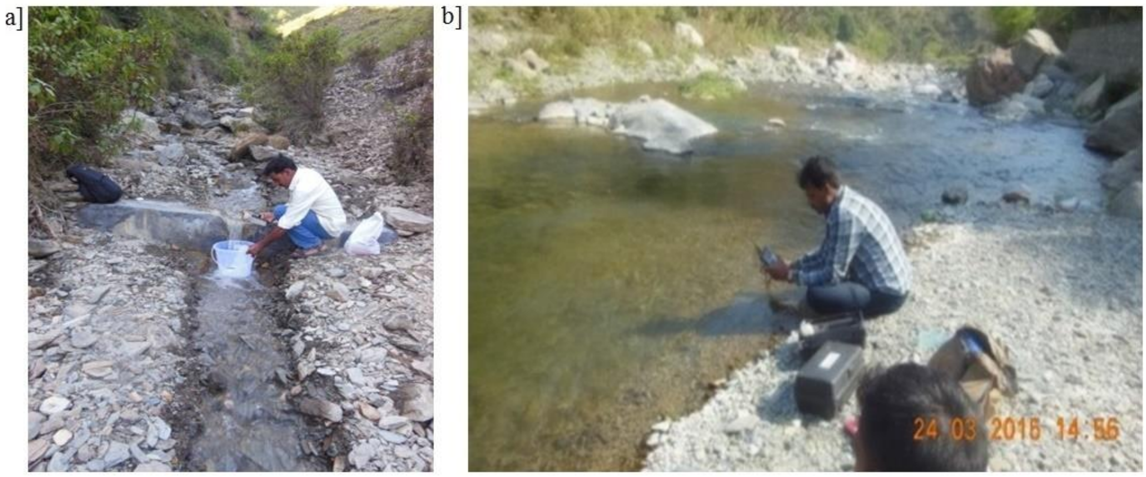


Figure 4a, b. Discharge measurement and pH, EC, and temperature measurement

4 Results and discussions

4.1 Water quality

The hydrological behavior of the Semalta watershed was studied for one year (2015-2016). pH, EC, and temperature of stream water were measured in the field using a portable pH meter. The details of sampling sites with their location and altitude are given in Table 1. The observed pH variation from March 2015-March 2016 is shown in Table 2.

Table 1. Sampling site characteristics

Sample ID	Location	Stream Order	Altitude (m)	pH	EC (dSm^{-1})	T (^{o}C)
SW-1	Samalta Khad	IV	1173	8.53	0.318	23.0
SW-2	Samalta Khad	III	1400	7.85	0.150	16.5
SW-3	Samalta Khad	III	1504	7.90	0.134	17.1
SW-4	Sopani Khad	II	1696	8.01	0.112	15.3
SW-5	Bamrar Khad	II	1690	8.08	0.084	14.2
SW-6	Bamrar Khad	III	1659	8.10	0.087	15.0
SW-6B	Sopani Khad	III	1650	8.10	0.087	15.0
SW-7	Jusau Bhakhrou Khad	II	1427	8.11	0.106	19.6
SW-9	Bamrar Khad	III	1427	8.20	0.132	18.8
SW-10	Amlava River	V	990	8.81	0.188	23.7
SW-11	Amlava River	V	990	8.82	0.192	21.8
SW-13	Phatyou Khad	III	1307	8.24	0.425	20.4
RW-1	Patiala Chhani	-	1754	-	-	-
RW-2	Dugianao Chhani	-	1574	-	-	-
RW-3	Thateu village	-	1400	-	-	-

(SW- stream water sampling site and RW-rain water sampling site)

The pH of the stream water varied from neutral to moderately alkaline whereas EC was non-saline for all the streams

Table 2. pH variation from March 2015-March 2016

	March, 2015	August 2015	September 2015	December 2015	January 2016	March 2016
SW-1	8.53	8.07	8.32	7.94	7.87	8.05
SW-2	7.85	7.82	7.76	7.60	7.67	7.75
SW-4	8.01	7.70	7.56	7.72	7.10	7.55
SW-5	8.08	7.67	7.37	7.33	6.97	7.33

Ion chromatography analysis indicated that a higher concentration of NH_4^+ together with NO_3^- might be due to the anthropogenic addition of fertilizers at recharge sites of SW-5 and SW-10 (Figure 5).

A higher concentration of calcium, SO_4^- and F^- was due to the presence of limestone and lithological pyrite, whereas, a higher percentage of HCO_3^- was due to pyrite weathering of slate in the catchment area. A similar study by the US geological department showed that a high concentration of calcium, silica, magnesium, etc., was mainly due to the bedrock weathering (Stallard and Murphy, 2012). The results of major cations and anions indicated that water was good for irrigation as well as for drinking purposes.

4.2. Altitude effects

Thirteen samples were analyzed for $\delta^{18}O$ using IRMS to investigate the altitude effects and their results are given in Table 3.

Table 3. Isotope data measured for stream and rainwater

Sample id	**Altitude (m)**	**$\delta^{18}O$ Mean (%)**
SW2	1400	-10.32
SW3	1505	-10.01
SW4	1695	-10.44
SW5	1690	-10.50
SW6	1659	-10.43
SW7	1427	-10.48
SW9	1427	-10.26
SW10	990	-9.30
SW11	990	-9.05
SW13	1315	-9.58
RW-1	1754	-11.01
RW-2	1574	-10.03
RW-3	1400	-9.23

(SW- stream water and RW-rain water)

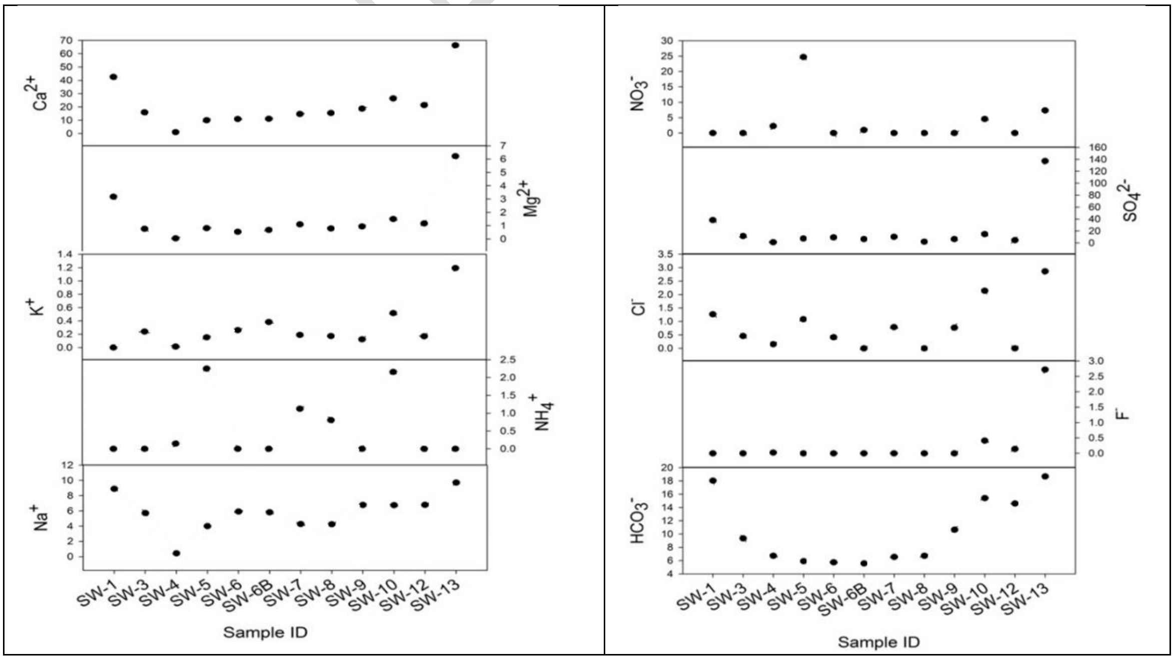


Figure 5. Hydrochemical analysis during March 2015-16 (mg/l)

The value of $\delta^{18}O$ was seen to decrease with increasing altitude and vice versa. Isotopic variation ($\delta^{18}O$ ‰) showed that samples collected with a total height difference of 700 m showed a variation of -1.5/700, i.e. -0.21‰ per 100 m (Figure 6); however, the effect of -0.5‰ per 100 m was better seen in rainwater samples which exhibited similar values as compared to reported values in Garhwal Himalayan region by Shivanna *et al.*, 2008. Here, it is important to note that the rain samples are better representatives of precipitation and have no interaction with lithological alterations. This provides a hope to use this proxy to detect the flow path of sub-surface water and helps in undertaking conservation measures and forms the basis for the dry spring rejuvenation. Only narrow and small subsurface pathways are found for recharge of springs located on higher altitudes, and therefore only small size of structures (measures) are required for recharging. But down the stream, size of the pathway increases and thus flow volume is also increased; therefore relatively larger structures (measures) are required for recharging. Discharge of a subsurface pathway/stream increases from higher elevation to lower elevation, and accordingly dimensions of path way/stream increases depending upon hydraulic gradient, lineaments intensity and geology of the terrain.

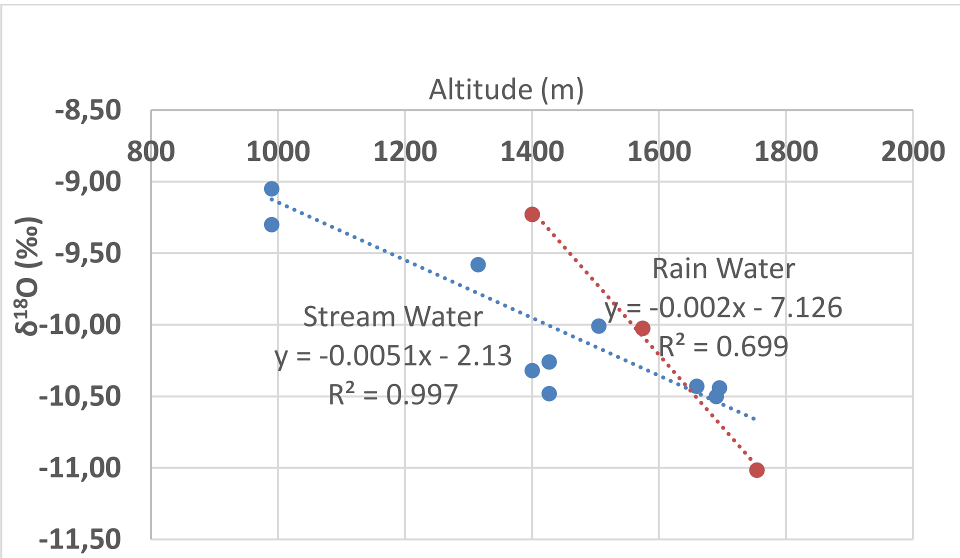


Figure 6. $\delta^{18}O$ vs altitude of stream water samples from Samalta watershed.

4.3. Stream discharge

Data on stream discharge indicated a gradual decrease in the post-monsoon and pre-monsoon season and the discharge rate varied in all the four sampling sites (Figure 7).

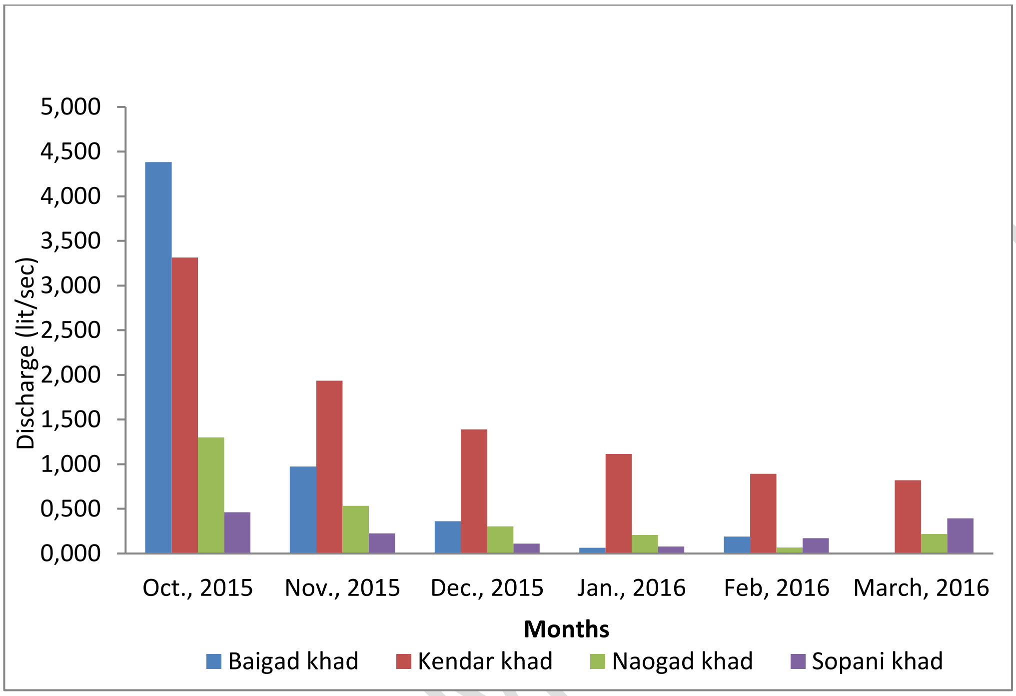


Figure 7. Stream discharge (lit/sec)

The Baigad khad showed the highest results in October 2015 and the lowest in March 2016. In addition to this, the Kendar khad and Naogad khad showed similar trends, whereas Sopani khad exhibited a fluctuating graph.

4.4. Isotope studies in locating artificial recharge structures

Stable isotopes studies are immensely used to locate artificial recharge structures and help in enhancing our efficiency of interventions in implementing artificial recharge mechanisms to increase the water retention in the physiographically and structurally delineated recharge zone which include (i) the bio fencing by planting trees with good rooting systems which could retain water, and (ii) putting multiple structures such as concrete dykes and saucer-shaped bowls along the subsurface flow paths to enhance the localized recharge and to increase water discharge downstream. Bioengineering measures such as staggered/contour trenches with plantation and geo-jute conservation with plantation were identified for the different springs/streams based on their position/location, geological formations, geomorphological characteristics, altitude, land use, and land cover characteristics. Based on the observations of isotopic study, Uplatal spring located near the village Damta was selected for the intervention of soil and water conservation measures, and accordingly, 300 staggered trenches of dimensions (3.0m x 0.5m x 0.3m.) were planned in the mountainous land of 1.22 ha area and oak tree plantation in between the trenches were also undertaken (ICAR-IISWC Annual Report, 2019). The effects of moisture retention by these trenches and their effects on spring discharge are under observation.

5 Conclusions

Narrow and enlarged subsurface pathways on higher and lower altitude springs are found respectively and therefore, discharge of a stream increases from higher elevation to lower elevation. Hence relatively larger structures are required for recharging in lower altitude as compared to higher altitude. Dip and strike of fracture and joints present in different geological units have given clues in ascertaining the direction of groundwater flow, which has formed the basis of recharge/catchment areas identification. The study indicated the discharge rate at different gauging sites gradually decreases from post-monsoon to pre-monsoon. Water quality parameters indicated that the pH of most of the stream water was mildly alkaline whereas EC was non-saline. The higher percentage of NH_4^+, NO_3^-, SO_4^- and F^- is due to anthropogenic additions and lithological pyrite, and the higher percentage of HCO_3^- is due to pyrite weathering in the slate. Results on the isotopic variation of $\delta^{18}O$ show that sample collected with a total height difference of 700 meters showed a variation of -1.5/700 *i.e.*,-0.21‰ per 100m for stream water and -0.5‰ per 100m for rainwater. This may be used as sampling techniques to ascertain the altitude of recharge of springs and may form the basis for taking appropriate measures for spring/stream rejuvenation.

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