

Hydrogeochemical assessment of spring water resources around Melamchi, Central Nepal

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Abstract

Groundwater in the hills and mountains is manifested as springs, the major water sources for people in Nepal's mountainous regions. The aim of this study was to investigate the seasonal variations of in-situ groundwater physicochemical parameters, evaluate groundwater hydrochemistry with respect to water types, and identify groundwater chemistry control mechanisms by analyzing spring water. The area's geology is dominated by schist and gneiss. Depression and fracture springs occur widely. The study involved observation of seasonal variations in in-situ physicochemical parameters, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), and temperature, and major ion concentrations – Ca^{2+} , Mg^{2+} , Na^+ , K^+ , HCO_3^- , Cl^- , SO_4^{2-} – to describe the water's chemical characteristics. The seasonal variations in physicochemical parameters arose mainly from monsoonal precipitation and its interactions with host rocks. Chemical analysis showed that Ca- HCO_3 type water dominated, indicating shallow aquifer groundwater processes. The relative abundance of cations was, in order, $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+$ and of anions $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$. Lithological contributions from the interactions of rocks with water across spring flow networks were the major mechanisms controlling spring water chemistry.

Key words: hydrogeochemistry, seasonal variation, springs, water quality

Highlights

- Springs are major sources of drinking water mainly in rural and semi-urban areas as well as in the surroundings of urban areas in the middle hill region of Nepal. Spring water quality dynamics in different seasons also affect human health. Therefore, spring water quality and seasonal variations of spring water quality become very important to assess for increasing water security of rural populations in Nepal. Moreover, springs are also major sources of non-snowfed rivers during the lean season, maintaining base flows. Thus, it is very important to understand how spring discharge variation is happening in a watershed.
- This manuscript investigates the spring discharge, quality of spring water in the Indrawati River. The Indrawati River is a major tributary of the Melamchi River, depending on which a major drinking water supply project to Kathmandu Valley is almost completed.
- The in-situ physicochemical water quality parameters along with major cations and anions are determined with spring discharge of the area providing new insights; how water and rock interactions generate ultimate water quality of spring water is highlighted.

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INTRODUCTION

Groundwater in the hills and mountains appears on the surface as springs, the natural discharge features of aquifers/groundwater systems. Springs are major lifelines for people in Nepal's mountainous regions, and are precious resources that play important roles in securing human requirements, maintaining balance in the ecosystem and providing riverine base flows.

According to Kresic & Stevanovic (2010), a spring is a location where groundwater discharges from the aquifer create visible flow on the land surface. The discharge is caused by the difference in elevation of the aquifer's hydraulic head and the land surface at that point. Geology is important in aquifer formation and, consequently, on groundwater accumulation and movement. It is also important in relation to local groundwater quality because of rock-water interactions. Reactions between groundwater and aquifer materials change water quality, which is also important in understanding groundwater genesis (Cederstrom 1946), because groundwater quality depends on the total amounts and kinds of minerals dissolved from the surrounding rocks. The concentration of dissolved ions depends on groundwater flow paths, and the interactions between rock and water (Hem 1985). The main cations in groundwater are derived mainly from the solution of minerals during chemical weathering, while the anions may be derived from non-lithologic sources.

Water quality has been an important issue in groundwater studies. The hydrogeochemical study of groundwater includes measurement of physicochemical parameters such as temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), and dissolved oxygen (DO), and the concentration of major cations: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+), and the major anions: bicarbonate (HCO_3^-), sulfate (SO_4^{2-}) and chlorine (Cl^-). These are important tools and decisive factors for water quality assessment (Ali & Ali 2014; Bharti *et al.* 2017).

Groundwater chemistry arises from geological and anthropogenic activities (Subramani *et al.* 2005). Different geochemical processes within the groundwater and aquifer materials affect the water's chemical quality. Study of the hydrogeological regime and groundwater chemistry shows the possible geological and anthropogenic influences on water quality (Kumar *et al.* 2006; Bhat & Jeelani 2016). It also aids water resource management by identifying the water's quality and its suitability for different purposes. For spring conservation, the term 'springshed' is introduced and the importance of springshed management in the Nepal Himalaya is highlighted (Rijal 2016). The aim of this study was to investigate seasonal variations in the in-situ physicochemical parameters of the groundwater, evaluate its hydrogeochemical characteristics with respect to water type, and identify the groundwater chemistry control mechanism. The water's suitability for drinking was also evaluated.

METHODS

The study area is in the Sindhupalchok district, northeast of the Kathmandu Valley, in Central Nepal. It includes Jyamire and Dubachaur, two major villages within Melamchi municipality. Geographically, the study area extends from $26^{\circ}49'30''$ N to $27^{\circ}53'00''$ N latitude and $85^{\circ}32'30''$ E to $85^{\circ}38'00''$ E longitude. The study area and relevant spring locations are shown in Figure 1.

Field measurements

An inventory of springs was an important part of this work and began with a field survey of springs using GPS (Global Positioning System). The physicochemical parameters: pH, EC, TDS, DO and temperature, were measured in-situ along with notes of the spring type, nature of discharge, surrounding land use and type of deposit. In-situ parameters were measured with a Mettlor Toledo field kit and discharge was determined using a bucket and stopwatch. The in-situ parameters were measured in

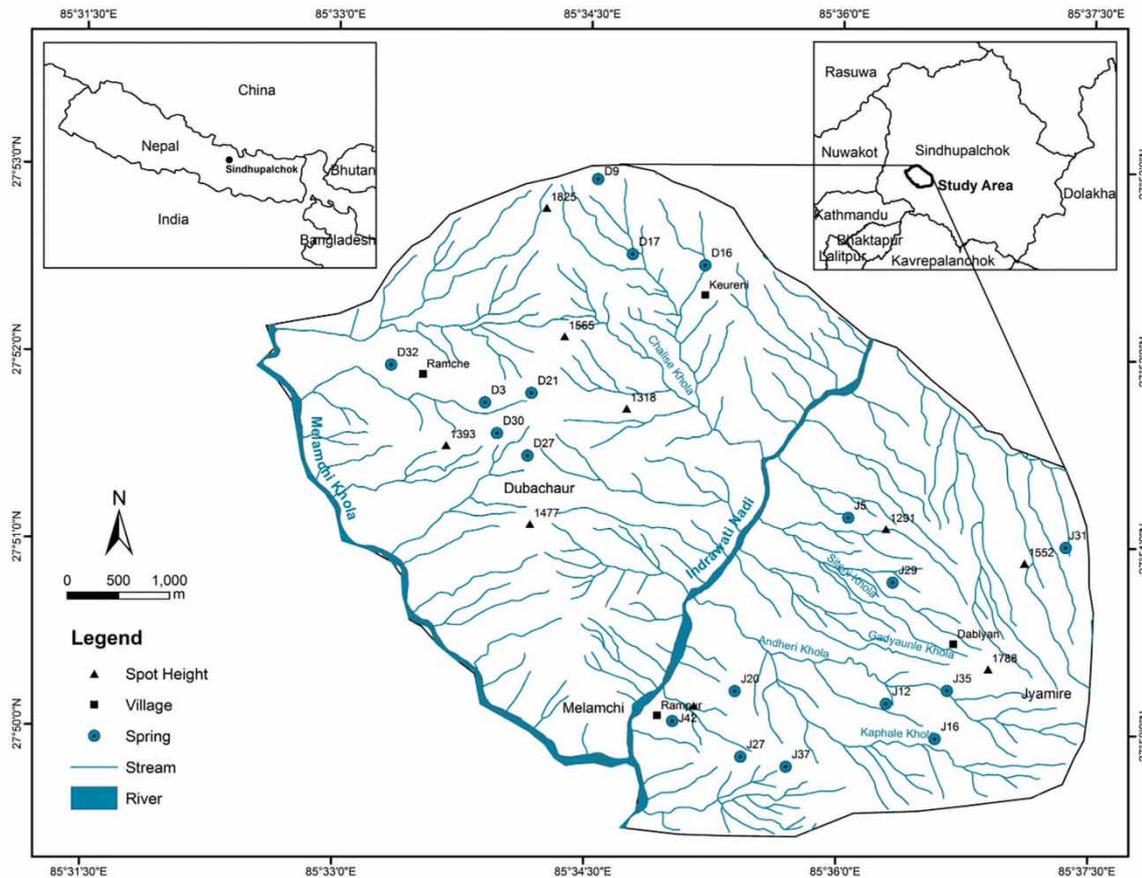


Figure 1 | Study area showing spot heights, major villages, drainage systems and springs.

May (pre-monsoon) and October 2017 (post-monsoon). The samples for laboratory analysis were collected post-monsoon only. Samples were collected in standard 1,000 ml bottles. Geological parameters, including rock type, structure, inclinations of rock strata with horizontal plane, dip and strike were also noted at the spring location where rock was exposed.

Laboratory analysis

A total of 18 springs were sampled post-monsoon (October 2017) for laboratory determination of the major cations and anions, and the data obtained were used for hydrogeochemical characterization using Piper diagrams and Gibbs plots. Piper (1944) uses a trilinear diagram for water classification with two triangles, one each for cations and anions. The diamond-shaped field between them is used to represent the water's composition with respect to both ionic groups. The Gibbs plot (1970) is used to determine the groundwater hydrogeochemistry control mechanisms and explain the relationship between groundwater chemistry and aquifer materials. The plot has three zones representing evaporation, rock, and precipitation dominance from top to bottom.

RESULTS AND DISCUSSION

Geological setting and spring occurrence

The study area lies in the Higher Himalaya region of Nepal Himalaya, where the major rock types observed were schist and gneiss. Dhital *et al.* (2002) note that the area is covered by the Talarang

Formation, with light to dark grey kyanite schist, garnetiferous schist, banded gneiss and quartzite (Figure 2). The sequence dips generally to the NW. The part of the study area east of Indrawati Nadi exhibits mostly medium to thick bedded, light to dark grey, slightly weathered schist. In some locations, garnetiferous schist and quartzite were also observed. Kyanite schist was observed mainly north of Siteni Khola. West of Indrawati Nadi, the geology mainly comprises highly weathered schist and medium to thick bedded gneiss exposed at a few locations.

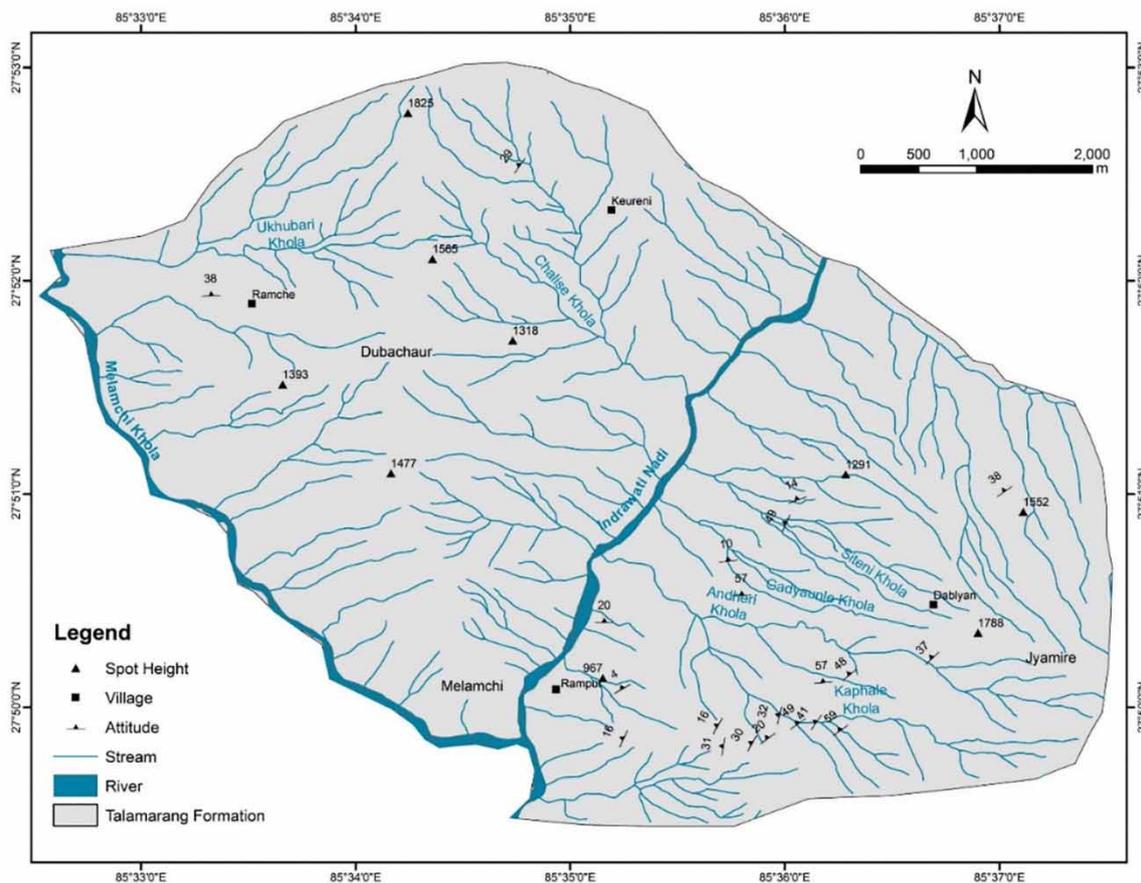


Figure 2 | Map showing major villages and the drainage system – as Figure 1 – and rock formations, dips and strikes (modified after Dhital *et al.* 2002).

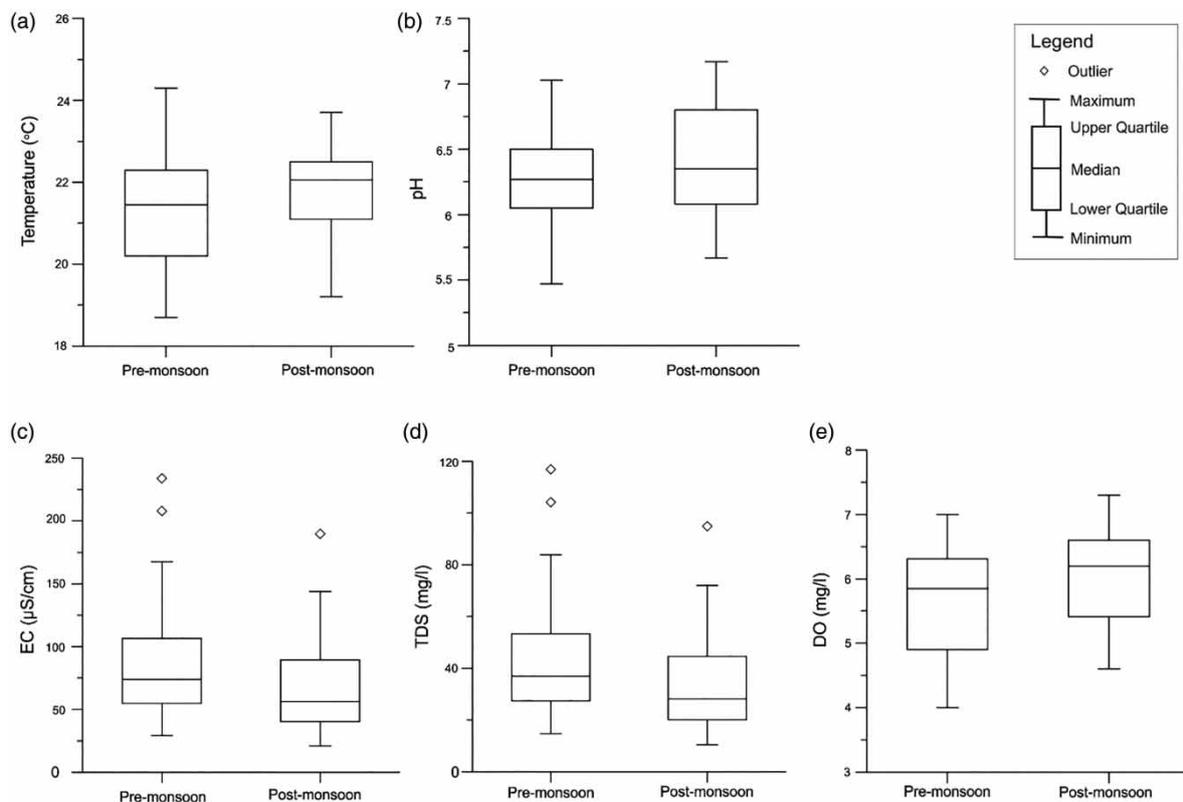
The type and nature of spring observed is characteristic of the local geology and structures. The springs mostly emerged from unconsolidated sediments in topographic depressions, mostly as seepages or concentrated discharges. Some springs emerged, however, from the contact between sediments and underlying strata. A third type of spring emerges from planes of weakness – e.g., rock fractures. Using Bryan's classification system (Bryan 1919) of the geological occurrence of springs, the majority were found to be depression and fracture springs. The presence of thick unconsolidated sediments on the slopes make depression springs prevalent in the region, while fracture springs were also observed. Fractured gneiss and schist account for groundwater storage and transmission. Eighteen springs were selected for study and are described in Table 1.

Seasonal variation of in-situ physicochemical parameters

The water's physicochemical parameters were analyzed statistically. The results are presented in box and whisker plots (Figure 3). The pH values fell within the range 5.5–7.0 pre-monsoon and 5.7–7.2

Table 1 | Springs with their inventory parameters – elevation, type, discharge, land use and surface condition

Code	Name	Elevation (m)	Type	Discharge	Land use	Surface condition
J5	Chalise mul	1,294	Depression	Flowing	Cultivation	Residual soil
J12	Kharichaur mul	1,542	Depression	Flowing	Sparse forest	Residual soil
J16	Thulo dhara	1,416	Depression	Flowing	Cultivation	Residual soil
J20	Nayaghari tol mul	1,217	Depression	Flowing	Bush	Residual soil
J27	Nyare mul	1,227	Depression	Seepage	Cultivation	Residual soil
J29	Kole dhara	1,493	Depression	Flowing	Cultivation	Residual soil
J31	Maiti khola mul	1,625	Depression	Flowing	Dense forest	Colluvium
J35	Adheri Khola mul	1,658	Fracture	Flowing	Dense forest	Rock (Schist)
J37	Salle dhara	1,352	Depression	Flowing	Bush	Residual soil
J42	Thari dhara	1,187	Fracture	Flowing	Bush	Rock (Schist)
D3	Thulichaur ko kuwa	1,518	Contact	Seepage	Bush	Residual soil
D9	Angare khet mul	1,700	Depression	Flowing	Bush	Colluvium
D16	Nagthan mul	1,372	Depression	Flowing	Sparse forest	Colluvium
D17	Andheri mul	1,348	Fracture	Flowing	Dense forest	Rock (Schist)
D21	Birtako Padhero	1,546	Depression	Seepage	Bush	Residual soil
D27	Syanbotol mul	1,428	Depression	Flowing	Sparse forest	Residual soil
D30	Dhungedhara	1,479	Depression	Flowing	Bush	Residual soil
D32	Jaleshwori mul	1,221	Fracture	Flowing	Sparse forest	Rock (Gneiss)

**Figure 3** | Box and whisker plot of spring water in-situ physicochemical parameters, pre- and post- monsoon. (a) Temperature (b) pH (c) EC (d) TDS (e) DO. The boxes and whiskers indicate the statistical distribution parameters – minimum and maximum, first and third quartiles, and medians. The open dots outside the boxes represent outliers.

post-monsoon; that is, local spring waters are slightly acidic to marginally alkaline. The minimal alkalinity may be attributed to the presence of bicarbonate ions produced by the formation of carbonic acid. The spring water EC ranges from 29.3 to 234 $\mu\text{S}/\text{cm}$ pre-monsoon and 20.9 to 189.8 $\mu\text{S}/\text{cm}$ post-monsoon. Pre-monsoon values are higher than post-monsoon because there is less groundwater recharge before the monsoon and groundwater residence time is longer. After the monsoon, when there has been significant groundwater recharge and shorter residence time, less rock-water interaction has led to lower ion concentrations. Springs showed changes in EC levels between seasons. In the majority of springs, the change was less than 30 $\mu\text{S}/\text{cm}$ but in a few (5) it was between 30 and 70 $\mu\text{S}/\text{cm}$. The TDS ranged from 14.6 to 116.9 mg/l pre-monsoon and 10.5 to 94.9 mg/l post-monsoon, the high pre-monsoon TDS values and their significant decrease post-monsoon indicate rocks as the source of dissolved solids in the water. Similarly, DO ranged from 4 to 7 mg/l pre-monsoon and 4.6 to 7.3 mg/l post-monsoon. The concentration of DO decreased during summer as temperatures rose, but biochemical processes and water-rock interactions might also have played role in the change. Slight differences between spring water temperatures were recorded in May and October 2017, with a range from 18.7 to 24.3 °C pre-monsoon and 19.2 to 23.7 °C post-monsoon.

Chemical parameters

The concentration ranges of major ions obtained from the laboratory analyses are presented in Table 2 – see also Figure 4, which shows the related box and whisker plots.

Table 2 | Minimum and maximum concentrations of major cations and anions in spring waters post-monsoon

Parameter	Minimum (mg/l)	Maximum (mg/l)
Ca ²⁺	0.8	44
Mg ²⁺	0.5	5.8
Na ⁺	2.7	11.9
K ⁺	0.6	5.7
HCO ₃ ⁻	14.9	124.4
SO ₄ ²⁻	0.9	4.1
Cl ⁻	0.5	25.1

Groundwater is derived from precipitation such as rainfall, which contains very low concentrations of dissolved minerals. When it seeps into the ground, it begins by moving through the inter-connected pores in the soil, unconsolidated sediments, and rock fractures. Mineral dissolution in soil, sediments and rocks is slow and depends on their solubility. Because of this, the water from spring J20 (outlier in Figures 3(d) and 4), which is at a lower elevation (1,217 m) than the others, contains high concentrations of ions. The exception is spring J42 (1,187 m), which has lower concentrations than spring J40, possibly due to the different spring types – J40 is a depression spring and J42 a fracture spring. The fracture networks provide direct pathways for water flow towards discharge points; that is, springs, allowing less time for interactions than the paths to depression springs.

Comparing the spring waters' physical and chemical parameters, all are within the limits in the National Drinking Water Quality Standards (NDWQS 2005) and the World Health Organization's recommendations (WHO 2011), except that the majority of spring waters report pH below 6.5.

Seasonal variation in discharge

The discharges for 13 springs at the two sampling times are shown in Figure 5. Spring discharges are higher post-monsoon than pre-monsoon, and ranged from 1.7 to 62.5 L/m pre-monsoon and 5.5 to

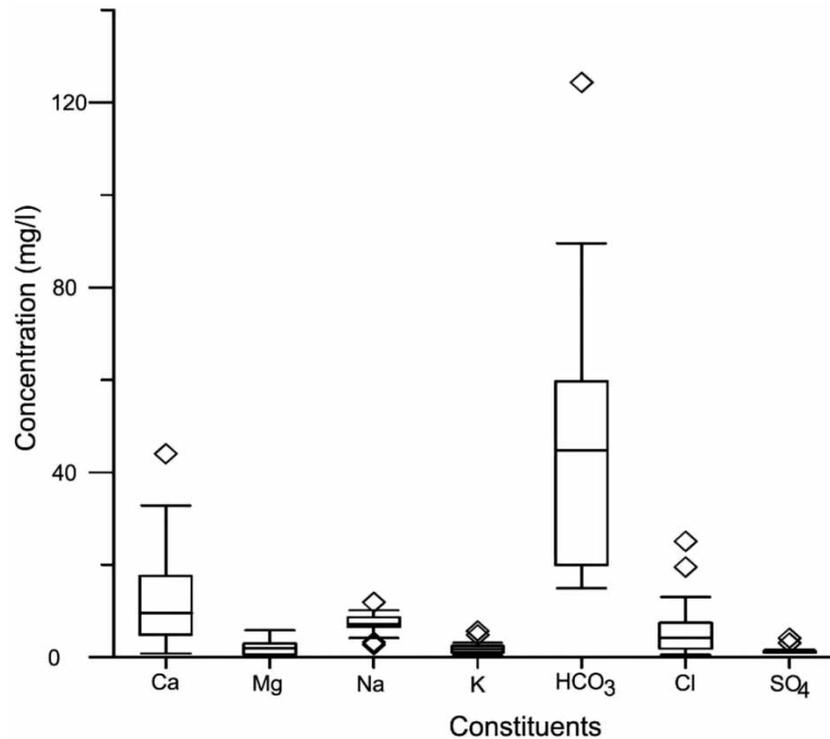


Figure 4 | Box and whisker plot of major cations and anions in post-monsoon spring water. Values above the boxes are outliers.

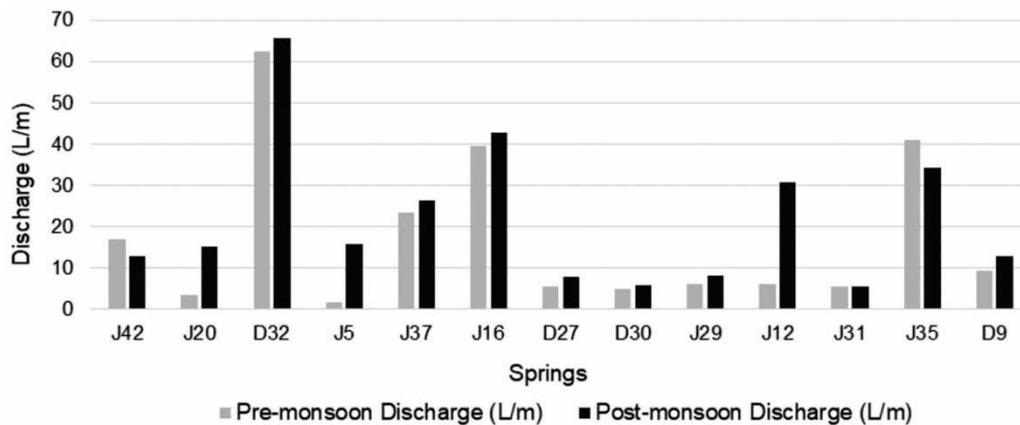


Figure 5 | Pre- and post- monsoon spring discharges.

65.7 L/m post-monsoon. Post-monsoon spring discharges are very high in most springs, indicating enhancement by monsoonal precipitation. However, two fracture springs (J42 and J35) have higher pre-monsoon than post-monsoon discharge because the high discharge rates disturbed the original fracture network, creating new flow-paths during the summer monsoon, all of which could not be captured during discharge measurement. In some places, regolith removal by shallow, rain-induced landslides is also related to such spring discharge behavior patterns. The change in discharge rate in springs seem to be similar except spring J12, which shows much more significant increase after the monsoon than any other. J12 emerges in a topographic depression whose primary storage is the unconsolidated soil and sediments around the spring, which are recharged quickly, increasing the flow.

Hydrogeochemical characterization of spring water

Identifying areas with different groundwater types helps in the sustainable management of groundwater resources. The hydrogeochemical regime of groundwater in the study area can be determined by plotting the spring waters' analytical values on a Piper (1944) trilinear diagram. The classification was done using USGS GW Chart (Version 1.29) to plot the cationic and anionic concentrations. All seven ionic species were included in the data clustering. Of the spring waters studied, 16 are of Ca-HCO₃ type, one (D16) appears in field 4, indicating a mixed Ca-Mg-Cl type, and one (D9) in field 3, indicating mixed Ca-Na-HCO₃ type (Figure 6).

The study suggests that, in the waters of the study area, alkaline earth metals (Ca²⁺ and Mg²⁺) predominate over alkali metals (Na⁺ and K⁺) and weak acids (HCO₃⁻) predominate over strong ones (Cl⁻ and SO₄²⁻). Spring D9 reported the lowest calcium, sodium and bicarbonate concentrations, while spring D16 reported the highest chlorine concentration. The majority having Ca-HCO₃ water type indicates that most springs are fed by shallow aquifers.

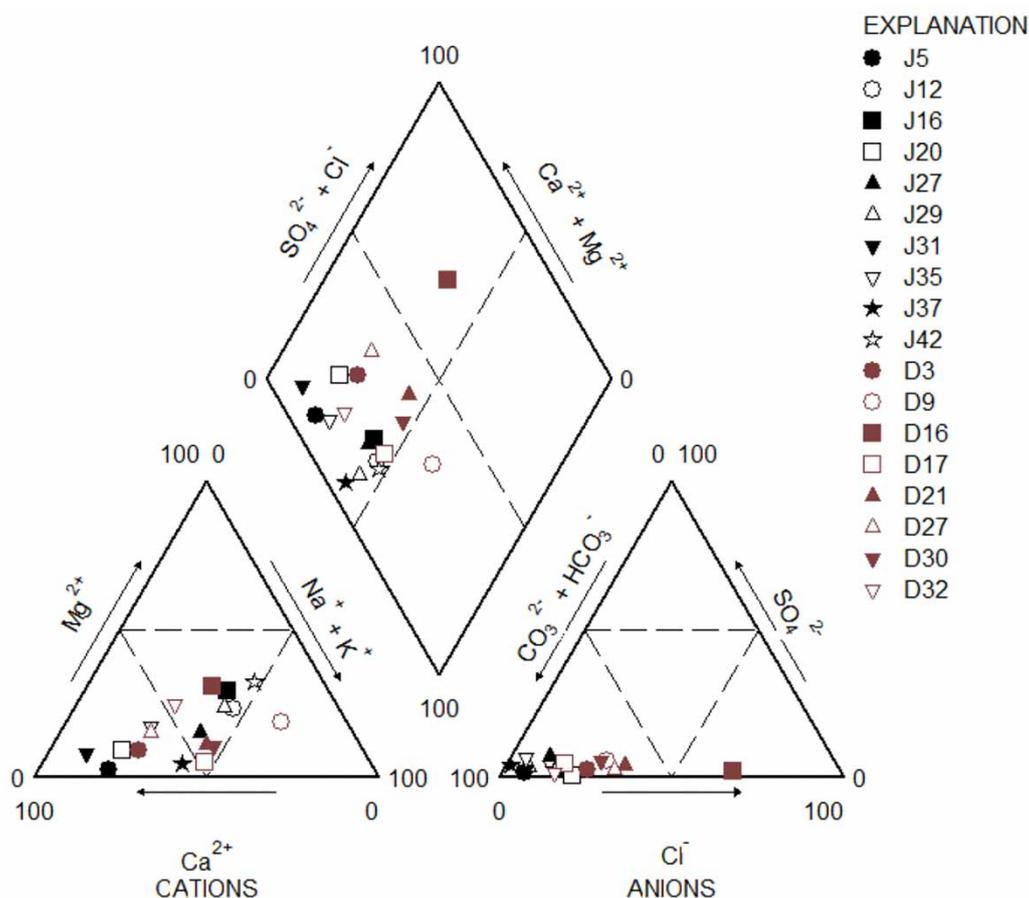


Figure 6 | Piper diagram of the major ion content of the spring waters studied.

Mechanisms controlling groundwater chemistry

Gibbs plots (Gibbs 1970) were used to study the relationship between water composition and the aquifers' lithologic characteristics. As shown in Figure 7, lithology and precipitation are the most significant contributors to spring water chemistry.

The concentration of major cations and anions present in the groundwater depends on the hydrogeochemical processes occurring in the aquifer system (Glover *et al.* 2012). As the groundwater

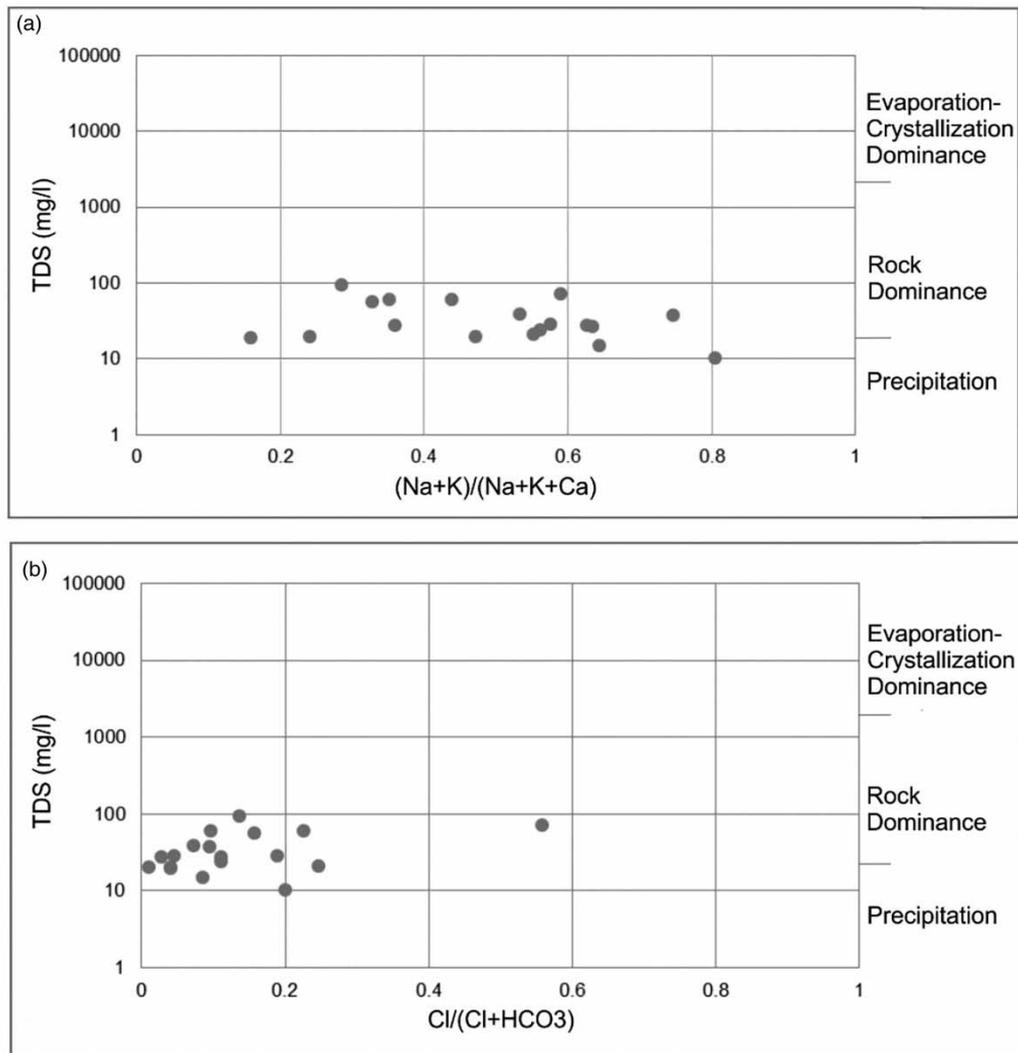


Figure 7 | Gibbs diagram showing TDS vs (a) $[Na^{2+} + K^+ / (Na^{2+} + K^+ + Ca^{2+})]$ (b) $[Cl^- / (Cl^- + HCO_3^-)]$.

travels from recharge to discharge, a variety of hydrogeological processes alter its chemical content so that, at the discharge zone, it has higher mineral content than in the recharge area due to its residence time and contact with the aquifer matrix (Freeze & Cherry 1979; Sridhar *et al.* 2013). The low ionic concentrations in spring D9, which is at 1,700 m elevation, are related to the limited contact time and interactions with the aquifer matrix there. The analytical results for most samples fall into the rock-water interaction zone of the Gibbs plot, indicating the predominance of interaction between the rocks and the percolating water.

CONCLUDING REMARKS

Variation in the in-situ physicochemical parameters (pH, EC, TDS, DO, temperature) of spring waters in different seasons was studied. The type of water was characterized with respect to content of major ionic species (Ca^{2+} , Mg^{2+} , Na^+ , K^+ , HCO_3^- , SO_4^{2-} and Cl^-) and the hydrogeochemical processes responsible for the ionic concentrations identified. Geologically, the study area comprises light to dark grey kyanite schist, garnetiferous schist, banded gneiss and quartzite. The local geological conditions indicate a majority of depression and fracture springs. Seasonal variations in the in-situ

physicochemical parameters and spring discharge were observed mainly due to the influence of monsoon precipitation.

The spring water is slightly acidic to marginally alkaline. The general order of dominance of major cations is $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+$ and major anions $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$. Piper and Gibbs diagrams were used to study the waters' hydrogeochemical composition. The major ion concentrations, when plotted in the Piper diagram, indicate calcium and bicarbonate dominating the aquifer, suggesting that springs are fed by shallow water-bearing zones. The Gibbs plot shows that groundwater quality in the area is influenced mainly by rock-water interactions.

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DISCLAIMER

The views and interpretations in this publication are those of the authors and they are not necessarily attributable to their organizations.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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