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Hydro-geochemical characterization and suitability analysis of spring water of the Mai Khola watershed, Ilam, eastern Nepal

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ABSTRACT

The interaction of different physical and chemical factors as well as anthropogenic activities influences the chemistry of groundwater. The hydro-geochemical assessment of the groundwater is the basic part of the water resources management and its assessment in regards to its usability is considered vital. The study involves the measurement of physicochemical parameters (pH, EC, EH, DO, TDS) of the observed 147 springs and the ionic concentration of the representative 32 springs along the Mai Khola Watershed using standard analytical procedure. The results of the physicochemical parameters and ionic concentration were analysed and interpreted using different indices and graphical methods. The physicochemical parameter suggests that spring water is weakly acidic to alkaline and the measured EC and TDS suggest low interaction of rocks and water therein. The piper diagram indicates Ca^{2+} and Mg^{2+} together (alkaline earth metals) dominate over combined Na^+ and K^+ (alkali metals) and Cl^- and SO_4^{2-} (strong acids) predominate over HCO_3^- (weak ones). The Gibbs plot also satisfies the movement of groundwater from the precipitation domain to the rock-water interaction domain. The groundwater in this area is derived from a shallow aquifer with low rock-water interaction and the water is good for drinking purpose and excellent to good for irrigation. The spring water in the study area possesses no threat to quality deterioration, however proper management and conservation plans are required to maintain the quality of the water.

Keywords: Hydrogeochemistry, groundwater characterization, springs, WQI, suitability

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INTRODUCTION

Springs are the manifestation of groundwater on the surface of the hills and mountains, as the natural discharge through the aquifer system (Khadka and Rijal, 2020). These springs serve as the lifeline for the residents of the mountainous area by fulfilling their daily requirements (domestic and agricultural), balancing the ecosystem, and providing base flow to the river.

Groundwater quality tends to vary with time, and the variation occurs either by natural phenomena or due to human-induced activities. The quality depends upon the chemical and mineralogical composition of geological materials that makes up the aquifer, the quality of water recharging the aquifer, interaction of the water with the rock or soil, and residence time in the aquifer (Freeze and Cherry, 1979). The industrial effluents and agricultural activities is presently the most prominent anthropogenic factor governing the hydrogeochemistry of the region (Paudel et al., 2015). Meanwhile, the over-abstraction of this subsurface water is also believed to threaten the quality in many parts around the globe (Kaur et al., 2019).

The information on the geology of the aquifer system, hydrogeochemical characterization, and suitability analysis is an initial step toward the management of groundwater resources (Howarth, 2013). The assessment of groundwater quality provides comparative insight on whether the quality is the function of rock-water interaction or human-induced alteration. The groundwater hydrogeochemistry can be better used in understanding the different processes and changes, that the water has undergone, starting from precipitation to surface flow, infiltration, and ultimately during the residence time in an aquifer (Kaur et al., 2019). The assessment of the water quality from the perspective of usability is also the most critical part of the assessment. In the present study, the effort has been made to evaluate the hydro-geochemical processes influencing the groundwater in the Mai Khola watershed. Similarly, an attempt has been made to analyze the excellence of water for drinking and irrigation purposes, where spring water is the major source of water for usage. The result could be best used for groundwater resource management for sustainable use of these vulnerable sources. The result also provides baseline data that could be used for comparison in the future for detecting water quality changes.

Study area

The study area is in the Ilam district of Province 1, Eastern Nepal (Fig. 1), with hilly terrain, which is characterized by spur, saddle, and ridge morphology. The Mai Khola watershed is a sub-watershed of a larger Kankai River Basin and is a rainfed perennial river system in Eastern Nepal. The river is a major tributary of the Kankai River Basin that originates in the Sandakpur area and flows south to confluence with the Jogmai Khola. The land surface elevation in the watershed varies from 879 and 3586 meters above mean sea level. The river has a dendritic pattern with multiple small streams mixing and contributing to the river base flow. The area is bounded by the two major south trending spurs with a deep and narrow valley in between During the summer monsoon, these little rivers and streams are drained with a large amount of water and have the potential to cause flooding and other water-induced disasters. The area is well known for the tea cultivation and dairy products. Agriculture and animal husbandry is the major income-generating source for the people of rural area. The landuse mainly comprises of the forest area, cultivation area, and settlements. The northern and northeast part of the watershed is covered by the dense mixed forest. Whereas, the settlements are concentrated on the saddle and flat parts of the hills. The geology of the area has been described as the Mahabharat Crystallines (southern extension of Higher Himalayan thrust sheet), consisting of foliated kyanite-sillimanite bearing gneiss, biotite schist, metaquartzite, amphibolite, calc-silicate gneiss, and augen gneiss (Schelling, 1992). The kyanite-sillimanite bearing gneiss of the area resembles the schistose gneiss consisting of kyanite, sillimanite, garnet, quartz, and plagioclase feldspar (Chamlagain et al., 2003).

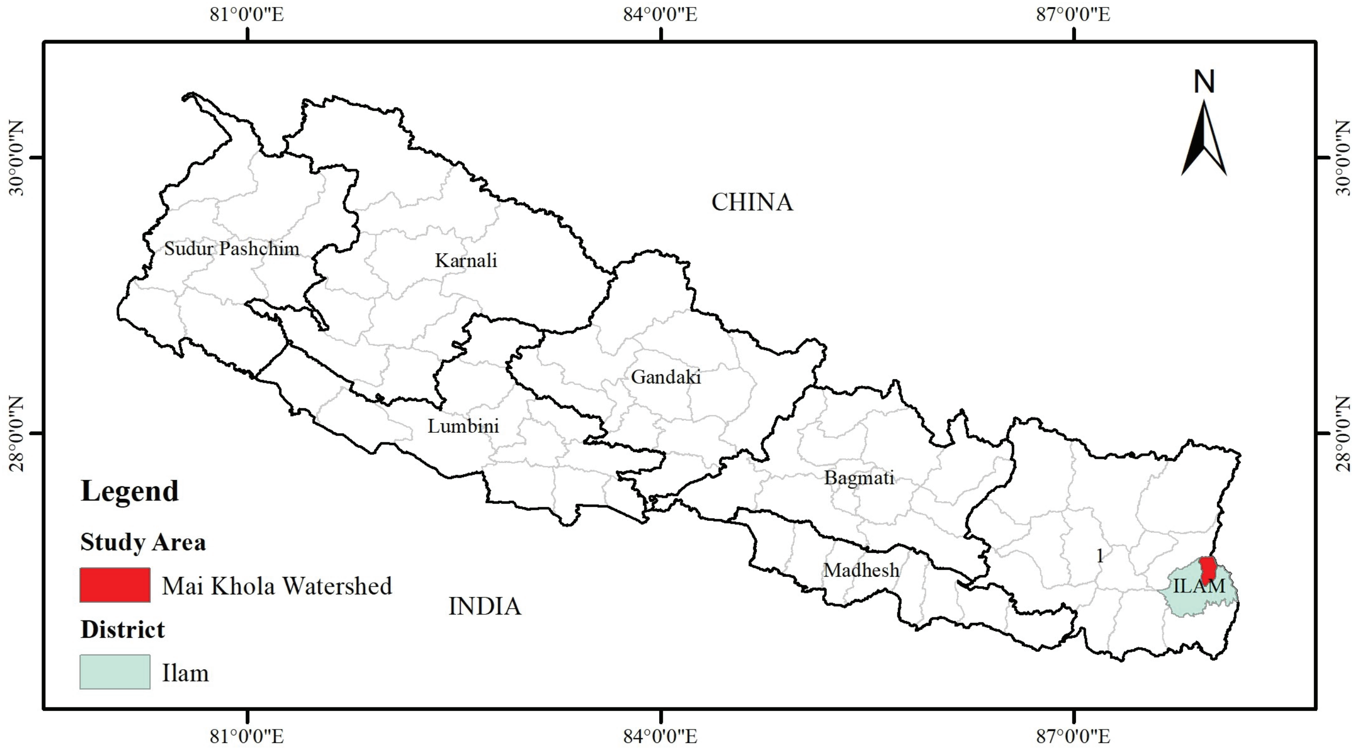

Fig. 1: Location map of the study area.

METHODOLOGY

The hydrogeochemical assessment includes the measurement of in-situ physicochemical parameters, that is pH, Eh, EC, TDS, and DO along with the chemical analysis for major cations and anions (Bharati et al., 2017). For the hydrogeochemical characterization and suitability analysis of the spring water, the spring inventory of 147 springs was conducted in March 2021 using standard kits and devices. Among them 32 spring water samples were collected, for laboratory analysis (Fig. 2). Figure 2 represents the location of springs along the study area, on which the dot represents the springs under consideration. The springs denoted by the red dots are the spring sampled for laboratory analysis. The springs were selected in such a way, that they represent all the aspects of the watershed including the spatial distribution, landuse, geological formation, and elevation. The water samples were collected and stored at ~4°C in 1 L capacity plastic water bottles, until analysis. The bottles were rinsed several times with the same spring water before filling with water samples to minimize the chance of any contamination. American Public Health Association (APHA, 2005) was adopted as the standard method for sample preservation and analytical techniques. The physicochemical parameters: Hydrogen ion concentration (pH) and Oxidation Reduction Potential (ORP/Eh), Total Dissolved Solids (TDS) and Electrical Conductivity (EC), and Dissolved Oxygen

(DO) of the water samples were measured in the field using a portable Eh/pH meter (HI98121), EC/TDS meter (HI98312), and a DO meter (HI98193) by Hanna Instruments, respectively. The concentration of Sodium (Na^{2+}), Potassium (K^{+}), and Calcium (Ca^{2+}) ions were determined by Flame Photometry, whereas, the Hardness, Alkalinity (HCO^{3-}), and Chloride (Cl^{-}) concentrations were determined by titration, while that of Iron (Fe^{3+}), Nitrate (NO_3^{-}), and Sulfate (SO_4^{2-}) was measured by Spectrophotometric method. The concentration of magnesium (Mg^{2+}) was determined from the calculation method following the APHA (2005). Before analysis, the concentration of ions determined was evaluated using the ion balance error method. The hydrogeochemical characterization and control mechanism of the spring water was determined using the Piper diagram (Piper, 1944), Gibbs plot (Gibbs, 1970), and Chloro-alkaline Indices (Schoeller, 1965). The suitability analysis was determined using the Weighted Arithmetic Water Quality Index (WAWQI) with a comparison to Nepal Drinking Water Quality Standard (NDWQS, 2005) for drinking purposes, while, Wilcox's diagram (Wilcox, 1948) and the United States Salinity Laboratory Staff (USSLS's diagram) (USSLS, 1954) were used for irrigation purposes.

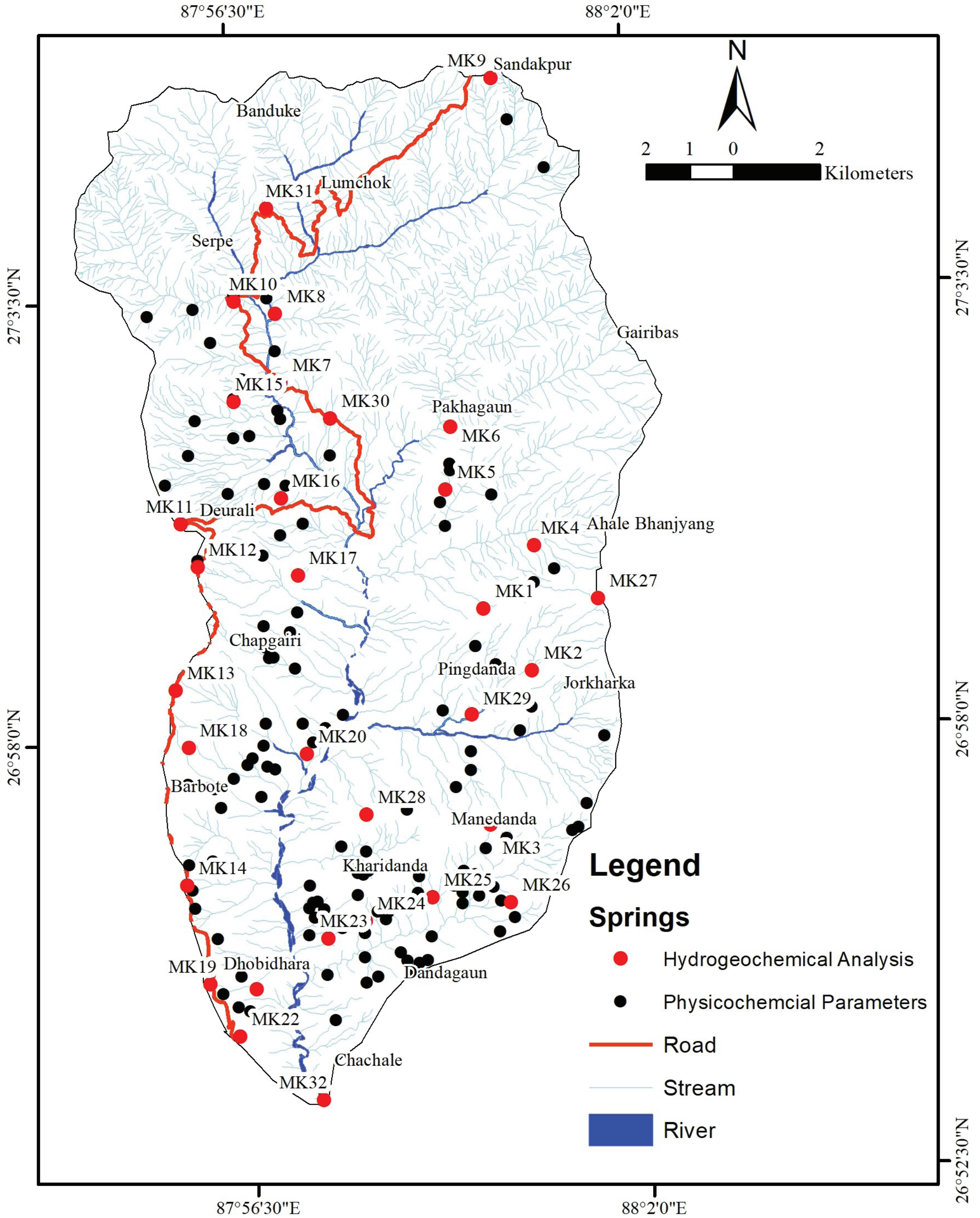

Fig. 2: Distribution of springs for physicochemical parameters and the hydrogeochemical analysis.

RESULT AND DISCUSSION

The majority of the 147 springs identified in the area suggest that soil deposit, dense forest, terrace farming, topographic break, rock sediment interface, and rock fracture contributes to the occurrence of the springs along the area. The majority of the springs observed are perennial and are being used for residential and agricultural purposes.

In-situ physicochemical parameters

The physicochemical parameters of the 147 springs (Fig. 2) were analyzed statistically (Table 1). The results are presented in box and whisker plots (Fig. 3). The pH values lie within the range of 6.06–8.970, with an average of 7.13, which indicates the spring's water is slightly acidic to alkaline. Similarly, the Eh concentrations ranged from 42 - 414 mV, with an average of 311.67 mV indicating alkaline water, which is safe for drinking. EC ranges from 11 - 408 µS/cm with an average of 106.12 µS/cm and indicates that the area as a whole appears to be in low interaction of water with aquifer materials. This is also well supported by the low TDS level that ranges from 6 - 310 mg/l, with 65.69 mg/l as an average. The DO level ranges from 2.25 - 7.95 mg/l, with 5.23 mg/l as an average suggesting that the water might have gone through water-rock interaction and other biochemical reactions.

Chemical parameters

For interpretation of the chemical analysis of water, it is essential to compute the ionic-balance-error, expressing the concentrations of ions in milliequivalent per litre (meq/l) by converting their concentrations from milligram per litre (mg/l). The difference between the total cations (Ca^{2+}+ Mg^{2+}+ Na^{+}+ K^{+}) and total anions (Cl^{-}+ SO_4^{2-}+ NO_3^{-}+ HCO_3^{-}) lies within the acceptable limit of ±10% for the interpretation of data for any purpose from the hydro-geochemical point of view (Fig. 4).

Table 1: Summary statistics of measured in-situ physiochemical parameters.

Statistic	pH	Eh (mV)	EC (µS)	TDS (ppm)	DO (mg/l)
Minimum	6.06	42.00	11.00	6.00	2.25
Maximum	8.97	414.00	408.00	310.00	7.95
Mean	7.13	311.67	106.13	65.69	5.23
Standard deviation (n)	0.61	57.90	85.11	51.01	0.97
Coefficient of Variation	0.08	0.19	0.80	0.78	0.19

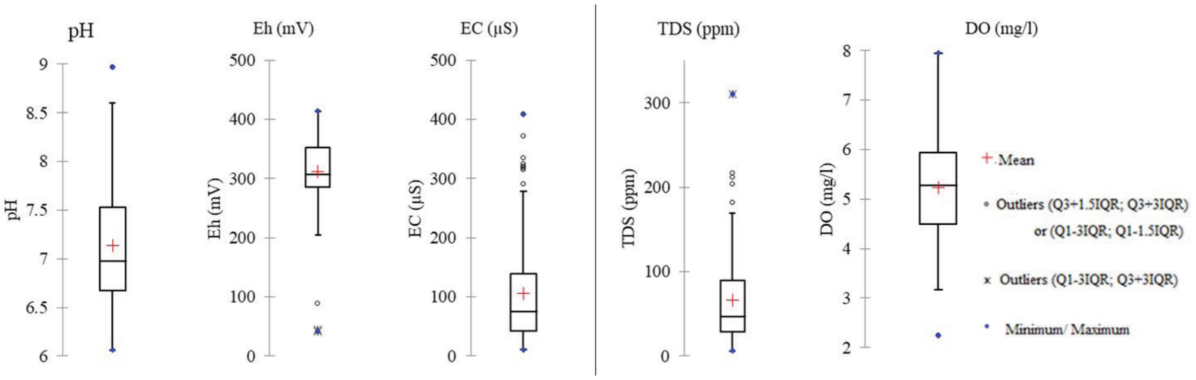

Fig. 3: Box and whisker plot showing the statistical distribution of in-situ physicochemical parameters of the spring water.

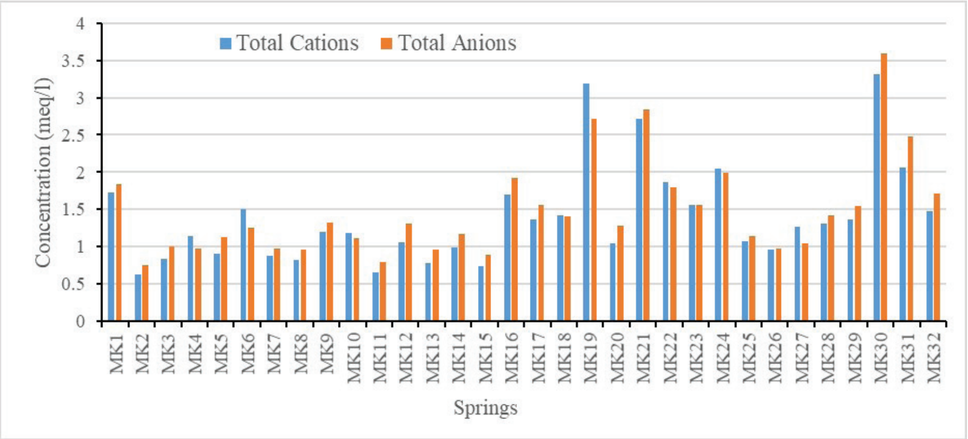

Fig. 4: Bar graph showing the total cation and anion (meq/l) for ionic balance errors.

The concentration ranges of major ions obtained from the laboratory analyses are presented in Table 2, and Figure 5 represents the respective box and whisker plots, which indicates that HCO_3 has a higher concentration and central value than the other ions present in the water. The mean of the ionic concentration shows the relative abundance of cations in the order of $Na^+ > Mg^{2+} > Ca^{2+} > K^+ > Fe$, while the anions are in order $HCO_3^- > Cl^- > SO_4^- > NO_3^-$. The relatively low concentrations of the ions in the water suggest shallow aquifer zones with low residence time and less rock water interaction.

Hydro-geochemical characterization of the spring water

The identification of areas with various groundwater types aids in the long-term management plans of groundwater resources. Plotting the analytical values of spring waters on a Piper/trilinear diagram (Piper, 1944) can indicate the hydrogeochemical regime of groundwater. Analysis of the major anions and cations using the piper diagram (Fig. 6) reveals, the dominance of alkaline earth metals (Ca^{2+} and Mg^{2+}) over alkali metals (Na^+ and K^+) (Zone1) and strong acids (Cl^- and SO_4^{2-}) over weak ones (HCO_3^-) (Zone 3), indicating the permanent hardness. The dominance of alkaline earth metals signifies the prevalence of natural weathering over the anthropogenic source (Srivastava and Ramanathan, 2018). Similarly, 8 samples show the carbonate hardness predominates over alkaline earth and weak acids (Zone 5), and 17 water samples reported that no cation-anion pair exceeds 50% or Mixed type (Zone 9). Similarly, 6 groundwater samples indicate non-carbonate alkali predominates other (Zone 7), while, only one shows non-carbonate predominates other (Zone 6). Groundwater derives the major cations from the interaction with the geological material. Whereas, the anions may be derived from non-lithological sources (Khadka and Rijal, 2020). The hydrolysis of plagioclase (Ca- feldspar) alters it to Kaolinite and releases Ca^{2+} in solution and similar is released from Sodium and Potassium feldspars (Earle, 2019). The quartzite and gneisses of the region consists of abundant feldspars, that alters to the clay minerals (Kaolinite, vermiculite, smectite and chlorite) during the chemical weathering and has been identified by the thin section study and XRD analysis of soil in the region (Regmi et al., 2014). The Na^+ and Ca^{2+} in the water thus, can be attributed to the products by the hydrolysis of feldspar in the gneiss and schist of the area. Whereas the concentration of HCO_3^- and Ca^{2+}, can be attributed to the calc-silicates of the Higher Himalayan Crystallines.

Table 2: Summary statistics of major cations and anions in spring water.

Statistic	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	NO_3^-	Fe	HCO_3^-
Minimum	1.4	2.7	0.0	0.5	8.5	1.7	0.2	0.0	16
Maximum	30.2	3.7	30.0	18.7	44.0	29.9	9.8	1.3	184
Mean	10.7	2.9	4.8	7.0	20.9	8.2	2.2	0.3	43.6
Standard Deviation	6.4	0.3	5.9	4.7	8.1	6.5	2.7	0.3	33.1
Coefficient of Variation	0.6	0.1	1.2	0.7	0.4	0.8	1.2	0.9	0.8

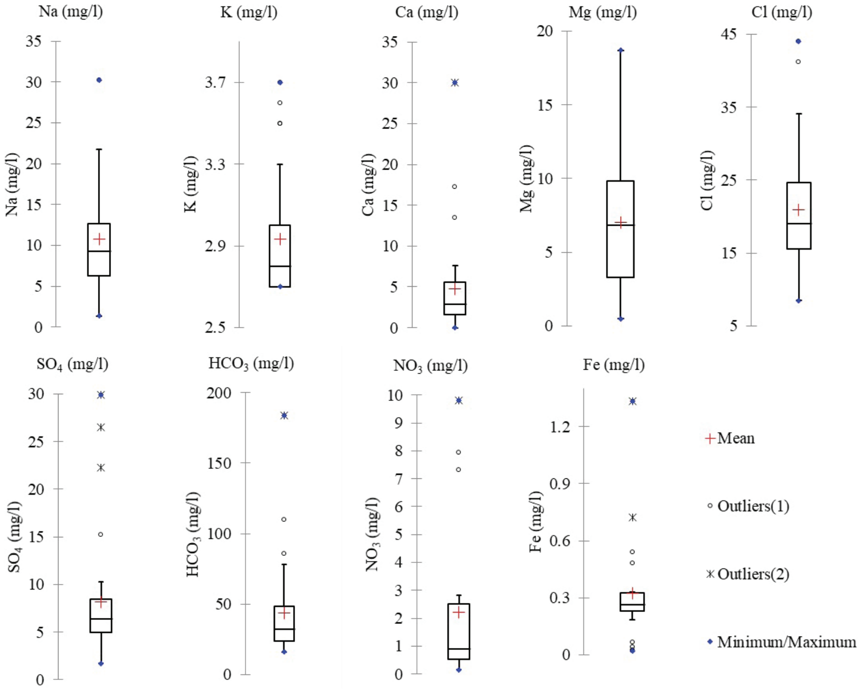

Fig. 5: Box and whisker plot showing the statistical distribution of the ionic constituents of the spring water.

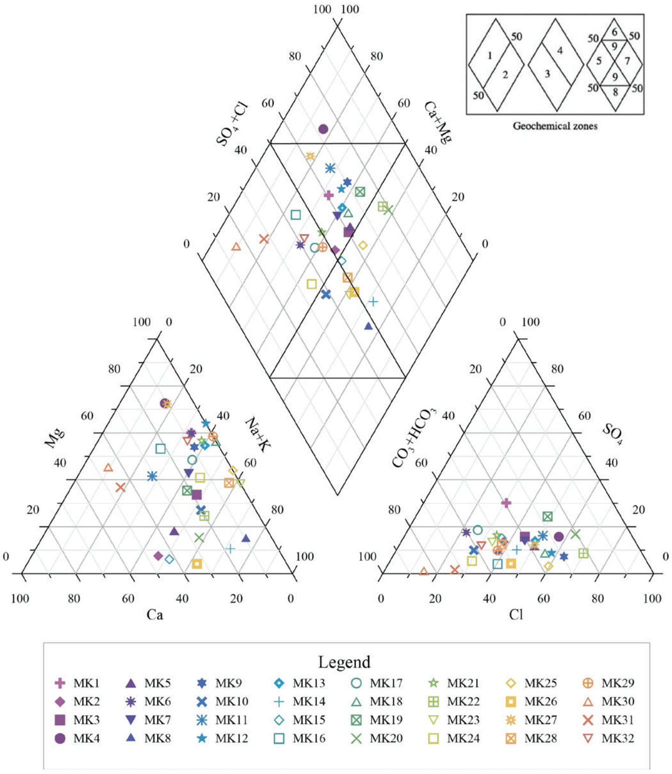

Fig. 6: Piper diagram for the hydrogeochemical characterization of spring water.

Mechanisms controlling groundwater quality

For the evaluation of the mechanism controlling groundwater quality, Gibbs (1970) proposed two diagrams: one related to the ratio of cations (Na^+/ Na^++ Ca^{2+}) and another with the ratio of anions (Cl^- / Cl^- + HCO_3^-), which are plotted against the TDS. The mechanisms are classified concerning the atmospheric precipitation, rock, and evaporation dominance (Fig. 7). The dominance of Ca^{2+} and HCO_3^- over Na^+ and Cl^- signifies the precipitation domain, which indicates a meteoric origin. Similarly, rock-water interaction indicates the predominance of interaction between the rocks and the percolating water, with a progressive increase in Na^+ and Cl^- ions over Ca^{2+} and HCO_3^-. Out of 32 samples, 16 lies in the rock domain and 16 under the precipitation zone (Fig. 7, Table 3). As a result, the groundwater samples move from the domain of precipitation toward the domain of rock-water interaction.

Chloro-alkaline indices

The chloro-alkaline indices can be used to understand changes in the chemical composition of groundwater along its flow path (CA). For the interpretation of ion exchange between groundwater and the host environment, Schoeller (1965) proposed two chloro-alkaline indices (CA1, CA2). A positive CA index shows that Na^+ and K^+ from the water are exchanged with Mg^{2+} and Ca^{2+} from the rocks, whereas a negative CA index suggests that Mg^{2+} and Ca^{2+} from the water are exchanged with Na^+ and K^+ from the rocks**.** The chloro-alkaline (CA) indices are computed using the following equations 1 and 2.

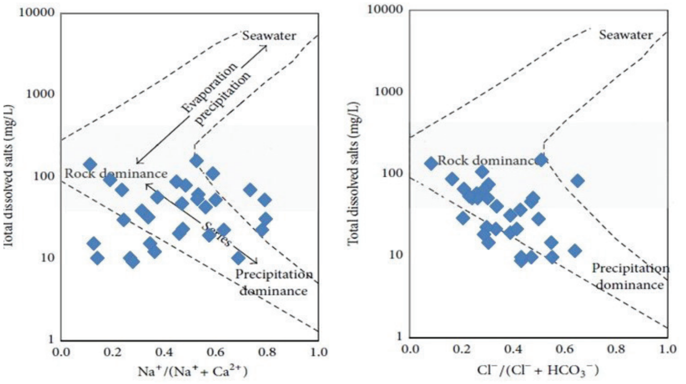

Fig. 7: Gibbs diagram showing TDS vs. Na^+ / (Na^+ + Ca^{2+}) and Cl^- / (Cl^- + HCO_3).

$$CA1 = (Cl^- - (Na^+ + k^+))/Cl^- \qquad (1)$$

$$CA2 = (Cl^- - (Na^+ + k^+))/(SO_4^- + HCO_3^- + NO_3^-) \qquad (2)$$

The negative values of indices (CAI1 and CAI 2) suggest that the primary source of dissolved ions in the groundwater (MK1, 2, 6, 8, 10, 14, 15, 17, 19, 21, 23, 24, 25, 26, 27, 28, and 29) is the host rock and the ion exchange (Ca^+ and Mg^+ from groundwater exchanges with Na^+ and K^+ in aquifer materials) is the probable major contributors to greater Na^+ and K^+ concentration (Table 6). The remaining samples with positive values confirm a base exchange reaction, where exchange occurs between Na^+ and K^+ of the groundwater with the Ca^{2+} and Mg^{2+} of the aquifer material.

Suitability analysis

The amount and concentration of dissolved ions in water determine its usability for a different purposes. Suitability analysis of groundwater is important to deduce the appropriateness of the subsurface water, which has been used for agricultural and household purposes. It acts as a determinative factor in defining the standard of human health (WHO, 1997). Here, the suitability analysis has been carried out for household (drinking) and agricultural purposes.

Drinking purposes

As the quality of drinking water determines the health condition of the people, the water in the area has been analyzed for the Water Quality Index using the Weighted Arithmetic Water Quality Index method, which determines the degree of purity, using the commonly measured water quality parameters. As the basic standard permissible values of concentration Nepal Drinking Water Quality Standard has been used (NDWQS, 2005). The Weighted Arithmetic Water Quality Index calculates the WQI using the following expression (Eq. 3 to 6).

$$WQI = (\sum W_n \times q_n)/\sum W_n \qquad (3)$$

$$\text{where, } W_n = k/S_n \qquad (4)$$

$$\text{And, } q_n = 100\{(V_n - V_{i0})(S_n - V_{i0})\} \quad (5)$$

and k is a proportionality constant expressed as $k = (1/(\frac{1}{\sum Si})$ (6)

where, S_i= Standard permissible concentration of n^{th} parameter (expression iii)

where, V_n= Estimates concentration of n^{th} parameter, V_{i0}= Ideal value of the n^{th} parameter in pure water (Eq. 5)

The Water Quality Index (WQI) is a popular and effective tool for evaluating surface and subsurface water quality for drinking purposes globally. It compares the measured concentration of the parameter, with the standard and permissible value, along with the ideal value in pure water. Table 4 shows the Water Quality Index for 32 springs, which value ranges from 27.87-45.25. The water from the springs is a good water type based on the WQI values (25-50) (Table 5). The WQI suggests the water is good for drinking, however, the microbial and some few pollutants have not been analyzed.

Table 3: The calculated values of the chloro-alkaline indices for the 32 springs. The value in bold indicates the positive chloro-alkaline indices and *indicates the spring influenced by rock water interaction.

Spring ID	CAI 1	CAI 2	Inferences	TDS	Spring ID	CAI 1	CAI 2	Inferences	TDS
MK1*	-0.01	0.00	-	77	MK17*	-0.21	-0.08	-	53
MK2	-0.08	-0.05	-	15	**MK18***	**0.19**	**0.22**	+	47
MK3	**0.16**	**0.13**	+	32	MK19*	-0.12	-0.10	-	155
MK4	**0.65**	**0.84**	+	15	**MK20**	**0.25**	**0.41**	+	12
MK5	**0.23**	**0.23**	+	38	MK21*	-0.07	-0.04	-	109
MK6*	-0.14	-0.07	-	60	**MK22***	**0.11**	**0.20**	+	85
MK7	**0.02**	**0.02**	+	20	MK23*	-0.85	-0.43	-	53
MK8	-0.53	-0.37	-	22	MK24*	-0.55	-2.90	-	68
MK9	**0.47**	**0.81**	+	10	MK25*	-0.05	-0.08	-	52
MK10	-0.95	-0.38	-	30	MK26*	-0.38	-0.31	-	42
MK11	**0.55**	**0.57**	+	10	MK27	-0.28	-0.28	-	10
MK12	**0.51**	**0.68**	+	29	MK28*	-0.44	-0.25	-	52
MK13	**0.38**	**0.38**	+	9	MK29	-0.01	-0.01	-	19
MK14	-0.27	-0.25	-	22	**MK30***	**0.40**	**0.07**	+	139
MK15	-0.32	-0.18	-	23	**MK31***	**0.35**	**0.12**	+	90
MK16*	**0.45**	**0.29**	+	68	**MK32***	**0.13**	**0.06**	+	55

Table 4: Water Quality Index (WQI) for each spring.

Spring Id	WQI	Spring Id	WQI	Spring Id	WQI	Spring Id	WQI
MK1	32.98	MK9	32.60	MK17	42.42	MK25	31.48
MK2	34.98	MK10	31.53	MK18	36.40	MK26	45.25
MK3	34.12	MK11	37.44	MK19	41.78	MK27	29.20
MK4	35.30	MK12	35.28	MK20	42.14	MK28	39.55
MK5	27.87	MK13	38.25	MK21	34.13	MK29	35.88
MK6	35.57	MK14	30.53	MK22	38.80	MK30	32.82
MK7	34.86	MK15	39.10	MK23	29.33	MK31	33.05
MK8	30.72	MK16	40.87	MK24	34.39	MK32	30.39

Table 5: Comparison of WQI value of spring.

WQI	Status
0-25	Excellent
26- 50	Good
51- 75	Poor
76- 100	Very poor
Above 100	Not Suitable for Drinking

Irrigation purpose

The amount of excess ion concentration alters the soil permeability, and aeration, which directly influences productivity (Rao et al., 2002). The parameters like EC, Percent Sodium (% Na), Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC), Permeability Index (PI), and Magnesium Ratio (MR) have been well utilized to establish the excellence of groundwater for irrigation purposeThe EC, % Na and SAR had been calculated for the assessment (Table 5).

The EC and concentration of Na^+ provide a simple way to determine the fitness of groundwater for irrigation. The excess amount of Na in irrigation water increases Na in the soil thus, making it hard to plow and inappropriate for the germination of seeds and aeration (Jeevandam et al., 2012).

For irrigation water quality, the percent Na^+ can be divided into two groups: less than 60% appropriate for irrigation water and more than 60% unsuitable for irrigation purposes. The percentage of Na in the area ranges from 9–74 (Table 6). However, only 5 springs (Table 6) show marginally higher value and are considered unsuitable. The EC also ranges from 19-320 µs/cm and only two springs show EC higher than 250 µs/cm, which indicate a medium Salinity Hazard, while other are excellent.

Wilcox (1948) proposed a diagram based on % Na and EC for evaluating the suitability of water quality for irrigation. This combination divides the diagram into five zones: excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable, and unsuitable. All of the groundwater samples were found to be excellent for irrigation as shown in Figure 8.

The United States Salinity Laboratory Staff (USSLS) diagram categorizes water quality to determine the degree of suitability of water for irrigation, with the salinity hazard (EC) plotted on the x-axis. Similarly, the sodium hazard (S) plot y-axis with SAR values. The study area values of EC vary from 21 µS/cm (Sample Mk27) to 330 µS/cm (sample Mk19) and those of SAR vary from 0.19 (Sample Mk30) to 1.6211 (Sample Mk23), respectively (6a).

Groundwater samples Mk19 and Mk30 from the C2S1 zone have a medium salinity and low sodium hazard, making them suitable for irrigation (Fig. 9). The remaining 30 samples are categorized as C1S1, suggesting low salinity and sodium hazard for irrigation. The low hazards indicate the water is suitable for irrigation and doesn't require any treatment.

Table 6: Calculated values of % Na, SAR, and measures EC for spring water in the study area (Bold values represent the concentration above the threshold value).

S.N	% Na	SAR	EC (µs/cm)	S.N	%Na^+	SAR	EC(µs/cm)
MK1	33	0.62	154	MK17	39	0.68	106
MK2	49	0.58	30	MK18	44	0.87	97
MK3	44	0.60	64	**MK19**	44	1.39	**330**
MK4	17	0.18	31	MK20	58	1.14	24
MK5	47	0.73	75	MK21	38	1.03	217
MK6	31	0.54	121	MK22	55	1.46	169
MK7	50	0.77	41	**MK23**	**62**	1.62	106
MK8	**74**	1.66	45	MK24	45	1.15	138
MK9	37	0.61	21	**MK25**	**67**	1.48	104
MK10	53	1.05	61	**MK26**	**63**	1.26	84
MK11	28	0.23	22	MK27	53	1.09	21
MK12	34	0.49	57	MK28	57	1.27	102
MK13	38	0.46	19	MK29	42	0.78	38
MK14	**72**	1.72	44	**MK30**	9	0.19	**279**
MK15	57	0.87	45	MK31	20	0.38	182
MK16	25	0.44	137	MK32	31	0.53	111

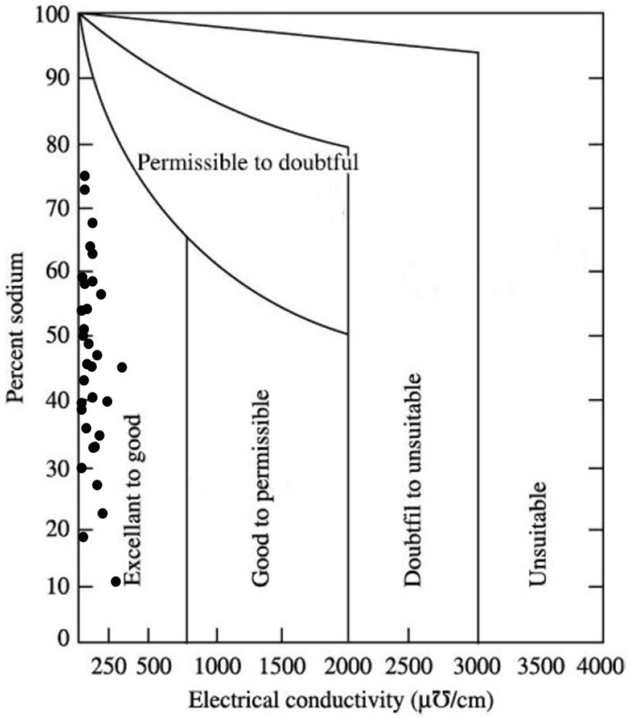

Fig. 8: Classification based on Ec and % Na (Wilcox's, 1948).

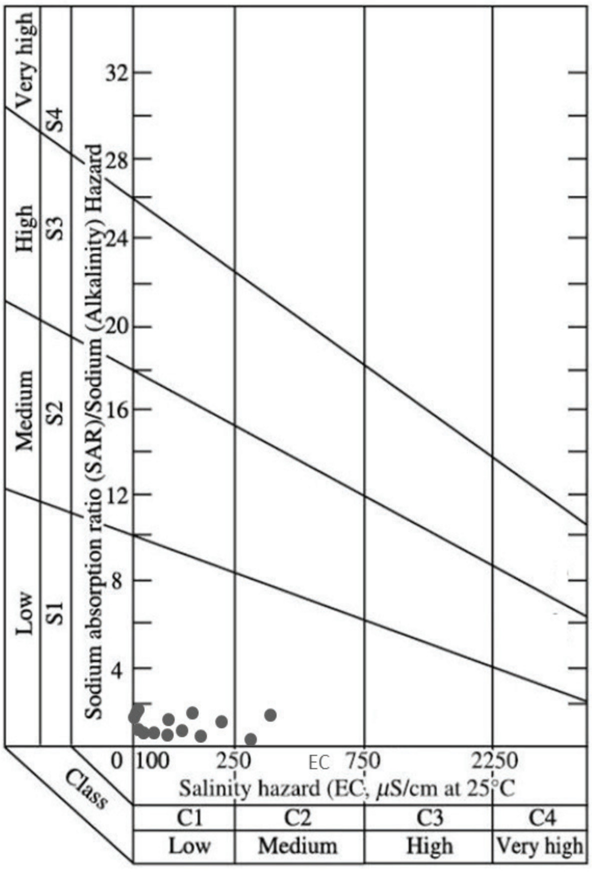

Fig. 9: Classification based on Salinity Hazard (EC) and Alkalinity Hazard (SAR) (USSLS, 1954).

CONCLUSIONS

Spring water in the study area is slightly acidic to marginally alkaline and the remaining physicochemical parameters lie within the permissible limit. The general order of dominance for major cations is Ca^{2+}, Na^{+}, Mg^{2+}, K^{+}, and for major anions is HCO_3^{-}, Cl^{-}, SO_4^{2-}, NO_3^{-}. The major ion concentrations, when plotted in the Piper diagram, indicate alkaline earth metals (Ca^{2+} and Mg^{2+}) predominate over alkali metals (Na^{+} and K^{+}) and strong acids (Cl^{-} and SO_4^{2-}) predominate over weak ones (HCO_3^{-}), indicates the permanent hardness and the source of ions in water is from natural weathering of the plagioclase of the schistose gneiss of the area. The Gibbs plot shows that groundwater quality in the area is influenced mainly by the domain of precipitation along with the domain of rock-water interactions. The groundwater in the area lies in the shallow aquifer with low rock water interaction.

The water from the springs are good for drinking and excellent to good for irrigation. The present scenario of water quality along the watershed possesses no threat to quality deterioration. However regular monitoring and proper management and protection plans are utmost for the maintenance of the chemical integrity of the spring water in the area.

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REFERENCES

APHA, 2005, Standard methods for the examination of water and wastewater. American Public Health Association, Washington DC, USASS.

Bharti, V. K., Giri, A., Kumar, K., Leong, Y. H., Samin, A. S. M., and Majid, M. I. A., 2017, Evaluation of physico-chemical parameters and minerals status of different water sources at high altitude. Annals of Environmental Science and Toxicology, v. 2(1), pp. 010–018.

Chamlagain, D., Rai, S. M., and Hayashi, D., 2003, Geology, structure and metamorphism of the Mai Khola area, southwestern part of Ilam Bazaar, eastern Nepal. Bulletin of faculty of Science, University of Ryukyus, v. 75, pp. 55–74.

Earle, S., 2019, Physical Geology – 2nd Edition. Victoria, B.C.: BCcampus. Retrieved from https://opentextbc.ca/physicalgeology2ed

Jeevanandam, M., Nagarajan, R., Manikandan, M., Senthilkumar, M., Srinivasalu, S., and Prasanna, M. V., 2012, Hydrogeochemistry and microbial contamination of groundwater from lower ponnaiyar basin, cuddalore district, Tamil Nadu, India. Environmental Earth Sciences, v. 67(3), pp. 867–887.

Kaur, L., Rishi, M. S., Sharma, S., Sharma, B., Lata, R., and Singh, G., 2019, Hydrogeochemical characterization of groundwater in alluvial plains of River Yamuna in Northern India: an insight of controlling processes. Journal of King Saud university-science, v. 31(4), pp. 1245 –1253.

Khadka, K. and Rijal, M. L., 2020, Hydrogeochemical assessment of spring water resources around Melamchi, Central Nepal. Water Practice and Technology, v. 15(3), pp. 748–758.

NDWQS, 2005, National Drinking Waterr Quality Standard and Directives, Ministry of Physical planning and works, Government of Nepal, 21 p.

Paudel, D., Thakur, J. K., Singh, S. K., and Srivastava, P. K., 2015, Soil characterization based on land cover heterogeneity over a tropical landscape: an integrated approach using earth observation data-sets. Geocarto International, v. 30(2), pp. 218–241.

Piper, A. M., 1944, A graphic procedure in the geochemical interpretation of water-analyses. Transactions American Geophysical Union, v. 25(6), pp. 914–928.

Rao, N. S., Rao, J. P., Devadas, D. J., Rao, K. S., Krishna, C., and Rao, B. N., 2002, Hydrogeochemistry and groundwater quality in a developing urban environment of a semi-arid region, Guntur, Andhra Pradesh. Journal of the Geological Society of India, v. 59(2), pp. 159–166.

Regmi, A. D., Yoshida, K., Dhital, M. R. and Pradhan, B., 2014, Weathering and mineralogical variation in gneissic rocks and their effect in Sangrumba Landslide, East Nepal. Environmental Earth Sciences, v.71, pp. 2711–2727.

Schelling, D., 1992, The tectonostratigraphy and structure of the eastern Nepal Himalaya. Tectonics, v. 11(5), pp. 925–943.

Schoeller, H., 1965, Qualitative evaluation of groundwater resources. Methods and techniques of groundwater investigations and development. UNESCO, pp. 54–83.

Srivastava, S. K. and Ramanathan, A. L., 2018, Geochemical assessment of fluoride enrichment and nitrate contamination in groundwater in hard-rock aquifer by using graphical and statistical methods. Journal of earth system science, v. 127, 104.

USSLS, 1954, Diagnosis and improvement of saline and alkali soils. United States Soil Salinity Laboratory Staff, US Department of Agriculture, Washington, Agriculture handbook 60, pp. 69–81.

Wilcox, L. V., 1948, The quality of water for irrigation use. US Department of Agriculture Technical Bulletin 1962. Washington, DC.