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HYDROCHEMICAL CHARACTERIZATION AND WATER QUALITY OF PERENNIAL RIVULETS (DARCHULA), SUDURPASHCHIM PROVINCE, NEPAL

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ABSTRACT

Rivers and rivulets hold significant importance, serving as primary sources for various purposes, particularly for drinking water and irrigation. This study was conducted in Lekam Rural Municipality, Darchula, Nepal, focused on Rithegaad, Bhuddobgaad, and Daanugaad Rivulets to evaluate hydrochemistry and water suitability for drinking and irrigation. To achieve this objective, a total of 18 samples were collected, with 6 samples taken from each rivulet. Parameters such as pH, EC, TDS, total hardness, alkalinity, turbidity, Ca^{2+}, Mg^{2+}, Na^+, K^+, NH_4^+, HCO_3^-, NO_3^-, Cl^-, PO_4^{3-}, and SO_4^{2-}, were analyzed to determine hydrochemistry and water quality index (WQI) whereas EC, SAR, Na%, MH, KR, PI, PS, CROSS, and RSBC were calculated to determine irrigation suitability. These indices were further modeled across the rivulets using the IDW geostatistical technique for spatial interpolation. The hydrochemical parameters indicated similar water chemistry among the rivulets, aligning with WHO and NDWQS guidelines. The cationic sequence showed slight variations, with Rithegaad and Bhuddobgaad having a sequence of $Ca^{2+}>Mg^{2+}>Na^+>K^+>NH_4^+$, while Daanugaad showed $Ca^{2+}>Na^+>Mg^{2+}>K^+>NH_4^+$. However, anionic order remained consistent across all streams, with $HCO_3^->Cl^->SO_4^{2-}>NO_3^->PO_4^{3-}$. The WQI classified these rivulets as 'Good' to 'Excellent,' suitable for drinking. Irrigation indices confirmed compliance with FAO standards. Furthermore, the Wilcox diagrams classified 100% of Bhuddobgaad and 30% of Rithegaad samples as C1-S1 (low salinity and sodium hazard), while 100% of Daanugaad and 70% of Rithegaad samples fell under C2-S1 (medium salinity, low sodium hazard). These findings can offer insights to decision makers for the proper utilization and management of water resources at the local level.

Keywords: hydrochemistry, water quality, suitability, irrigation, drinking water, interpolation, Wilcox diagram

INTRODUCTION

Water resources are a vital component on earth, essential for the sustenance of all living organisms. Clean and reliable water resources are essential for human health (Tiwari *et al.,* 2023; Joshi *et al.,* 2024). These resources encompass both freshwater and marine water, with a particular emphasis on safeguarding and preserving freshwater, which is recognized as a precious natural asset (Dewulf *et al.,* 2015). Freshwater sources are essential for fulfilling basic needs such as drinking, agriculture, and industry (Gleick, 2000), yet they are limited in both quantity and quality (Figueres *et al.,* 2012). The situation is exacerbated by factors like land use changes, climate variability, and environmental degradation, posing significant challenges to water sustainability (UNFCCC, 2011; Gedefaw *et al.,* 2023).

Nepal, nestled in the Himalayan region, boasts a wealth of freshwater resources including a significant number of rivers, rivulets, lakes, ponds, glacial lakes, and glaciers (WECS, 2011; Upadhyay & Gaudel, 2018). Despite possessing an immense reservoir of 237 billion m^3 Nepal harnessed only 15 billion m^3 for societal and economic enhancement (WECS, 2011). It is worth noting that the majority of this abundant water supply traverses through the expansive Indo-Gangetic Plain (IGP) before ultimately reaching its destination in the Bay of Bengal (WECS, 2011; WB, 2014). This underscores Nepal's unique standing in terms of its freshwater endowment and highlights the untapped potential for sustainable development (WECS, 2011; Poudel, 2019).

Rivers and rivulets play a crucial role, carrying significant socioeconomic, aesthetic, cultural, and ecotourism values (Desjarlais, 1992; Sharma *et al.,* 2020). They serve as primary sources for various applications such as drinking water supply, irrigation systems, and hydropower plants of different sizes (Rautanen, van Koppen & Wagle, 2014). It is essential to bear in mind that streams are dynamic entities, subject to fluctuations in characteristics over time influenced by a variety of factors, including underlying geology and land use/land cover (Khatri & Tyagi, 2015; Gorgoglione *et al.,* 2020). Consequently, it is of paramount importance to conduct comprehensive studies and assessments of rivers and associated tributaries to understand their dynamism (Pant *et al.,* 2018).

Hydrochemistry plays a pivotal role in understanding water bodies, influenced by geological, climatic, hydrological, biological factors, and human activities (Khatri & Tyagi, 2015). Various hydrochemical components are crucial in this assessment. Water Quality Indices (WQI) streamline this complex data into a single value, offering a quick and efficient method to gauge water suitability for purposes like drinking or irrigation (Chidiac *et al.*, 2023). In Nepal, WQI has been extensively utilized to evaluate both surface and subsurface water resources for diverse applications (Pant *et al.,* 2018; Sharma *et al.,* 2021). The integration of WQI with a Geographic Information System (GIS) facilitates the interpolation of water quality across entire channels and basins, a method frequently employed due to the costliness and impracticality of sampling every point (Shil, Singh & Mehta, 2019). Spatial interpolation assigns the value of the nearest sampled location to all unsampled locations, providing a logical and cost-effective approach to analyzing water quality distribution (Khouni, Louhichi & Ghrabi, 2021).

In the hilly regions of Nepal like Darchula, streams or rivulets serve as the primary sources of water for both drinking and irrigation, primarily due to the deep groundwater levels in the region. The success of crop production hinges on the accessibility and quality of freshwater (Bishwakarma *et al.*, 2022). Analyzing the hydrochemistry of these stream resources holds significant importance in gaining insights into the current state of these resources and their suitability for various applications. Thus, the present study is carried out to assess the physicochemical characteristics of rivulets/streams and evaluate their water quality for drinking and irrigation in the Lekam Rural Municipality, Darchula, Nepal.

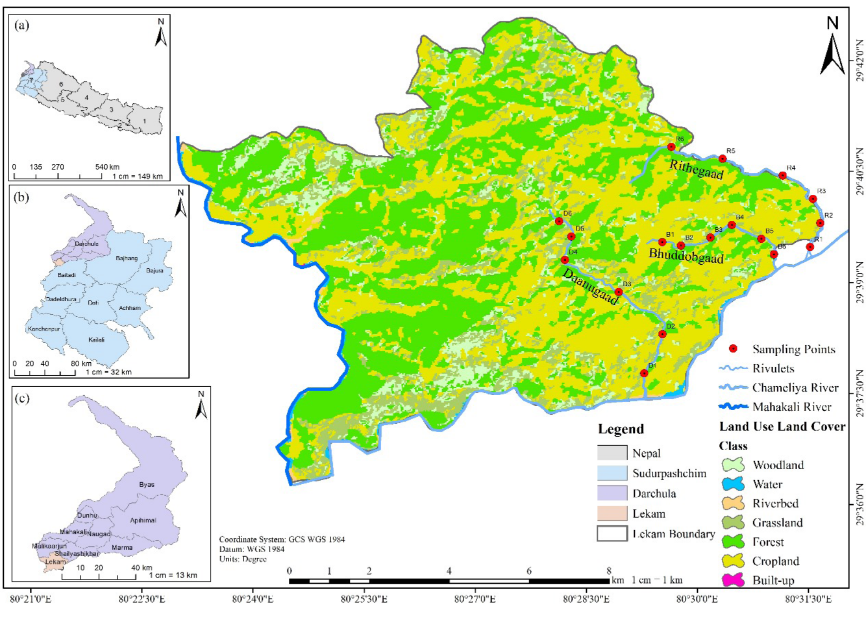
METHODS AND MATERIALS

Study Area

This study was conducted in the three major rivulets in Lekam Rural Municipality, Darchula, which are the tributaries of the Chameliya River (Figure 1). Lekam Rural Municipality (LRM) is located in the Southwestern part of Darchula, Sudurpashchim Province, Nepal. It is a hilly rural municipality that ascends with an elevation from 500 m to 1950 m above sea level. The geographical location of the municipality extends from 29.605657° N to 29.705050° N and from 80.383433° E to 80.528639° E, covering an area of 83.98 km². Rithegaad, Bhuddobgaad, Daanugaad, and Manbishagaad are the major rivulets that originate and flow through LRM and ultimately join the Chameliya River and Mahakali River. These rivulets play a crucial role in providing water for both drinking and irrigation purposes in this rural municipality. Moreover, some of these streams support traditional water mills, and there is also an operational micro-hydro project in Daanugaad Rivulet. *(Note: Gaad means rivulet in local language).*

Figure 1

Map Showing a) Nepal, b) Sudurpashchim Province, c) Darchula, and the Study Area; Lekam Rural Municipality and its Rivulets



LRM has a population of 13,743 individuals residing in 3,030 households, with a population density of approximately 164 people per km^2 (NSO, 2021). The primary livelihood in this rural municipality revolves around agriculture with major crops cultivated including wheat, maize, paddy, pulses, soya bean, and tobacco, among others. The climate of this rural municipality is mostly subtropical to temperate. Darchula faces an average maximum temperature of 18.6°C and a minimum temperature of 7.7°C, with an average annual rainfall of 2129 mm. The majority of rainfall occurs during the period from May to September. During this time, the area experiences consistently high rainfall levels, ranging between 125 mm to 350 mm over 24 hours. This region falls within the sub-tropical to alpine climatic zone, characterized by the prevalence of sub-tropical vegetation and dominant forest types in the southern mid-hills (Bhandari, 2014).

Sampling Design and Field Measurements

The samples were collected during the post-monsoon season of 2022. The selection of sampling location in all three rivulets is based upon the LULC change and alongside the introduction of notable stressors into the streams. The major land use types and structures in the study area were residential areas, forest areas, agricultural land, water mills, irrigation canals, river confluence, etc. In each rivulet, 6 samples were collected, totaling 18 samples (6*3=18) (Figure 1).

Before collecting the samples, each sample bottle was cleaned with nitric acid to remove cations and then rinsed with distilled water. The sample bottles were rinsed twice with the same river water before collecting the samples. The samples were taken from a depth of about 20 to 25 cms below the water surface. pH, electrical conductivity (EC), and total dissolved solids (TDS) were recorded on-site using a multi-parameter device (HI-98129, HANNA, Romania). Similarly, dissolved oxygen (DO) was also measured on-site using an OXY 70 DO meter. After that, these collected water samples were carefully transported to the Central Department of Environmental Science (CDES) laboratory, Tribhuvan University, Kirtipur, for further chemical analysis.

Laboratory Analysis

Analysis of parameters, including total hardness (TH), bicarbonate (HCO_3^-), and chloride (Cl^-), was conducted using titrimetric techniques by the standardized procedure recommended by the American Public Health Association (APHA, 2017). Furthermore, chemical attributes such as nitrate (NO_3^-), sulfate (SO_4^{2-}), and phosphate (PO_4^{3-}) were ascertained by employing a UV-visible spectrophotometer (SSI UV 2101), whereas the levels of potassium (K^+) and sodium (Na^+) were evaluated through the help of a Microprocessor Flame Photometer, specifically the ESICO MODEL 1382.

DATA ANALYSIS AND CALCULATION

Statistical Analysis

Descriptive statistical analysis, including calculations for minimum, maximum, mean, and standard deviation was carried out using SPSS version 22.0 software. Moreover, additional sets of physicochemical parameter data were subjected to analysis using ArcGIS 10.5 and Origin 2024 Software.

Drinking Water Quality

To assess the suitability of surface water for drinking, the Weighted Arithmetic Water Quality Index (WQI) was calculated (Brown *et al.,* 1970; Tyagi *et al.,* 2013). This calculation involves twelve parameters: pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, NO_3^{-}, Cl^{-}, SO_4^{2-}, and TH. In the context of rivulets, this method is effective and provides insights into water quality relevant to drinking (Singh *et al.,* 2022). The equations involved in the determination of WQI are as follows:

The scores of parameters (Qi) were calculated as follows:

$$Q_i = \left[\left(\frac{V_o - V_{id}}{S_n - V_{id}}\right)\right] \times 100$$

Where, V_o is the actual value of the parameter obtained through analysis, S_n is the standard value proposed by WHO guidelines, and V_{id} is the ideal value in pure water, considered as 7 for pH and zero for other parameters.

The relative weight of each indicator (W_i) was calculated as follows:

$$W_i = \left[\frac{K}{S_n}\right], K = \left[\frac{1}{\sum \frac{1}{S_n}}\right]$$

Finally, the water quality index (WQI) was evaluated by using the following equation.

$$WQI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i}$$

WQI provides faster and more efficient performance compared to individual parameters, offering a simple and concise approach to express the suitability of water for drinking or irrigation (Chidiac *et al.*, 2023). For drinking, the water quality status concerning the WQI range has been classified as 'Excellent': 0-25, 'Good': 26-50, 'Poor': 51-75, 'Very poor': 76-100 and 'Unsuitable': >100 (Brown *et al.,* 1970; Shrestha & Basnet, 2018).

Irrigation Suitability

To determine whether water is suitable for irrigation, a wide range of parameters has been carefully examined, including the electrical conductivity (EC), sodium percent (%Na), sodium absorption ratio (SAR), magnesium hazard (MH), Kelly's ratio (KR), permeability index (PI), cation ratio of soil structure suitability (CROSS), potential salinity (PS), and residual sodium bicarbonate (RSBC) (Zaman, Shahid & Heng, 2018; Kumar *et al.*, 2022). The mathematical expressions for calculating these indices are illustrated in the Table 1.

Table 1

Indices and the Corresponding Mathematical Formulae Used for Their Calculation

Indices	Formula	Reference
Percentage Sodium	$\%Na^{+} = \left[\frac{Na^{+}+K^{+}}{Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}}\right]\times 100$	Todd & Mays (2004)
Sodium Absorption Ratio	$SAR = \frac{Na^{+}}{\sqrt{\left(Ca^{2+}+Mg^{2+}\right)/2}}$	Richards (1954)
Magnesium Hazard	$MH = \left[\frac{Mg^{2+}}{Mg^{2+}+Ca^{2+}}\right]\times 100$	Richards (1954)
Kelly's Ratio	$KR = \left[\frac{Na^{+}}{Mg^{2+}+Ca^{2+}}\right]$	Kelly (1940)
Permeability Index	$PI = \left[\frac{Na^{+}+K^{+}+\sqrt{HCO_3^{-}}}{Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}}\right]\times 100$	Doneen (1964)
Cation Ratio of Soil Structure Suitability	$CROSS = \frac{Na^{+}+0.56K^{+}}{\sqrt{\left(Ca^{2+}+0.6Mg^{2+}\right)/2}}$	Rengasamy & Marchuk (2011)
Potential Salinity	$PS = \left(Cl^{-}\right)+\frac{1}{2}\left(SO_4^{2-}\right)$	Doneen (1964)
Residual Sodium Bicarbonate	$RSBC = \left(HCO_3^{-}\right)-\left(Ca^{2+}\right)$	Eaton (1950)

The water quality class for irrigation has been categorized on the basis of corresponding values of significant indices as illustrated in Table 2.

Table 2

Limit of Indices for Rating Surface Water Quality for Irrigation Purpose

Parameter	Class	Range	Reference
EC	Excellent	<700	Ayers & Westcot (1985)
	Fair	700-3000	
	Good	>7000	
Na%	Excellent	<20	Wang *et al.* (2023)
	Good	20-40	
	Permissible	40-60	
	Doubtful	60-80	
	Unsuitable	>80	
SAR	Excellent	<10	Richards (1954)
	Good	10-18	
	Permissible	18-26	
	Doubtful	>26	
MH	Suitable	=<50	Richards (1954)
	Unsuitable	>50	
KR	Safe	=<1	Kelly (1940)
	Unsafe	>1	
PI	Class I	>75	Doneen (1964)
	Class II	25-75	
	Class III	<25	
CROSS	Excellent	<10	Rengasamy & Marchuk (2011)
	Good	10-18	
	Permissible	18-26	
	Unsuitable	>26	
PS	Suitable	=<3	Doneen (1964)
	Unsuitable	>3	
RSBC	Safe	=<1.25	Eaton (1950)
	Unsafe	>1.25	

Geostatistical Analysis

This study also involved conducting a geostatistical analysis utilizing the Inverse Distance Weighted (IDW) interpolation tool accessible within the ArcGIS (ArcMap 10.5), which includes exploring spatial autocorrelation and interpolating indices values at locations where data hasn't been sampled (Khouni, Louhichi & Ghrabi, 2021). The fundamental concept of IDW interpolation involves employing a weighted linear combination of sample points, relying on both statistical and mathematical techniques to generate surfaces and estimate values at unmeasured points (Patil, 2019; Khouni, Louhichi, & Ghrabi, 2021). The general equation utilized for IDW is as follows:

$$\hat{Z}(x_0) = \frac{\sum_{i=1}^{n} z(x_i).d_{ij}^{-p}}{\sum_{i=1}^{n} d_{ij}^{-p}}$$

Here, Z represents the interpolated value of a grid node, Z_i represents the neighboring data points, and d_{ij} signifies the distances between the grid node and data points.

Wilcox Diagram

The Wilcox diagram, or U.S. Salinity diagram, was first introduced by Wilcox in 1948 and later enhanced by Torn in 1951. This graphical tool is instrumental in evaluating water suitability for irrigation (Tiri *et al.*, 2020; Khatri *et al.*, 2022; Bishwakarma *et al.*, 2022). It categorizes irrigation water quality into four zones (C1, C2, C3 and C4) based on salinity hazard (EC) along the horizontal axis and four zones (S1, S2, S3, and S4) based on sodium hazard (SAR) along the vertical axis (Basnet *et al.,* 2024).

According to this diagram, low salinity water (C1) is considered the most suitable for irrigation, medium salinity water (C2) is deemed permissible, high salinity water (C3) is classified as poor quality, and very high salinity water (C4) is considered extremely dangerous. The primary factor for categorizing irrigation water based on sodium hazard is how exchangeable sodium impacts the physical state of the soil. Low sodium water (S1) suggests compatibility with most soil types, medium sodium water (S2) is significant, high sodium water (S3) may be detrimental, and extremely high sodium water (S4) is generally unsafe for irrigation purposes (Wilcox, 1955).

RESULTS AND DISCUSSION

General Hydrochemistry

Based on a comprehensive set of descriptive statistics (Table 3) for various hydrochemical parameters, the characteristics of three rivulets, namely Rithegaad, Bhuddobgaad, and Daanugaad rivulets were elucidated. The average pH values of Rithegaad, Bhuddobgaad, and Daanugaad being 7.3, 7.4, and 7.6, respectively, indicated slightly alkaline conditions. Having said that, the pH value of all three rivulets was within the WHO drinking water limit (WHO, 2017).

Table 3

Descriptive Statistics of the Hydrochemical Parameters of the Rithegaad, Bhuddobgaad, and Daanugaad Rivulets along with their Comparison with Different Rivers

	Par	pH	TDS	EC	DO	Tur	Alk	HCO_3^-	Cl^-	K^+	Na^+	NH_4^+	TH	Ca^{2+}	Mg^{2+}	PO_4^3	NO_3^-	SO_4^2	Ref
Rithegaad	**Avg**	7.3	118.2	235.5	6.8	7.9	75	91.5	13.5	2.13	3.92	0.79	70.6	16.2	7.3	0.11	3.2	4.1	This study
	SD	0.3	21.9	43.8	0.3	4.2	7.1	8.6	1.9	0.5	1.17	0.11	3.7	0.85	0.7	0.07	0.52	1.03	
	Max	7.6	134	267	7.2	14.6	85	103	15.6	3.1	6.1	0.92	76	17.6	8.3	0.21	3.79	5.98	
	Min	6.8	78	156	6.5	3.1	65	79.3	11.4	1.6	2.8	0.66	66	15.4	6.4	0.06	2.4	2.8	
Bhuddobgaad	**Avg**	7.4	84.2	168	7.7	3.9	65.8	80.3	9.0	2.43	5.08	0.82	62	14.3	6.4	0.14	3.15	4.39	This study
	SD	0.2	13.1	25.9	0.3	0.94	4.9	6.0	1.9	0.4	0.58	0.04	1.8	0.37	0.4	0.1	0.62	0.88	
	Max	7.7	97	194	8.1	5.3	70	85.4	11.4	2.9	6	0.87	64	15.04	7.03	0.27	3.96	5.56	
	Min	7.3	66	132	7.3	3.15	60	73.2	5.7	1.9	4.2	0.75	60	14.1	6.05	0.03	2.42	3.09	
Daanugaad	**Avg**	7.6	191.3	382.7	7.7	4.58	76.6	93.5	5.7	3.0	6.17	0.8	58	17.1	3.7	0.11	2.06	4.83	This study
	SD	0.1	1.21	2.8	0.2	1.49	6.05	7.38	2	0.08	0.15	0.03	1.8	0.56	0.65	0.07	1.01	0.52	
	Max	7.8	193	388	7.9	7.41	85	103.7	8.5	3.1	6.3	0.82	60	17.6	4.5	0.21	3.31	5.2	
	Min	7.5	190	380	7.5	3.2	70	85.4	2.8	2.9	5.9	0.73	56	16.3	2.9	0.04	0.95	3.78	
Karmanasha	**Avg**	8.1	172.7	331.7				142.5	16.4	2.5	6.47			32.35	10		0.04		a
Ramganga		7.3	-	347		43		116.8	8.6	5.7	23.2			47.4	12.1		4.7	14.3	b
Global Mean		8	120					58.4	7.8	2.3	6.3			15	4.1		1	11.2	c
WHO limit	**Avg**	6-8.5	1000					600	250	100	200			100	50		50	250	d

All the units except for pH, EC (μS/cm), and Turbidity (NTU), are expressed in mg/L
[a: Acharya *et al.* (2020), b: Khan, Gani, & Chakrapani (2016), c: Meybeck (2003) and d: WHO (2017)]

The average values of TDS and EC at Daanugaad (191.3 mg/L and 382.7 μS/cm) are reported higher than the values at Rithegaad (118.2 mg/L and 235.5 μS/cm) and Bhuddobgaad (84.2 mg/L and 168 μS/cm). This deviation may be attributed to the local rock types, watershed erosion, and vegetation cover. The watershed of Daanugaad is cropland-dominated, causing prominent agricultural runoff to the rivulet, thus elevating the value of TDS and EC in post-monsoon. Runoff from croplands generally contributes to the value of EC and TDS (Mishra & Gupta, 2018; Son *et al*., 2020). Whereas the more vegetation cover and springs from nearby forest may have caused dilution in the Rithegaad resulting in less TDS and EC than the other two rivulets in the study area (Erdoğan *et al.,* 2018). However, the average TDS and EC values of all rivulets were within the safe limit of WHO (2017) and FAO (Ayers & Westcot, 1985).

The relative abundance of cations in Rithegaad and Bhuddobgaad was in the order $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+} > NH_4^{+}$, whereas, in the case of Daanugaad, the cationic pattern was $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+} > NH_4^{+}$. However, in all the rivulets, Ca^{2+} was the dominant cation. For anions, HCO_3^- being the dominant, the average ionic pattern for all three rivulets was $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > PO_4^{3-}$. Globally, Ca^{2+} and HCO_3^- are the dominant ions in freshwater systems (Wetzel, 2001; Meybeck, 2003), which is also reported in the Nepalese Rivers such as Gandaki and Karmanasha (Pant *et al*., 2018; Acharya *et al.,* 2020). The abundance of Ca^{2+}, Mg^{2+}, and HCO_3^- in the water can be attributed to the weathering of limestone-dolomite deposition in the watershed (Pant *et al*., 2018).

Drinking Water Quality

The Drinking Water Quality Index (WQI) for the three rivulets Rithegaad, Bhuddobgaad, and Daanugaad is calculated by aggregating the mean concentration values of physicochemical parameters measured for each respective rivulet. The computed WQI according to Brown *et al.* (1970) and Tyagi *et al.* (2013), indicates that the water quality in three rivulets of Lekam is classified as 'Excellent' to 'Good' for drinking as illustrated in Table 4.

Table 4

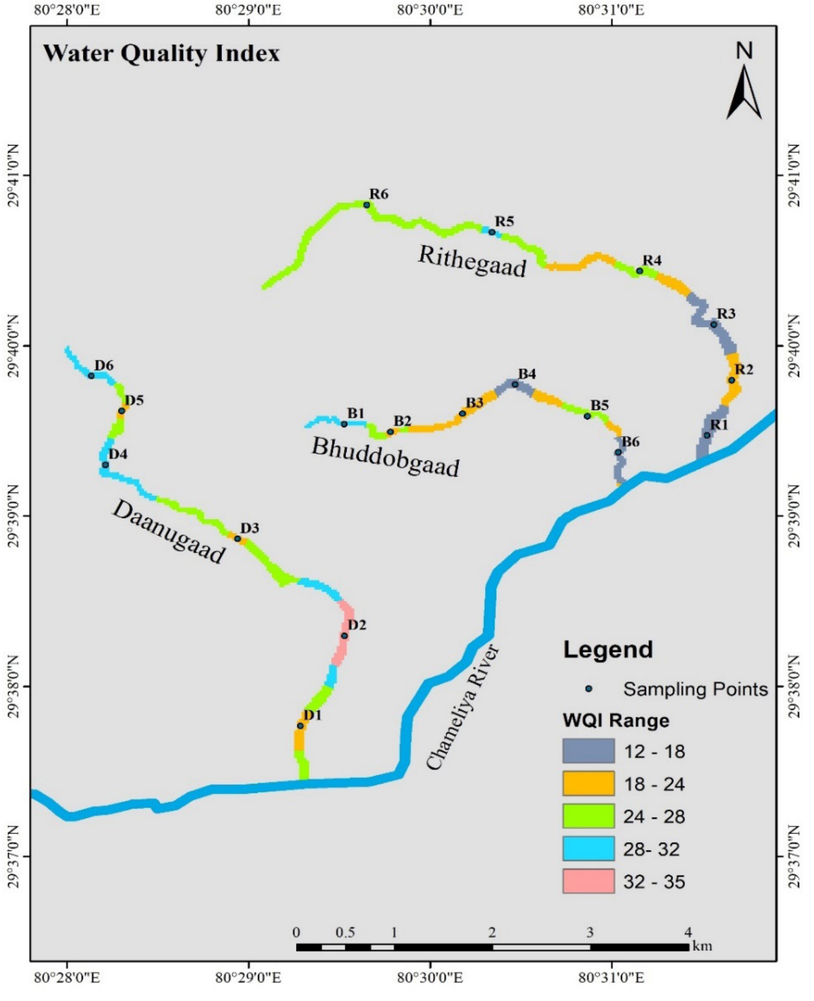
Drinking Water Quality Status of Samples from Rivulets: Rithegaad, Bhuddobgaad and Daanugaad

Rivulet	Code	WQI	Status	Rivulet	Code	WQI	Status
Rithegaad	R1	12.89	Excellent	Daanugaad	D1	23.51	Excellent
	R2	20.78	Excellent		D2	34.76	Good
	R3	12.93	Excellent		D3	23.88	Excellent
	R4	24.84	Excellent		D4	31.49	Good
	R5	28.19	Good		D5	23.56	Excellent
	R6	24.26	Excellent		D6	30.88	Good
	Average	20.65	Excellent		Average	28.01	Good
Bhuddobgaad	B1	31.93	Good				
	B2	23.88	Excellent				
	B3	20.18	Excellent				
	B4	16.17	Excellent				
	B5	28.11	Good				
	B6	16.0	Excellent				
	Average	22.71	Excellent				

In Rithegaad, 83.33% of the sampling sites are classified under the 'Excellent' category of water quality, while 16.66% of the sites, i.e., R5 is categorized as 'Good'. This divergence could potentially be attributed to agricultural runoff stemming from the prevalent croplands surrounding R5. The overall water quality status of Rithegaad is reported to be ‘Excellent’. Similarly, in Bhuddobgaad 66.66% of the sampling sites fall in the ‘Excellent’ class while 33.33% of the sites, i.e., B1 and B5 fall under the ‘Good’ class. However, Daanugaad water samples equally share ‘Excellent’ and ‘Good’ quality status. The overall status of Daanugaad is ‘Good’. The comparatively lower water quality in Daanugaad is attributed to the dominance of croplands and residential area, mixing of multiple small tributaries and erosion in local watershed (Mishra & Gupta, 2018; Son *et al.*, 2020). The majority of studies carried out in the Central Himalayan Rivers and streams such as the Gandaki, Brahmaputra, Karmanasha, and others that flow through mid-hills also claimed that the water in those sources was in ‘Good’ to ‘Excellent’ quality for drinking (Acharya *et al.,* 2020; Bishwakarma *et al.,* 2022; Pant *et al.,* 2023), except some microbiological obligations. The interpolation map of the water quality index based on the sampling points in each rivulet is demonstrated in Figure 2.

Figure 2

Water Quality Index Interpolation Map along the Rivulets: Rithegaad, Bhuddobgaad and Daanugaad



Irrigation Water Quality

The summary of the findings for various indices of irrigation is illustrated in Table 5. The average value of EC in all 18 sampling locations along the three rivulets lie within the range of 500 µS/cm suggesting that the water quality falls in the excellent category, signifying its suitability for irrigation (Ayers & Westcot, 1985). In terms of Na%, there is a similarity between Rithegaad and Bhuddobgaad, with 83% of samples in each rivulet classified as ‘Excellent’, and only 17% in each rivulet fell into the 'Good' class. Meanwhile, in Daanugaad, 17% of samples are classified as 'Excellent,' while 83% are categorized as ‘Good’. Thus, the water quality for irrigation is suitable in the Rithegaad, Bhuddobgaad, and Daanugaad Rivulets.

Table 5

Analysis of Water Quality Classes of Rivulets: Rithegaad, Bhuddobgaad, and Daanugaad, Concerning Irrigational Purpose

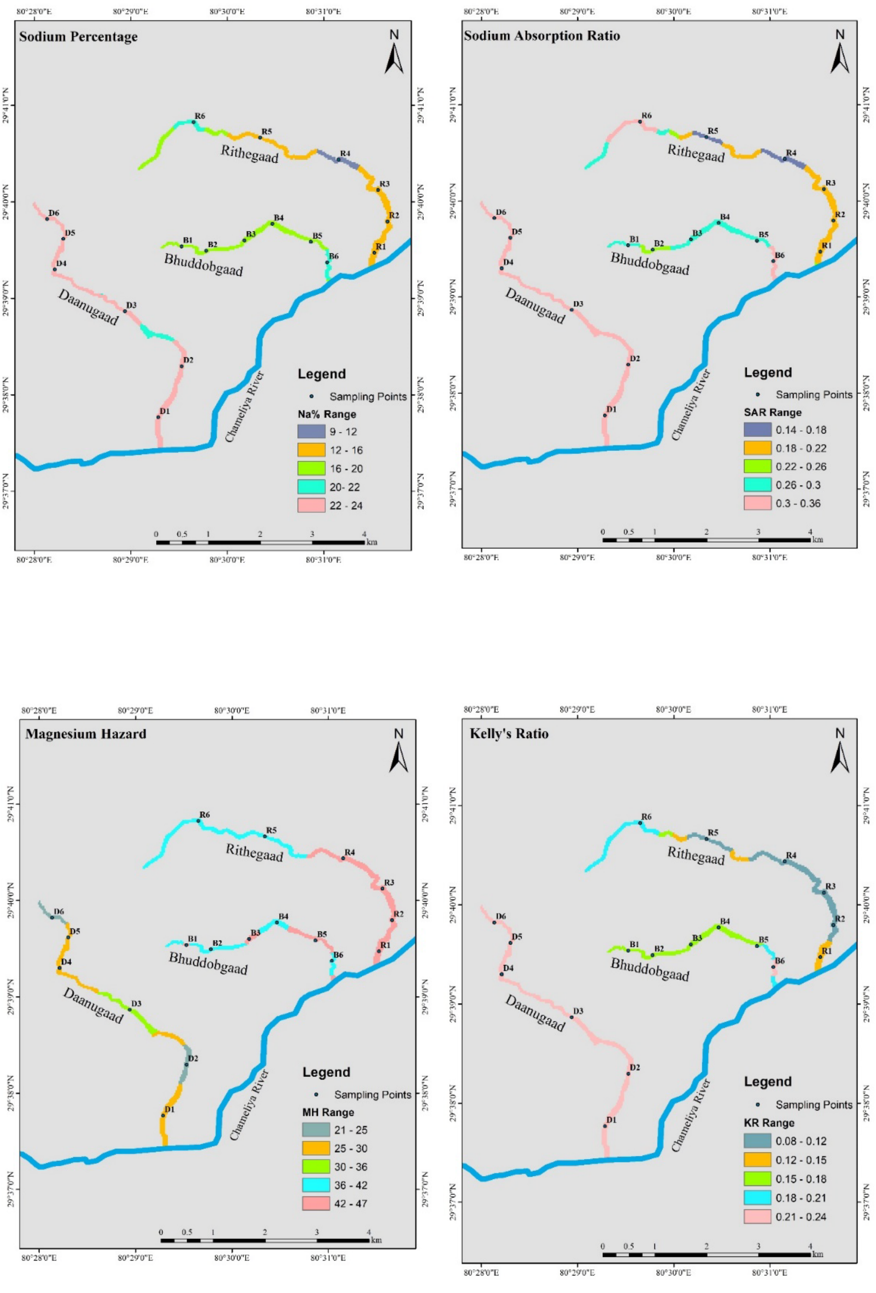
Parameter	Class	Range	Rithegaad		Bhuddobgaad		Daanugaad	
			Samples	%	Samples	%	Samples	%
EC	Excellent	<700	6	100	6	100	6	100
	Fair	700-3000	-	-	-	-	-	-
	Good	>7000	-	-	-	-	-	-
% Na	Excellent	<20	5	83	5	83	-	-
	Good	20-40	1 (R6)	17	1 (B6)	17	6	100
	Permissible	40-60	-	-	-	-	-	-
	Doubtful	60-80	-	-	-	-	-	-
	Unsuitable	>80	-	-	-	-	-	-
SAR	Excellent	<10	6	100	6	100	6	100
	Good	10-18	-	-	-	-	-	-
	Permissible	18-26	-	-	-	-	-	-
	Doubtful	>26	-	-	-	-	-	-
MH	Suitable	=<50	6	100	6	100	6	100
	Unsuitable	>50	-	-	-	-	-	-
KR	Safe	=<1	6	100	6	100	6	100
	Unsafe	>1	-	-	-	-	-	-
PI	Class I	>75	6	100	6	100	6	100
	Class II	25-75	-	-	-	-	-	-
	Class III	<25	-	-	-	-	-	-
CROSS	Excellent	<10	6	100	6	100	6	100
	Good	10-18	-	-	-	-	-	-
	Permissible	18-26	-	-	-	-	-	-
	Unsuitable	>26	-	-	-	-	-	-
PS	Suitable	=<3	6	100	6	100	6	100
	Unsuitable	>3	-	-	-	-	-	-
RSBC	Safe	=<1.25	6	100	6	100	6	100
	Unsafe	>1.25	-	-	-	-	-	-

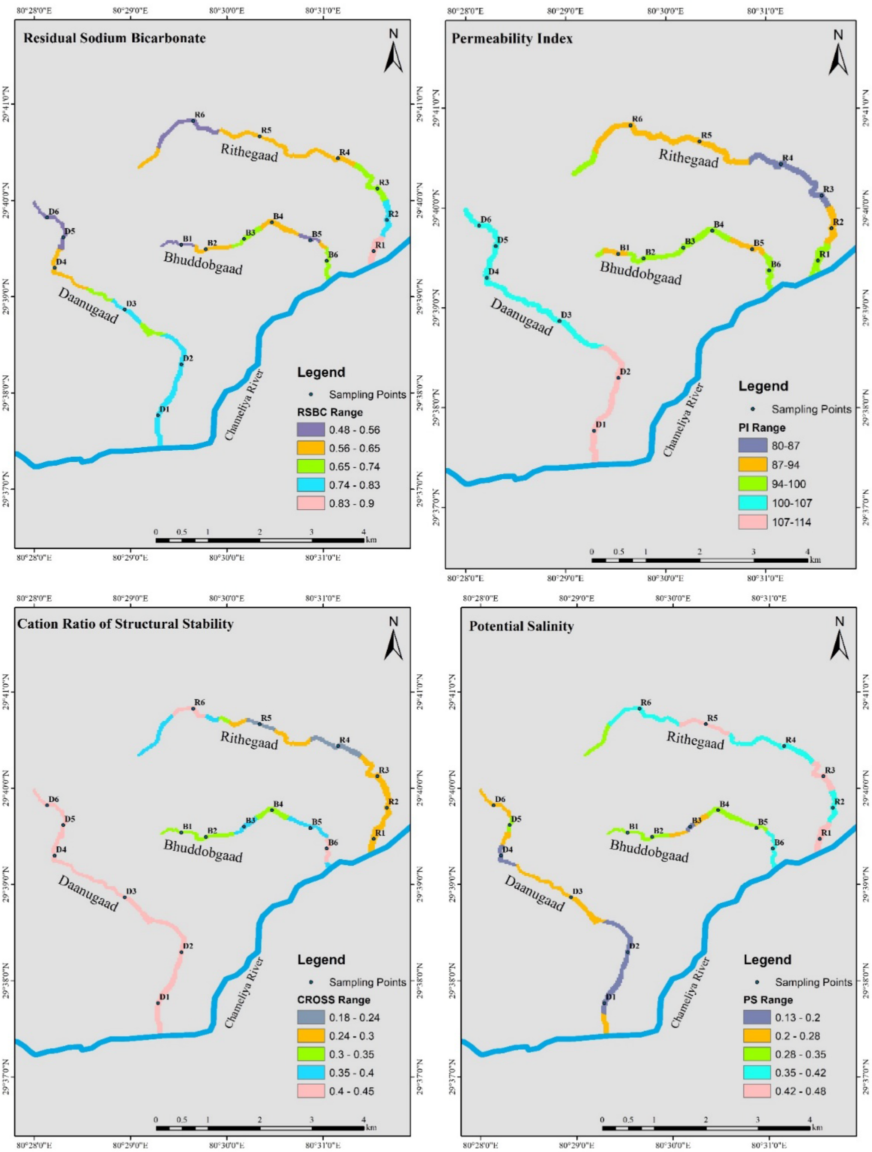
There haven't been any reports of high sodium levels in these water sources, indicating that they fall into the good and excellent categories for irrigation (Elsayed *et al.*, 2020). Sodium or alkali hazard occurs when there are elevated levels of sodium compared to other cations like calcium and magnesium. The higher the sodium proportion, reflected in SAR values, the greater the sodium or alkali hazard (Richards, 1954). Another parameter concerning sodium, calcium, and magnesium is the Sodium Adsorption Ratio (SAR), with values across all sampling points within the three rivulets remaining below 10, thereby classifying the rivulets as 'Excellent'. This signifies the potentiality of water of these rivulets suitable for irrigation (Richards 1954). The range of EC, Na%, and SAR in water as appraised in this study was found consistent with the range of such indices determined previously in the rivers and streams flowing through the Central Himalayas (Acharya *et al.,* 2020; Bishwakarma *et al.,* 2022).

Magnesium Hazard has also not been an issue for the rivulets as the MH value in all sampling points lies within the limit of 50. The MH range of less than 50 suggested the ‘suitable’ class of rivulets. The value of Kelly’s Ratio, PI, and CROSS also suggested the most decent water classes of rivulets. All the sampling points in three rivulets lie in the ‘safe’ class in terms of Kelly’s ratio with a value less than 10, ‘Class I’ in terms of PI>75, and ‘Excellent’ in terms of CROSS value less than 10. Potential salinity (PS) in 100 % water samples of three rivulets is less than 3 making the water from all sites suitable for irrigation. Similarly, RSBC is also in the safe range in all the sampling points of the studied rivulets. This suggested that there is no high salinity hazard in the rivulets’ water (Eaton, 1950). These irrigation quality indices shared consistencies with the findings from the previous studies on irrigation in Gandaki, Brahmaputra, Yarlung, Dudhkoshi and other central Himalayan Rivers and streams (Bishwakarma *et al.,* 2022). The geospatial interpolation of the important irrigation indices for the rivulets is displayed by using the IDW maps in Figure 3.

Figure 3

Spatial Interpolation Map of Na %, SAR, MH, KR, PI, PS, CROSS, and RSBC





Irrigation Water Quality Concerning FAO Standards

The typical water quality parameters of the water samples obtained from Rithegaad, Bhuddobgaad, and Daanugaad were assessed by the FAO irrigation standards (Ayers & Westcot, 1985). The average concentration of all assessed irrigation quality parameters including pH, TDS, EC, Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^- and SAR for the water samples collected from rivulets fall within acceptable limits as illustrated in Table 6. Therefore, it is advisable to suggest that the water in the examined streams of Lekam RM was chemically appropriate for supporting crop production.

Table 6

Irrigation Water Quality Indices of Rivulets in Lekam Rural Municipality Comparing with FAO Irrigation Standard

Parameters	Unit	FAO[a]	Percentage of samples in the range (%)		
			Rithegaad	Bhuddobgaad	Daanugaad
pH	-	6.0-8.5	100	100	100
TDS	mg/L	0-2000	100	100	100
EC	µS/cm	0-3000	100	100	100
Na^+	meq/L	0-40	100	100	100
K^+	meq/L	0-20	100	100	100
Ca^{2+}	meq/L	0-20	100	100	100
Mg^{2+}	meq/L	0-05	100	100	100
HCO_3^-	meq/L	0-10	100	100	100
SO_4^{2-}	meq/L	0-20	100	100	100
Cl^-	meq/L	0-30	100	100	100
NO_3^-	mg/L	0-10	100	100	100
SAR	-	0-15	100	100	100

a: Ayers & Westcot (1985)

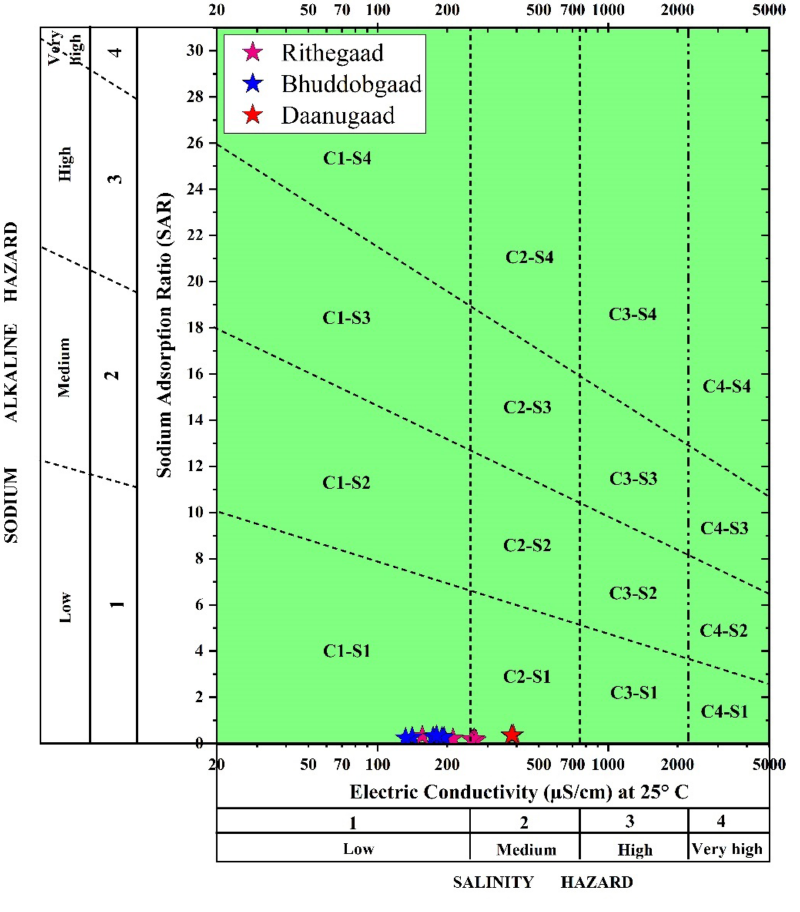
Evaluation of Irrigation Water Quality from Graphical Representation

The Wilcox diagram, as illustrated in Figure 4, depicts the relationship between salinity hazard (EC) and sodium hazard or alkalinity hazard (SAR), as proposed by Richards (1954) and Wilcox (1955). This diagram effectively illustrates the impact of both EC and SAR on soil conditions (Bishwakarma *et al.,* 2022).

This analysis reveals that 100 % of water samples from Bhuddobgaad fall within the C1-S1 class, indicating excellent quality. The results in the C1-S1 category, characterized by low salinity and low sodium hazard, demonstrate that the water in the stream is highly suitable for irrigation, representing the best quality (Acharya *et al.*, 2020; Richards, 1954). Contrastingly, for Rithegaad, 70% of the samples fall into the C2-S1 category, while the remaining 30% are in the C1-S1 class. In the case of Daanugaad, all samples, constituting 100%, lie in the C2-S1 class, indicating medium salinity and a moderate salt hazard. These findings were found consistent with some previous studies carried out in the central Himalayan and mid-hills rivers such as Kaligandaki, Karmanasha, Brahmaputra and others (Acharya *et al.,* 2020; Bishwakarma *et al.,* 2022), suggesting that the water is suitable for agricultural purposes (Richards, 1954).

Figure 4

Graphical Representation of EC vs. SAR Through Wilcox Diagram



CONCLUSION

The findings of this study in the rivulets Rithegaad, Bhuddobgaad, and Daanugaad showed that in terms of general hydrochemistry, there was similarity among them except for the value EC and TDS which is slightly higher in Daanugaad mainly the contributors being local watershed erosion and leaching of rocks and agricultural runoff of post monsoon. In Rithegaad and Bhuddobgaad, the cationic order was $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+} > NH_4^{+}$, whereas in Daanugaad this order was $Ca^{2+}>Na^{+}>Mg^{2+}>K^{+}>NH_4^{+}$. Similarly, the anionic order in these three rivulets was $HCO_3^{-}>Cl^{-}>SO_4^{2-}>NO_3^{-}>PO_4^{3-}$.

The drinking water quality index suggested that the water of rivulets Rithegaad and Bhuddobgaad is 'Excellent' for drinking whereas that of rivulets Daanugaad is reported as 'Good' for drinking. Most of the hydrochemical parameters complied with the NWQS and WHO guidelines for drinking in the rivulets. The average value of EC, SAR, Na%, KR, and PI suggested that the irrigation water quality class for the rivulets is 'fair' to 'excellent'. The mean values of pH, TDS, EC, Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, HCO_3^{-}, SO_4^{2-}, Cl^{-}, NO_3^{-} and SAR in all the sampling points lie under FAO irrigation standard. Similarly, the graphical representation by using the Wilcox diagram indicated that 100 % of samples of Bhuddobgaad lie in the C1-S1 class characterized by low salinity and low sodium hazard. Whereas, for Rithegaad, 70% of the samples fall into the C2-S1 category, and the remaining 30% are in the C1-S1 class. While in Daanugaad 100% of samples lie in the C2-S1 class, indicating medium salinity and a moderate salt hazard. This assessment of hydrochemistry and water quality indices of rivulets may provide insights for the decision-makers and local levels to manage them.

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