Major Ion Chemistry of the Bheri (Snow-Fed) and the Babai (Rain-Fed) River Systems in Western Nepal: Implication on Water Quality

Kumar Khatri[1,2], Smriti Gurung[1*], Bibhuti Ranjan Jha[1], Milina Sthapit[3], and Udhab Raj Khadka[3]

[1]Department of Environmental Science and Engineering, Kathmandu University, Dhulikhel, Nepal
[2]Mahendra Ratna Campus, Tribhuvan University, Kathmandu, Nepal
[3]Central Department of Environmental Sciences, Tribhuvan University, Kirtipur, Nepal

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*** Corresponding author:**
E-mail: smriti@ku.edu.np

ABSTRACT

Inter Basin Water Transfer (IBWT) is a water resource stressor globally with negative environmental impacts. This study describes the major ions and hydrochemistry of the first ever ongoing IBWT from snow-fed Bheri River to rain-fed Babai River in Western Nepal. Water samples from 10 sites, five from each river system, were collected in HDPE bottles for major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, CO_3^{2-}) along with the estimation of pH, temperature and conductivity encompassing winter, spring, summer, and autumn in 2018. $Ca^{2+}$and HCO_3^- were the most dominant cation and anion, respectively, with $Ca-Mg-HCO_3$ water type in both the river systems. Mann Whitney test revealed significant variation (p<0.05) between the two river systems with regard to Ca^{2+}, Mg^{2+}, HCO_3^-, and SO_4^{2-}. Kruskall Wallis test revealed significant variations between seasons in pH, temperature, Na^+, K^+, and Cl^- in Bheri River system, and in pH, TDS, temperature, Na^+, K^+, Cl^- and SO_4^{2-} in Babai River system. Carbonate weathering was the main mechanism of ionic sources with insignificant contribution from silicate weathering. Relatively higher concentrations of the major ions during the dry seasons probably indicate the dilution effect of monsoon. Higher concentrations of the ions in the Babai River system reflect the latter's bedrock geology with susceptibility to erosion. With Nepal's future plans of IBWTs and their environmental implications, this finding could be helpful in mitigating the negative consequences of IBWTs in the impact assessment and management of IBWT projects because of their implications on management of aquatic resources.

1. INTRODUCTION

Rivers are one of the main sources of freshwater that provide several ecosystem services and materials for human survival (Bolch et al., 2011). These include water for drinking and sanitation; fishery, irrigation and agriculture, hydropower generation, sand and gravel, transportation routes etc. (Tickner et al., 2017; WWF, 2018). These lotic systems are crucial components of hydrological cycles, climate regulation and material transport and cycling (Acreman, 1999; Kuchment, 2004). However, despite their huge significance, anthropogenic pressures associated with ever increasing dependency on river systems and their subsequent deterioration have become one of the major global environmental issues (MEA, 2005; Water UN, 2019). Major stressors on rivers include pollution, damming and diversion of rivers, and invasive species (Best, 2019). One of the major stressors in rivers is Inter Basin Water Transfer (IBWT) which involves construction of dams and diversion of naturally flowing waters. IBWTs are considered as crucial infrastructural developments to address the unequal distribution of crucial freshwater resources, however such transfers are associated with a range of negative environmental impacts in the upstream as well as downstream reaches of the rivers and their catchments (Snaddon et al., 1999; Lakra et al., 2011; Guo et al., 2020). Global reviews have shown their implications on terrestrial dynamics, biodiversity, and water quality (Ghassemi and White,

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2007; Snaddon et al., 1999; Zhuang, 2016) attributed to changes in water flow (Marak et al., 2020), which in turn affects transport capacity of the rivers, river water temperature, salinity, turbidity, mineral and nutrient concentrations, oxygenation, inorganic substrate composition, and sediment dynamics in both donor and recipient basins (Selge et al., 2016; Gallardo and Aldridge, 2018; Tian et al., 2019; Bui et al., 2020; de Lucena Barbosa et al., 2021).

Therefore, changes in natural flow due to IBWTs affect riparian eco-system health as it diminishes the water bodies' ability to assimilate pollutants and thus cause pollution, waterlogging, eutrophication, salinization, and acidification (Zhuang, 2016). Furthermore, water levels and renewal rates decline in downstream main channels (Pittock et al., 2009), disrupt river connectivity, and flood plains and channel connectivity (Bunn and Arthington, 2002; Grant et al., 2012). Changes in water transparency, nutrient and sediment loads, channel morphology and granulometry are some of the long-term physico-chemical effects of dams on downstream (Granzotti et al., 2018; Kamidis et al., 2021; Szatten et al., 2021; Yang et al., 2021), potentially leading to long-term oligotrophic-cation (Stockner et al., 2000; He et al., 2020). For instance, water transfer of São Francisco River in Brazil has been shown to cause algal blooms in receiving reservoirs (de Lucena Barbosa et al., 2021), decrease in dissolved oxygen content, and increased turbidity and salinity in Atibaia to Jundiaí transfer (Machado et al., 2018). These impacts in turn would affect the biodiversity (Schmidt et al., 2019), water quality (de Lucena Barbosa et al., 2021), and hydro-morphology of the river channels (Bui et al., 2020). Impacts on biodiversity include loss of biodiversity through blockade of migratory routes of fishes (ADB, 2018), interruption of life cycles (Pittock et al., 2009), introduction of invasive species (Gallardo and Aldridge, 2018), and change in biotic assemblages (Wang et al., 2021). For instance, blockade of salmon migratory routes in a large number of rivers is one of the well-known impacts of damming and diversion (Ferguson et al., 2011; Pringle et al., 2000). Likewise, water transfer from Orange River to Fish River resulted the replacement of dominant macro-invertebrate taxa like Chironomidae, Hydropsychidae, and Simuliidae by *Simulium chutteri* in Great Fish River, South Africa (O'keeffe and De Moor, 1988). In Great Berg River, reduction in macroinvertebrate taxa was reported where sensitive macroinvertebrate taxa, such as the Heptageniidae and Leptoceridae, were replaced by filter feeding Hydropsychidae (Snaddon et al., 1998). Thus, IBWTs compromise the ecological processes and benefits of the river systems (Machado et al., 2018) thereby making water quality assessments crucial prior to such transfers.

River water quality assessment often involves assessment of a range of physical, chemical, and biological parameters (MEA, 2005). Major ions, viz., calcium, magnesium, sodium, potassium, bicarbonate, sulphate, chloride, and nitrate in water are crucial components of water chemistry as they reflect the characteristics of ecological environment of the rivers and their catchments (Gergel, 2005; Novotny, 1999; Qishlaqi et al., 2016; Mallick, 2017). These ions form the bulk of the ionic composition in waters and account for salinity and conductivity, form important components of cellular structures and processes (Potasznik and Szymczyk, 2015), and play significant roles in osmoregulation and metabolism, and forms the basis for water quality for biotic assemblages and water use. For instance, elevated concentrations of major ions can induce osmotic stress in freshwater organisms (Ciparis et al., 2019), and affect soil properties (Biswas et al., 2018) and agricultural productivity. Thus, their presence and concentrations have important implications on the aquatic biodiversity, water quality and water use for various purposes such as irrigation, drinking and sanitation, and recreation (Moyel and Hussain, 2015).

The impact and consequences of IBWTs have been well documented in other parts of the world (Ghassemi and White, 2007). Nepal with its huge network of rivers possess tremendous potential for hydroelectricity and irrigation (WECS, 2011) and a number of IBWT projects are in pipeline to meet demands for irrigation water and electricity in the country (GoN/DWRI, 2019). This is also in line with the country's commitment to achieve Sustainable Development Goals (SDGs) 2016-2030 (GoN/NPC, 2017). The Bheri-Babai Diversion Multipurpose Project (BBDMP), is the first ever IBWT project of the country which aims to irrigate 51,000 ha of agricultural land in the southern districts of Bardiya and Banke and; generate 46 MW (Megawatt) of hydropower by transferring water from the snow-fed Bheri to the rain-fed Babai (GoN/BBDMP, 2018). Around two kilometers downstream of the proposed water release, the Babai River flows through one of the country's Protected Area harbouring rich and charismatic species of flora and fauna. Since the

BBDMP is the first of its kind project in the country, the study of IBWTs is important for Nepal as well. Considering the negative environmental impacts of such diversions, it is imperative to generate baseline data on major ions which can serve as a reference for future assessment of diversion. Therefore, the present study has focused on the status of major ions and hydrochemistry prior to water transfer from the Bheri to the Babai, which will be an important asset for managing IBWT projects with minimal negative impacts.

2. METHODOLOGY

2.1 Study area

The study was carried out in the Bheri and the Babai Rivers, respectively, lying in Surkhet and Dang Districts of Western Nepal (Figure 1). The Bheri River is about 264 km long originating from the permanent snow-capped mountains of the western Dhaulagiri range, and its basin covers an area of 13,900 km^2 with an elevational range of 200 to 7,746 m.a.s.l. (Mishra et al., 2018). The Babai River is about 400 km long originating from the low mountains in the Mahabharat hills, has springs, monsoon river water, and underground water, and has water all year, but the volume of water is low during the dry season and its basin covers an area of 3,250 km^2 extended between from 147 to 2,880 m.a.s.l. (Mishra et al., 2021). The BBDMP aims to transfer surplus water from the Bheri River to the Babai River through a 12.7 km tunnel which is expected to provide year-round irrigation facility with generation of electricity (GoN/BBMDP, 2018). In the lowlands, the Babai flows through the Bardiya National Park harbouring several of Nepal’s most charismatic and endangered wildlife fauna (Chhetri et al., 2020).

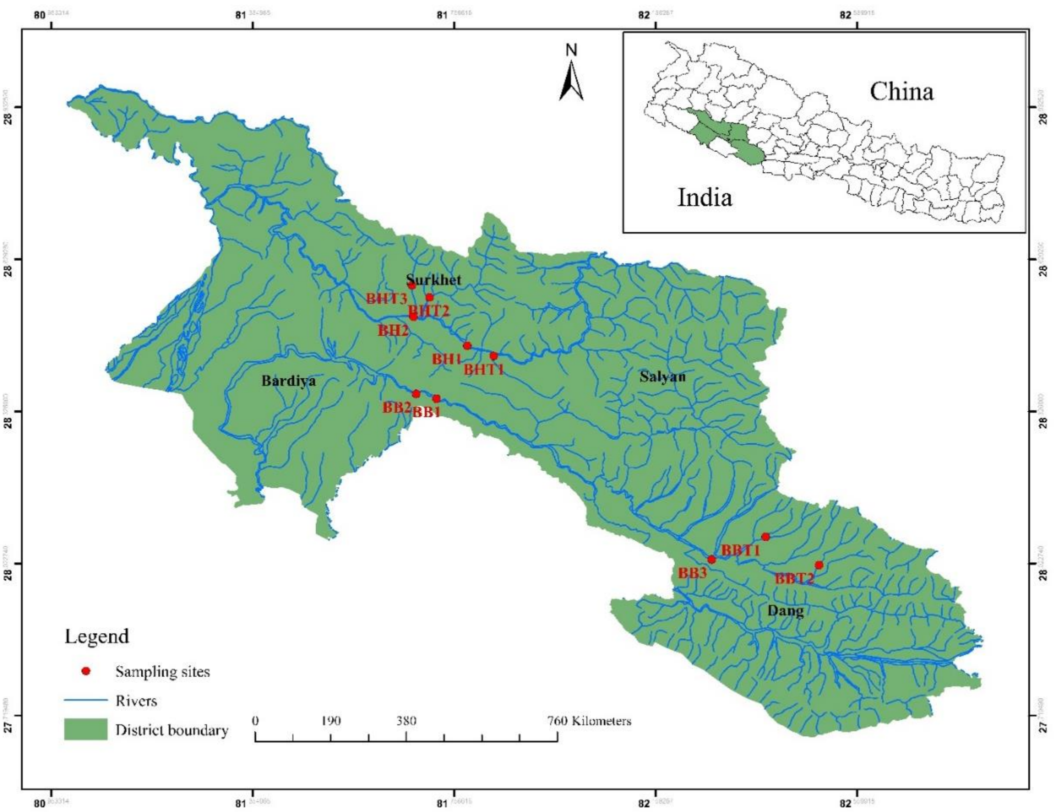

Figure 1. Study area map showing sampling sites

2.2 Sampling

Sampling was conducted in 2018 during January (winter), March-April (spring), June (summer), and November (autumn). A total of 10 sites (five from each river system) were selected based on strategic occurrence, accessibility, and retention of water in the tributaries throughout the year (Figure 1). Upstream and downstream sites of water transfer at the Bheri (BH1 and BH2 respectively) and water release at the Babai (BB1 and BB2 respectively), three tributaries from the Bheri, namely, Goche (BHT1), Chingad (BHT2); and Jhupra (BHT3); and one upstream main stem at the Babai (BB3) and two tributaries, viz., Patre (BBT1) and Katuwa (BBT2) were sampled.

From each site, 1,000 mL of water samples were collected in high density polyethylene (HDPE) bottles and the samples were stored at 4ºC in an icebox until laboratory analyses at the Department of Environmental Science and Engineering, Kathmandu University, to determine the concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, SO_4^{2-}, NO_3^{-}, and CO_3^{2-} following standard methods (APHA, 2005). Water pH, dissolved oxygen (DO), conductivity, total dissolved solids (TDS), and temperature were measured on-site using a Multi-parameter Hannah probe (Model: HI98193).

2.3 Data analysis

Descriptive statistical analysis for the major ions was computed. Because of the skewness of the obtained data, non-parametric statistical tests were used to assess significant variations between seasons and between two rivers. Mann Whitney U test was performed to compare the statistically significant variations between various parameters in the two river systems. Kruskal-Wallis H test was used to determine significant seasonal variations within each river systems. Piper trilinear diagram which is used to analyze the chemical composition of river water (Piper, 1944) was plotted. Gibbs diagram (Gibbs, 1970) which categorizes the ion sources of surface waters into rock weathering type, precipitation control type and evaporation crystallization was also plotted to show the relationships between the total dissolved solids (TDSs) and ions (anions and cations). In addition, scatter plots were also generated to identify the main sources and processes controlling the major ion chemistry in the Bheri and the Babai River systems. All mathematical and statistical analyses of the data were performed in OriginPro 2022.

3. RESULTS AND DISCUSSION

3.1 Major ions and their seasonal variation

The mean concentrations of major ions in the Bheri and the Babai rivers during different seasons are presented in Table 1. The concentration of cations in both the river systems was in the order of Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}, whereas those of the anions were in the order of HCO_3^{-} > SO_4^{2-} > Cl^{-} > NO_3^{-} in the Bheri system, and HCO_3^{-} > Cl^{-} > SO_4^{2-}> NO_3^{-} in the Babai system. Mann Whitney test revealed significant variation ($p<0.05$) between the Bheri and the Babai River systems with regard to Ca^{2+}, Mg^{2+}, HCO_3^{-} and SO_4^{2-} (Figure 2). Ca^{2+} and HCO_3^{-} are often the most dominant cation and anion in freshwater systems globally (Wetzel, 2001) and a large number of studies across Nepal and elsewhere have reported the dominance of these ions in different freshwater bodies (Lacoul and Freedman, 2005; Bajracharya et al., 2020; Bhatta et al., 2022). In contrast, the concentrations of K^{+} ions were lowest in both the water bodies. K^{+} is known to be absorbed by plants thereby making its concentrations lower in water (Skowron, 2018). The Kruskal Wallis test for pH, temperature, Na^{+}, K^{+}, and Cl^{-} in the Bheri revealed significant variation between seasons; and in the Babai system, significant variation between seasons was observed in pH, TDS, temperature, Na^{+}, K^{+} , Cl^{-}, and SO_4^{2-} (Table 1). In both the river systems, concentrations of most of the ions were higher during autumn except for SO_4^{2-}. Seasons tend to affect concentrations of ions in water bodies (Kannel et al., 2011) and seasonal variations in ion concentrations have been reported by various authors (Pant et al., 2018; Khadka and Ramanathan, 2021). Lower concentrations of ions during summer could be because of dilution effect attributed to heavy precipitation and glacial meltwater as summer months of June, July, August and September are characterized by monsoon in South Asia including Nepal (Shrestha and Aryal, 2011; Zhu et al., 2021).

pH was alkaline in both the river systems (Table 1). A large number of studies conducted in Nepalese rivers have also reported similar findings (Jha et al., 2018; Ghimire et al., 2021; Singh et al., 2021). Alkalinity is attributed to dissolved carbon dioxide, bicarbonate, and carbonate (Domenico and Schwartz, 1998; Ewaid, 2016), which in turn is affected by pH. The TDS was higher in the Babai River system. TDS values are usually attributed to natural as well as anthropogenic sources (Mikalsen, 2005). Bedrock geology and weathering are natural sources of dissolved ions (Singh et al., 2016), whereas drainage systems particularly in urbanized watersheds, wastewater leakages and fertilizer runoffs are the anthropogenic sources which contribute to increased TDS concentrations in water bodies (Mikalsen, 2005). The higher TDS concentrations indicate the presence of an appreciable quantities of bicarbonates, sulphates and chlorides of Ca^{2+}, Mg^{2+}, and Na^{+} (Hossain et al., 2017). The higher TDS concentrations in the Babai system particularly in sites BB3, BBT1, and BBT2 probably reflects the use of fertilizer run off, urbanized watershed and catchment geology. In both the river

Table 1. Seasonal variation of the major ions concentrations in the Bheri and the Babai River systems (units in mg/L except for pH)

Parameters	Bheri River system				Babai River System			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
pH	8.47 ± 0.16^{ab}	8.65 ± 0.17^{a}	7.88 ± 0.35^{b}	7.80 ± 0.44^{b}	8.46 ± 0.20^{a}	8.31 ± 0.25^{a}	7.69 ± 0.39^{b}	7.69 ± 0.19^{c}
TDS	141.00 ± 36.52^{a}	154.93 ± 28.47^{a}	152.40 ± 32.34^{a}	188.13 ± 42.07^{a}	186.40 ± 32.94^{abc}	175.13 ± 17.99^{a}	169.33 ± 58.54^{ac}	263.33 ± 49.80^{b}
Ca^{2+}	33.24 ± 3.53^{a}	36.64 ± 8.75^{a}	36.96 ± 8.61^{a}	31.52 ± 9.97^{a}	44.16 ± 8.62^{a}	37.12 ± 5.56^{a}	33.12 ± 8.50^{a}	41.60 ± 7.48^{a}
Mg^{2+}	14.56 ± 2.43^{a}	15.90 ± 2.49^{a}	14.06 ± 1.41^{a}	14.14 ± 3.92^{a}	22.24 ± 3.98^{a}	19.68 ± 3.05^{a}	15.50 ± 4.15^{a}	20.40 ± 4.02^{a}
K^{+}	1.67 ± 0.37^{ab}	1.92 ± 0.47^{a}	0.54 ± 0.03^{c}	1.17 ± 0.13^{bc}	1.73 ± 0.19^{a}	2.06 ± 0.30^{a}	0.64 ± 0.15^{c}	1.61 ± 0.17^{ac}
Na^{+}	5.22 ± 1.68^{a}	4.33 ± 0.68^{a}	0.39 ± 0.02^{b}	3.38 ± 0.99^{ab}	4.62 ± 1.32^{ab}	8.03 ± 2.75^{c}	0.33 ± 0.02^{a}	4.77 ± 0.42^{bc}
HCO_3^{-}	143.83 ± 53.48^{a}	136.01 ± 41.03^{a}	125.29 ± 29.61^{a}	156.02 ± 42.30^{a}	184.67 ± 22.96^{a}	165.84 ± 34.69^{a}	154.00 ± 25.47^{a}	196.49 ± 34.47^{a}
Cl^{-}	11.33 ± 3.09^{a}	14.15 ± 6.88^{a}	2.50 ± 0.00^{b}	6.50 ± 2.38^{ab}	13.13 ± 1.87^{a}	13.50 ± 1.92^{a}	6.00 ± 4.18^{b}	7.83 ± 1.51^{b}
NO_3^{-}	0.46 ± 0.24^{a}	0.25 ± 0.31^{a}	0.26 ± 0.15^{a}	0.23 ± 0.13^{a}	0.44 ± 0.34^{a}	0.44 ± 0.29^{a}	0.17 ± 0.07^{a}	0.46 ± 0.58^{a}
SO_4^{2-}	20.08 ± 8.36^{a}	21.97 ± 9.48^{a}	15.29 ± 10.01^{a}	16.15 ± 11.96^{a}	12.02 ± 1.50^{ab}	12.83 ± 1.72^{a}	4.43 ± 0.45^{c}	6.34 ± 1.63^{cb}

Note: Values followed by different letters are statistically significant ($p<0.05$).

systems, Ca^{2+} concentrations exceeded 15 mg/L which is higher than the concentrations in natural waters. This may be associated with carbonate-rich rocks (Bisht et al., 2018). The concentrations of Mg^{2+}, K^{+}, and Na^{+} are within the range of natural concentrations and thus, suitable for agricultural purposes (Boyd, 2020). The excess of K^{+} enters freshwaters with industrial discharges and runoffs from agricultural land as potassium is widely used in industry and fertilizers (Best, 2019; Mukate et al., 2020). Concentration of Cl^{-} in winter and spring from both the river systems surpassed the pristine limit of <10 mg/L. SO_4^{2-} concentrations were within range of concentrations in natural waters (Chapman, 1996). SO_4^{2-} is naturally present in surface waters though it can arise from the atmospheric deposition of oceanic aerosols, leaching of sulphur compounds, from sedimentary rocks, and industrial and atmospheric precipitation can add significant amounts of SO_4^{2-} to surface waters (Kurdi et al., 2015).

3.2 Hydrochemistry and mechanisms controlling water chemistry

The hydrochemical facies of both river systems is shown in a Piper plot (Figure 3). In the Bheri River system, Ca^{2+} accounted for the highest total cationic equivalent charge of 55.25% followed by Mg^{2+} with 38.95%, Na^{+} and K^{+} covering 5.80%. Among the anions, HCO_3^{-} contributed 78.30% of the total anionic equivalent charge followed by SO_4^{2-} with 13.71% and Cl^{-} covering 7.99%. In the Babai system also, Ca^{2+} accounted for the highest total cationic equivalent charge of 51.72% followed by Mg^{2+} with 42.38%, Na^{+} and K^{+} covering 5.89%. HCO_3^{-} contributed 86% of the total anionic equivalent charge followed by Cl^{-} with 8.38% and SO_4^{2-} covering 5.62%. Dominance of Ca^{2+} and HCO_3^{-} in both the river systems indicates their origin from carbonate weathering (Singh et al., 2005). The dominance of these ions has been reported in a number of freshwater bodies across the earth including Nepal (Reynolds et al., 1995; Wetzel, 2001; Gurung et al., 2018; Sharma et al., 2020). The points in ternary plots appear to support from the Ca^{2+} apex to the Mg^{2+} side accompanied by drifting from the Cl^{-} side to the HCO_3^{-} and SO_4^{2-} domain indicating general direction of progression from carbonate weathering in both the river systems (Figure 3). HCO_3^{-} mainly originates from carbonate weathering, reflecting the dominance of carbonates rocks as controls of water chemistry (Jiang et al., 2015).

Hence, the total cations and anions in both rivers in the Ca^{2+}, Mg^{2+}, HCO_3^- corners suggest a Ca^{2+}-Mg^{2+}-HCO_3^- river water (Khadka and Ramanathan, 2012; Qu et al., 2019).

Gibbs plots (Gibbs, 1970) reflecting the ratio of $Na^+/(Na^+ + Ca^{2+})$ and $Cl^-/(Cl^- + HCO_3^-)$ as a function of TDS further revealed that all the water samples fall in the dominated area of rock weathering indicating that various rock forming minerals as the primary factor controlling the water chemistry of the Bheri and the Babai River systems (Figures 4 and 5).

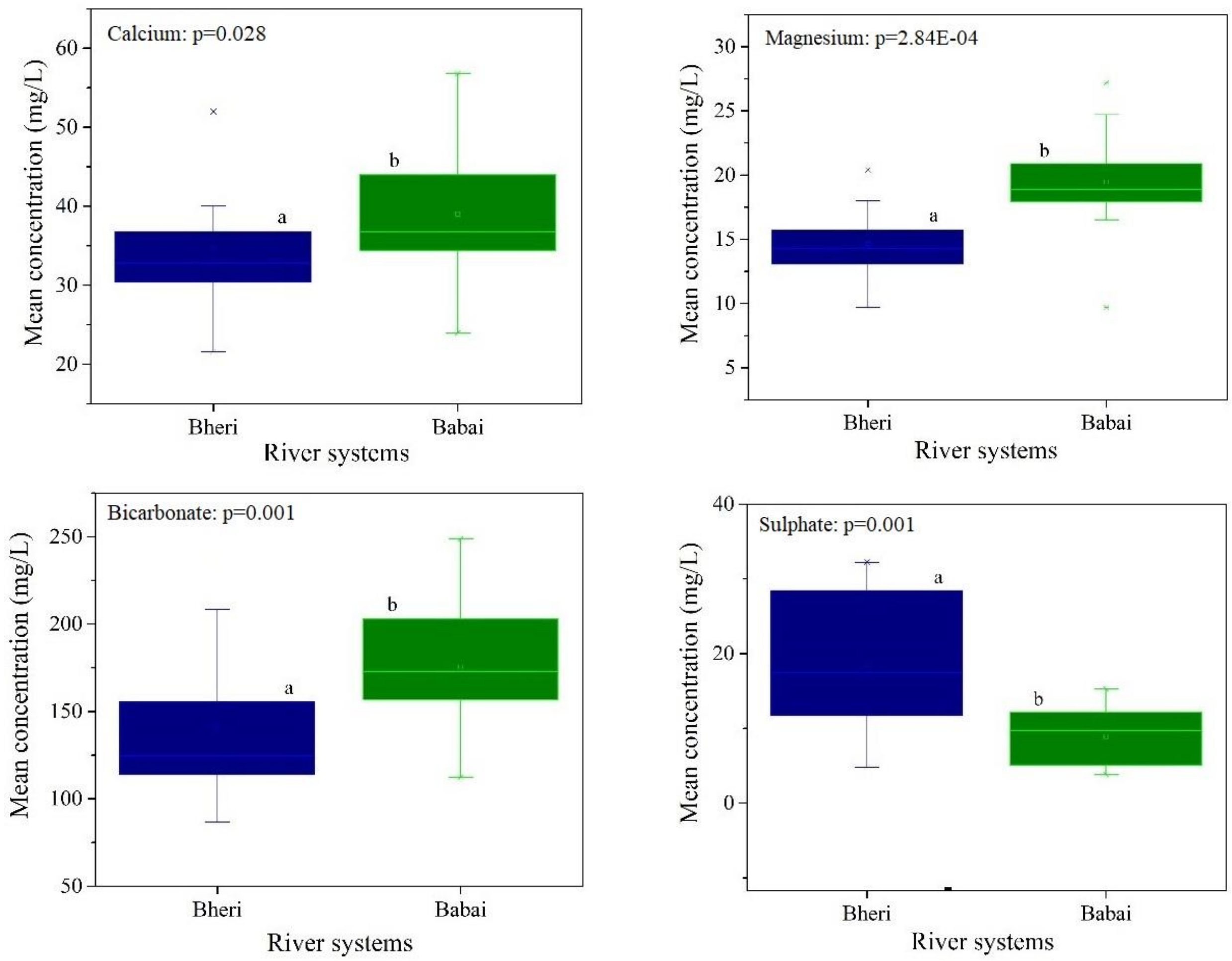

Figure 2. Mean concentration of different physico-chemical parameters of the Bheri and the Babai River system (Values followed by different letters are statistically significant (p<0.05).)

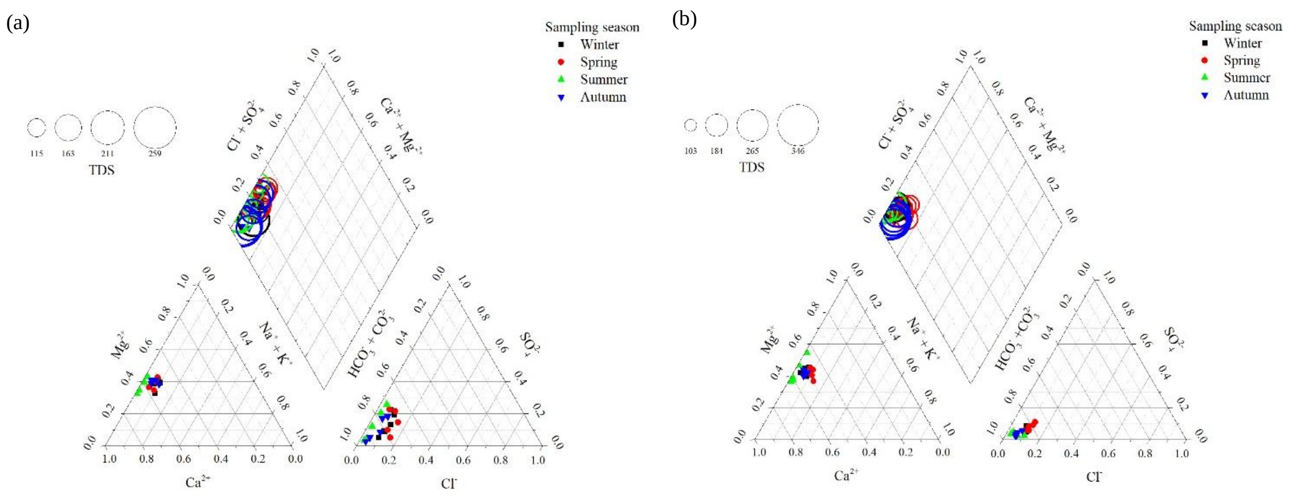

Figure 3. Ternary plots of cation and anion concentrations of the Bheri (a) and the Babai (b) River systems

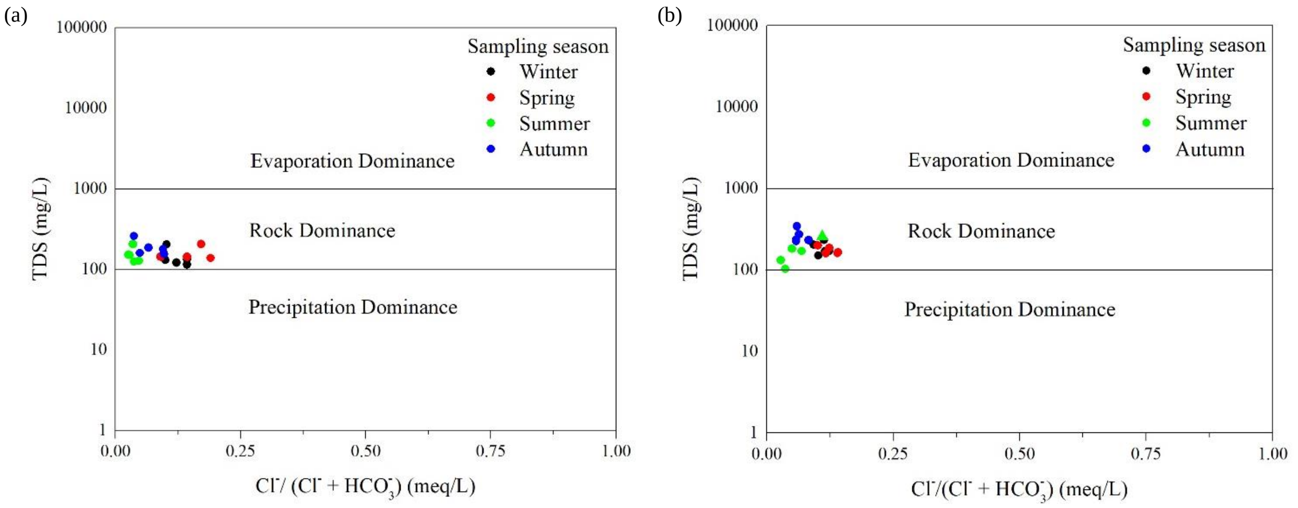

Figure 4. Gibbs diagrams indicating the Bheri (a) and the Babai (b) River system natural evolution mechanisms TDS vs. $Cl^-/(Cl^-+HCO_3^-)$.

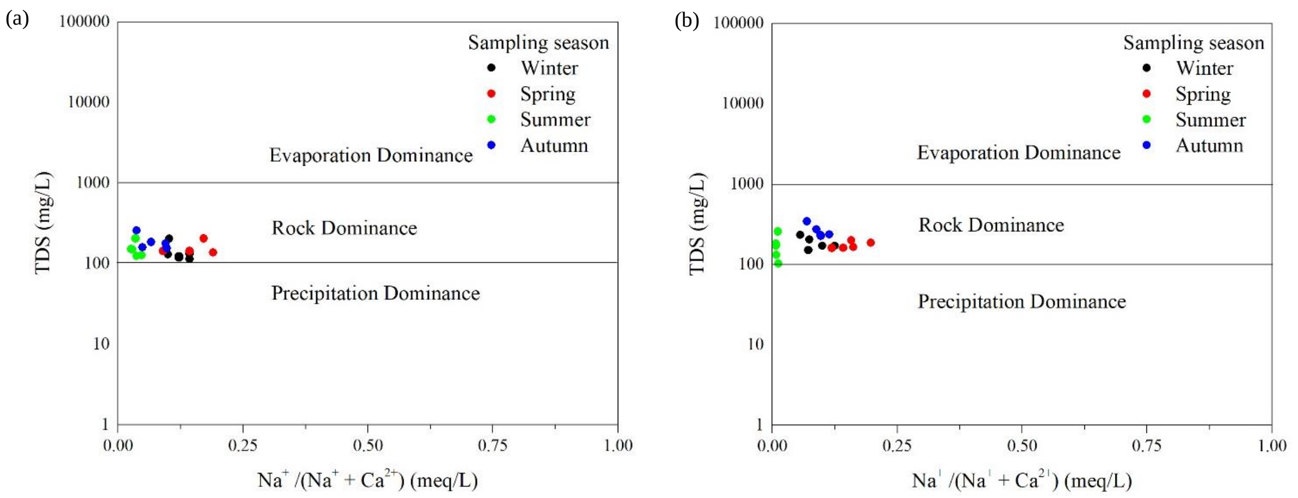

Figure 5. Gibbs diagrams indicating the Bheri (a) and the Babai (b) River system natural evolution mechanisms TDS vs. $Na^+/(Na^++Ca^{2+})$.

The hydrochemical facies reflect the chemical interactions on the lithological environment (Vasanthavigar et al., 2013). The high concentration of Ca^{2+} for all the water bearing units can probably be due to water-rock interaction as most of the rocks contain mineral species such as calcite, gypsum, and anhydrite (Dhital, 2015). The low level of K^+ relative to Ca^{2+}, Mg^{2+}, and Na^+ may be due to the fact that it can easily be fixed by clay minerals (Shakeri and Abtahi, 2020). Dominance of HCO_3^- indicates chemical weathering inferred from silicate and carbonate weathering rocks present in the river basin (Nisha et al., 2021). Dissolution of CO_2 in the surface water through natural gas exchange from atmosphere, respiration of riparian plants, and microbial activity in sediments results into the formation of CO_3^- and HCO_3^-, which in turn are mainly accountable for rock weathering, particularly carbonate rocks and alumino-silicate minerals (Gupta et al., 2022). Dominance of CO_3^- and HCO_3^- in both the river systems thus reflect carbonate weathering and atmospheric carbon oxide exchange. Furthermore, dominance of Ca^{2+} and HCO_3^- (weak acid) over SO_4^{2-} and Cl^- (strong acids) in both the river systems indicate the dominance of alkaline earth metals over alkaline elements thereby confirming bedrock geology as the main contributor to major ions (Tiwari et al., 2021). All analyzed samples are classified as calcium-magnesium-bicarbonate water. All the water samples are mainly towards carbonate and silicate end-members, indicating the main mechanism controlling the water chemistry of both river systems, and reflects the dissolution of minerals such as pyroxene, calcite, gypsum, anhydrite, and dolomite (Wanty et al., 2009). The sources of these minerals are associated with limestone, marl, dolerite, and pyroclastic materials associated with the slate rocks in the study area (Zaw et al., 2014). Chemical weathering has been identified as the major source of major ions in the rivers draining the Himalaya where carbonate weathering plays the dominant role in river hydrochemistry (Tsering et al., 2019). The weathering of carbonates is greater in most river systems in Western Nepal than the weathering of silicates (Quade et al., 2003). In the glaciated Himalayan regions, more than 90% of HCO_3^- and Ca^{2+} is derived from carbonate weathering, though the carbonates represent only ~1.0 wt% in fresh glacial till (Jacobson et al., 2002). The Bheri catchment consists of very thick (more than 5 m) alternating beds of red-purple, yellow, brown, and grey-green mudstone, calcareous mudstone, and shale with siltstone and medium to fine-grained grey and green-grey sandstone intercalations (Arita et al., 1984; Kafle et al., 2019). The Babai River system in the Dang Valley is filled up with Pleistocene to Holocene fluvial sediments, consisting of clay and peat, fluvial deposits, mixed up with various crush rocks silt soils with pebbles, cobbles, and boulders (up to 1 m) of quartzite, slate, and limestone. This also explains higher TDS in the Babai system particularly at sites BB3 (Babai River), BBT1 (Patre River), and BBT2 (Katuwa River). Most of these materials are highly weathered, resulting in the development of red soils and badlands (Kono, 1974). The Himalayan region has a high frequency of physical erosion and chemical weathering triggered by relief and elevation (Singh et al., 2005; Lupker et al., 2012). Calcareous rocks are predominantly carbonate rocks, usually limestone or dolostone with chemical compositions of $CaCO_3$ (Dhital, 2015) and $CaMg(CO_3)_2$ (Tamrakar and Shrestha, 2008), respectively. Presence of such calcite and dolomite rich geology explains the higher concentrations of Ca^{2+}, Mg^{2+}, and HCO_3^- in the Bheri and the Babai River waters.

The values of the ionic ratios also support the origin of major ions generated by chemical weathering. Scatter plots showing ionic source and mechanism controlling hydrochemistry of the Bheri and the Babai systems are shown in Figures 6, 7, 8, and 9. The ratio of Ca^{2+}+Mg^{2+}/(Tz^+) (Figure 6) in the Bheri and the Babai Rivers with the regression line having slope values of 0.95 and 0.90, respectively, suggests the majority of contributions from Ca^{2+} and Mg^{2+}. The ratio of Ca^{2+}+Mg^{2+}/HCO_3^-+SO_4^{2-} (Figure 7) in both the systems with slope values of 0.58 and 1.24, respectively, suggests the dominant role of carbonate weathering, suggesting calcite, dolomite, and gypsum dissolution to be dominating reactions. In both river systems, most of the sites have higher values of (Ca^{2+}+ Mg^{2+}) than HCO_3^- which requires additional anions such as SO_4^{2-} for ionic balance indicating the probable role of sulfuric acid in carbonate weathering in both river systems. However, Ca^{2+}+ Mg^{2+}/HCO_3^- ratio (Figure 8) with the regression line showing slope values of 0.56 and 1.19 in the Bheri and the Babai respectively, also suggests the contribution from silicate weathering in addition to carbonate weathering. Few samples appear below the equiline in both river systems indicating an excess of HCO_3^- over Ca^{2+} probably derived from silicate weathering (Vinnarasi et al., 2021). The (Na^++K^+)/Tz^+ ratio in the Bheri and the Babai River systems (Figure 9) with the regression line having a slope value of 0.046 and 0.096, respectively, further confirms carbonate weathering indicating that there is no significant contribution of cations to the river waters from of alumino-silicate weathering. Little ionic contribution from silicate weathering has been reported in several water bodies from Nepal for instance, from Dudh Koshi and Indrawati Rivers (Paudyal et al., 2016), lakes of Pokhara (Khadka and Ramanathan, 2012; Khadka and Ramanathan, 2021; Kafle et al., 2023), Chandragiri-Payaswini River system in India (Nisha et al., 2021), and Teesta River in Sikkim, India (Tsering et al., 2019).

Ca^{2+} and HCO_3^- are the most dominant cation and anion in both the river systems. Furthermore, the scatter plots revealed that carbonate weathering of sedimentary rocks rich in calcium minerals with limestone and gypsum is the main source of dissolved calcium in river water (Bhateria and Jain, 2016). The ionic composition of surface waters is usually considered to be relatively stable and is governed by exchanges with the underlying geology of the drainage basin and atmospheric deposition. Magnesium, sodium, and potassium concentrations tend not to be heavily influenced by metabolic activities of aquatic organisms, whereas calcium can exhibit marked seasonal and spatial dynamics as a result of biological activity (Wetzel, 2001; Carr and Neary, 2008). Similarly, chloride concentrations are not heavily influenced by biological activity, whereas sulphate and inorganic carbon (carbonate and bicarbonate) concentrations can be driven by production and respiration cycles of the aquatic biota (Carr and Neary, 2008). External forces such as climatic events that govern evaporation and discharge regimes and anthropogenic inputs can also drive patterns in ionic concentrations.

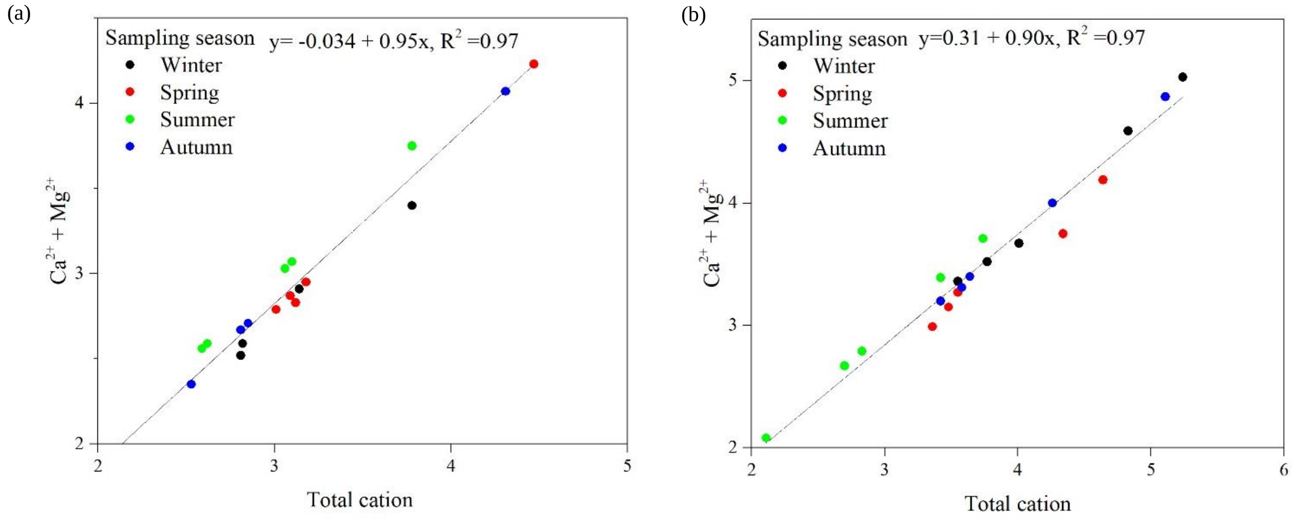

Figure 6. Scatter diagram of $(Ca^{2+}+Mg^{2+})/Tz^{+}$ of the Bheri (a) and the Babai (b) River systems

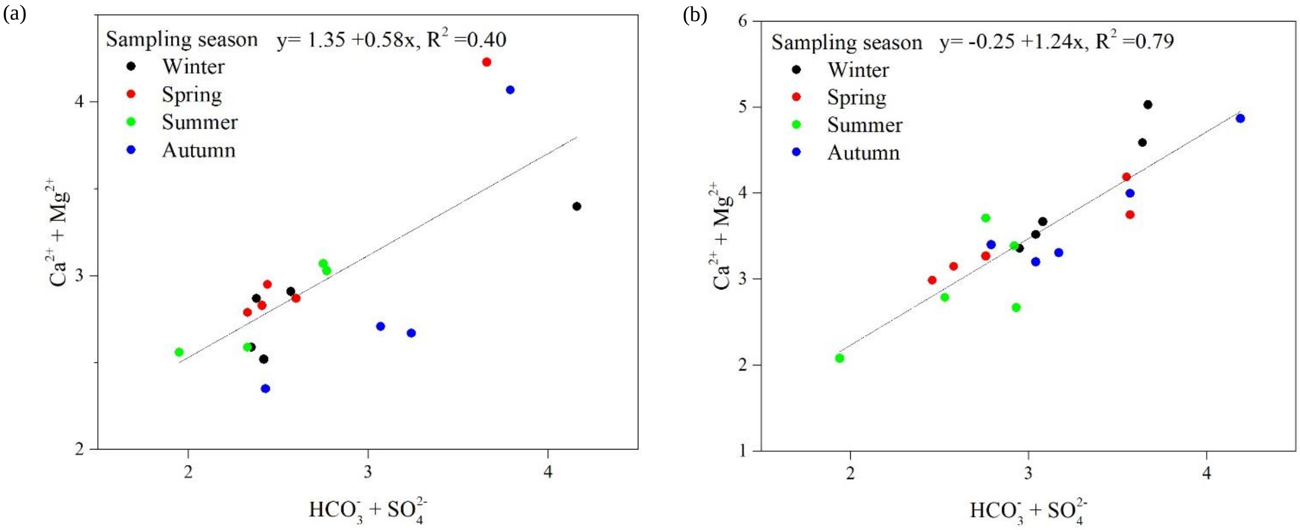

Figure 7. Scatter diagram of $(Ca^{2+}+Mg^{2+})/(HCO_3^- + SO_4^{2-})$ of the Bheri (a) and the Babai (b) River systems

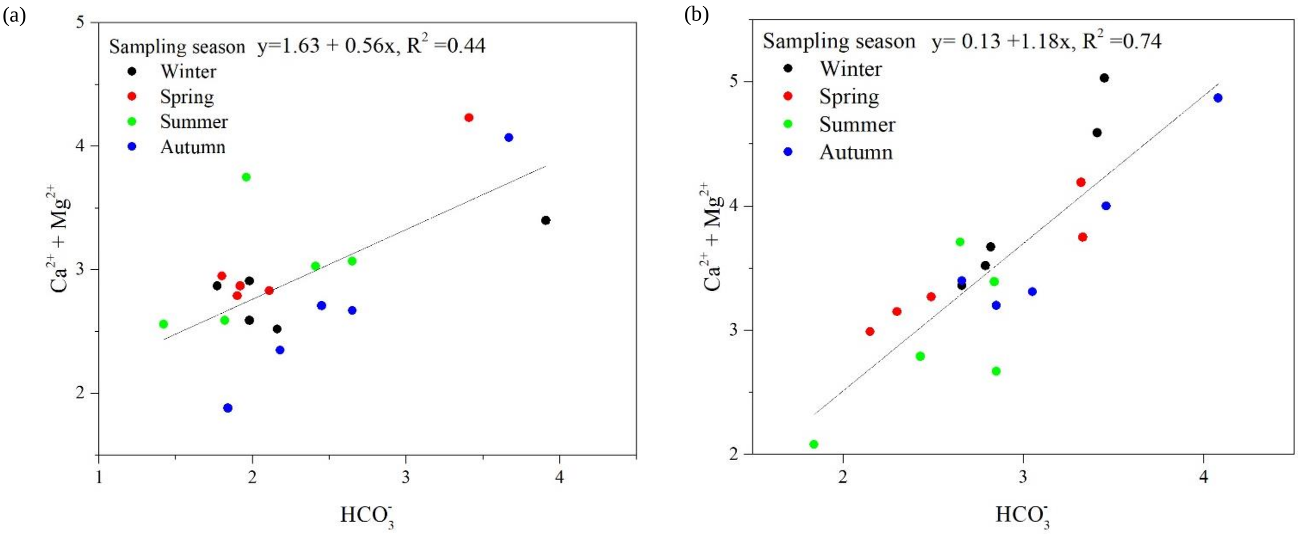

Figure 8. Scatter diagram of $(Ca^{2+}+Mg^{2+})/HCO_3^-$ of the Bheri (a) and the Babai (b) River systems

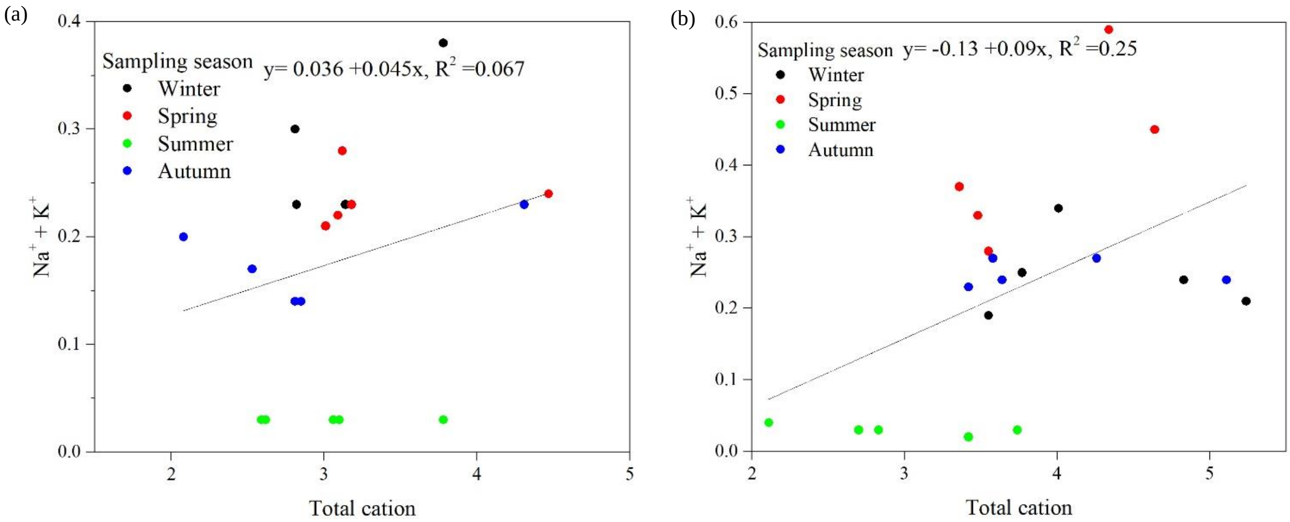

Figure 9. Scatter diagram of $(Na^{+}+K^{+})/Tz^{+}$ of the Bheri (a) and the Babai (b) River systems

4. CONCLUSION

This study has generated the status of major ions and hydrochemistry of the Bheri and the Babai Rivers in Western Nepal prior to inter-basin water transfer. In both rivers, Ca^{2+} and HCO_3^- were the most dominant cation and anion respectively. Carbonate weathering was the main mechanism of ionic sources with insignificant contribution from silicate weathering. Relatively higher concentrations of major ions during the dry seasons probably indicate the dilution effect of monsoon. Apart from this, higher concentrations of the ions in the Babai systems reflect the latter's bedrock geology which is susceptible to erosion. In order to balance the distribution of crucial water resource from water abundant river basin to the water deficit river basin, the IBWTs will be a common practice in the future. However, there will be the widespread impacts of such transfers, both positive and negative. While, the positives such as the redistribution of water, thereby helping water cycle and climate regime, protecting biota and repairing disrupted ecological system are most welcome, the information this study has gathered is more important in mitigating the negative consequences of such initiatives in the future. These findings are crucial baseline data particularly in the impact assessment of inter-basin water transfer and management of IBWT projects because of their implications on management of water quality and aquatic resources.

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