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Research Article

Evaluation of multiple water quality indices for irrigation purposes for the Bheri and Babai River systems, Nepal

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Abstract
The main purpose of this study was to assess the irrigation water quality of the Bheri and Babai Rivers and their tributaries prior to the proposed inter-basin water transfer (IBWT) in western Nepal. A total of 40 water samples from five sites in each river system were collected from January (winter), March-April (spring), June (summer) and October (autumn) in 2018; and some important irrigation water quality parameters were assessed. All the assessed parameters viz. pH, Total Dissolved Solids (TDS), Total Hardness (TH), permeability index (PI), percent sodium (%Na), sodium adsorption ratio (SAR), magnesium hazard (MAR), residual sodium carbonate (RSC), Kelly's index (KI) from all sites were observed suitable for irrigation. USSL diagram showed that water from both the rivers belongs to the S1-C2 category indicating good for irrigation purposes. The Wilcox diagram revealed that all samples fall into the excellent to a good class. Based on Irrigation Water Quality Index (IWQI), 3 sampling sites fall in the high restriction category and 7 sampling sites fall in the moderate restriction category, indicating anthropogenic impacts on irrigation water quality at some sites.

Keywords: Babai, Bheri, Inter-basin water transfer, irrigation water quality

Introduction
Water quality is the suitability of water for specific use (Omer, 2019) and entails the physical, chemical and biological characteristics of water (Boyd, 2020). Considering the use and significance of water for a range of purposes, land use and catchment geology, the type of water resources, the types and concentrations of different physical, chemical and biological components of water quality vary (Chapman, 1996). Accordingly, a large number of different water quality standards and indices for different water uses have been developed at global, regional and national scales to examine water quality for different purposes such as drinking (BIS, 1987; NDWQS, 2005; WHO, 2011) ecosystem health (Carr & Neary, 2008; Haynes et al., 2007; Trivedi, 2010); recreation (Cabelli, 1989; Fujioka et al., 2015); aquaculture (Boyd, 2003; Zweig et al., 1999); agriculture and irrigation (Bauder et al., 2011; Fipps, 2003).

Nepal with its rich freshwater resources (WECS, 2011) has tremendous potential for hydropower generation, agriculture and irrigation; aquatic biodiversity, fishery and aquaculture (ADB, 2018). Studies have suggested that the country has the hydropower potential of generating 83,000 MW (Zou et al., 2021). However, only an estimated 15 (BCM) billion cubic meters is reported to be in use out of 225 BCM available surface water. Of the 15 BCM also, the bulk of the water (around 95.9 %) is being used for agricultural purposes (WECS, 2011). Despite having rich freshwater resources and their tremendous significance, water quality degradation is a growing environmental concern in the country (ADB, 2018). Rivers and streams in the urban and semi-urban areas in particular are affected by a range of point as well as non-point sources of pollution and stressors. Most of the streams and rivers in the country receive untreated sewage (Mishra et al., 2017); agricultural runoff (Bhat & Qayoom, 2021; Pradhanang, 2012) and many rivers particularly in urban areas also contain high concentrations of heavy metals (Kayastha, 2015; Paudyal et al., 2016a). The problem is further exacerbated with increasing dependency of people on rivers and streams.

Of the different stressors in rivers and streams, damming and diversion of rivers are considered as one of the major causes of water quality deterioration (ADB, 2018). Damming and diversion in Nepalese context are done mainly for hydropower generation and irrigation purposes (Bhatt, 2017; Crootof et al., 2021). The Water Resources Act (1992) of the country gives irrigation third priority after the use of water for drinking and domestic purposes clearly signifying the importance of irrigation and food productivity in the country. However, damming and diversion for water availability have several negative environmental impacts too (Bui et al., 2020) on flow, biodiversity and water quality (Zhuang, 2016). Considering the significance of rivers and streams and their deterioration, increased use and dependency of freshwater, damming diversion projects in pipelines in the country, water quality assessments become crucial.

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Bheri Babai Diversion Multipurpose Project (BBMDP) is a first of its kind national pride project that aims to transfer water from glacial-fed Bheri to rain-fed Babai River in western Nepal mainly for irrigation of the terai lowlands in the southern districts of Banke and Bardiya. Infrastructural developmental projects of such scales require environmental assessment which was conducted in 2011 which provides some information on water quality and river biodiversity particularly the fish diversity. In this article, we have attempted to report the suitability of the water of the Babai and the Bheri River for irrigation prior to the proposed inter-basin water transfer.

Materials and Methods

Study area

The study was conducted in the selected stretches of the Bheri and the Babai Rivers and their tributaries in western Nepal. The Bheri is around 264 km long and is a glacial-fed river originating from the Mount Dhaulagiri range (Mishra et al., 2018). It is one of the major tributaries of the Karnali River. It covers an estimated drainage area of 13,900 km^2 with altitudes ranging from 200 – 7746 masl. Its catchment receives an annual rainfall of 1202 mm (Mishra et al., 2018). The Bheri catchment consists of calcareous mudstone and shale with siltstone and sandstone (Dhital, 2015).

The Babai River is around 400 km long and is a perennial spring/rain-fed river originating from the from the Siwalik range (Sharma, 1977). It has a low flow during dry seasons. The Sharada River originating in the Mahabharat range is the major tributary of the Babai contributing to Babai's discharge. It's drainage area around 3250 km^2 with altitudes ranging from 147 to 2880 masl. The Babai catchment mainly consists of quartzite, slate, and limestone (Mishra et al., 2021).

Sampling and analysis

Sampling was conducted in 2018 during January (winter), March-April (spring), June (summer) and October (autumn). Sampling sites were chosen strategically and both upstream and downstream stretches at the point of damming and diversion at Bheri; and at the point of water release in Babai (Table 1) were sampled. Apart from these sites, three tributaries of the Bheri namely Goche, Chingad and Jhupra at Surkhet; and two tributaries of the Babai namely Katuwa and Patre and mainstem Babai at Dang were also sampled based on accessibility and landuse. Thus, a total of 40 water samples from 10 sites (Fig. 1) were collected. One of the sampling points of the Babai River was located inside Bardiya National Park and for this, approval from the DNPWC was obtained prior to sampling.

At each site, selected physico-chemical parameters such as pH, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), and temperature were measured (three replicates) on-site using a multi-parameter probe at each site (Hannah Model: HI98193). From each sampling site, one liter of water sample was collected in HDPE (High density polyethylene) bottles. The samples were immediately stored at 4^{o}C until laboratory investigation at the laboratory of Department of Environmental Science and Engineering, Kathmandu University. The samples were analyzed to determine the concentrations of cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (Cl^{-}, SO_4^{2-}, NO_3^{-}, HCO_3^{-}, CO_3^{2-}) using standard methods (Table 2) (APHA, 2005). The suitability of river water for irrigation was examined based on different parameters and indices (Table 3). Furthermore, TDS vs TH diagram (Fig 2), Doneen diagram (Fig 3), USSL diagram (Fig 4), Wilcox diagram (Fig 5) and IWQI (Fig 6) were plotted.

Table 1 Sampling sites with geographical coordinates and elevation

Site Codes	Rivers	Places	Elevation (masl)	Latitude	Longitude	Remarks
BH1	Bheri	Cheepla, Surkhet	436	28.45742°N	081.78235°E	Upstream of water diversion at Bheri
BH2	Bheri	Bhanghari, Surkhet	403	28.51468°N	081.67520°E	Downstream of water diversion at Bheri
BHT1	Goche	Mehelkuna, Surkhet	475	28.43677°N	081.83489°'E	Tributary of Bheri
BHT2	Chingad	Gangate, Surkhet	466	28.55361°N	081.70715°E	Tributary of Bheri
BHT3	Jhupra	Jhupra, Surkhet	497	28.57791°N	081.67207°E	Tributary of Bheri
BB1	Babai	Chepangghat, Bardiya	293	28.35160°N	081.72109°E	Upstream of water release at Babai
BB2	Babai	Mulghat, Bardiya	287	28.36127°N	081.68044°E	Downstream of water release at Babai
BB3	Babai	Bel Takura, Dang	561	28.03095°N	082.26972°E	Upstream of Babai
BBT1	Patre	Majhgaun, Dang	594	28.07607°N	082.37733°E	Tributary of Babai
BBT2	Katuwa	Ghorahi, Dang	625	28.01966°N	082.48380°E	Tributary of Babai

Source: Khatri et al. (2022)

Table 2 Methods followed for determination of ions

Parameters	Test Methods/
Total Hardness as $CaCO_3$	EDTA Titration
Total Alkalinity	Titration with H_2SO_4
Calcium and Magnesium	EDTA Titration
Sodium and Potassium	Flame Emission Photometry
Nitrate	Spectrophotometry
Chloride	Argentometric Method

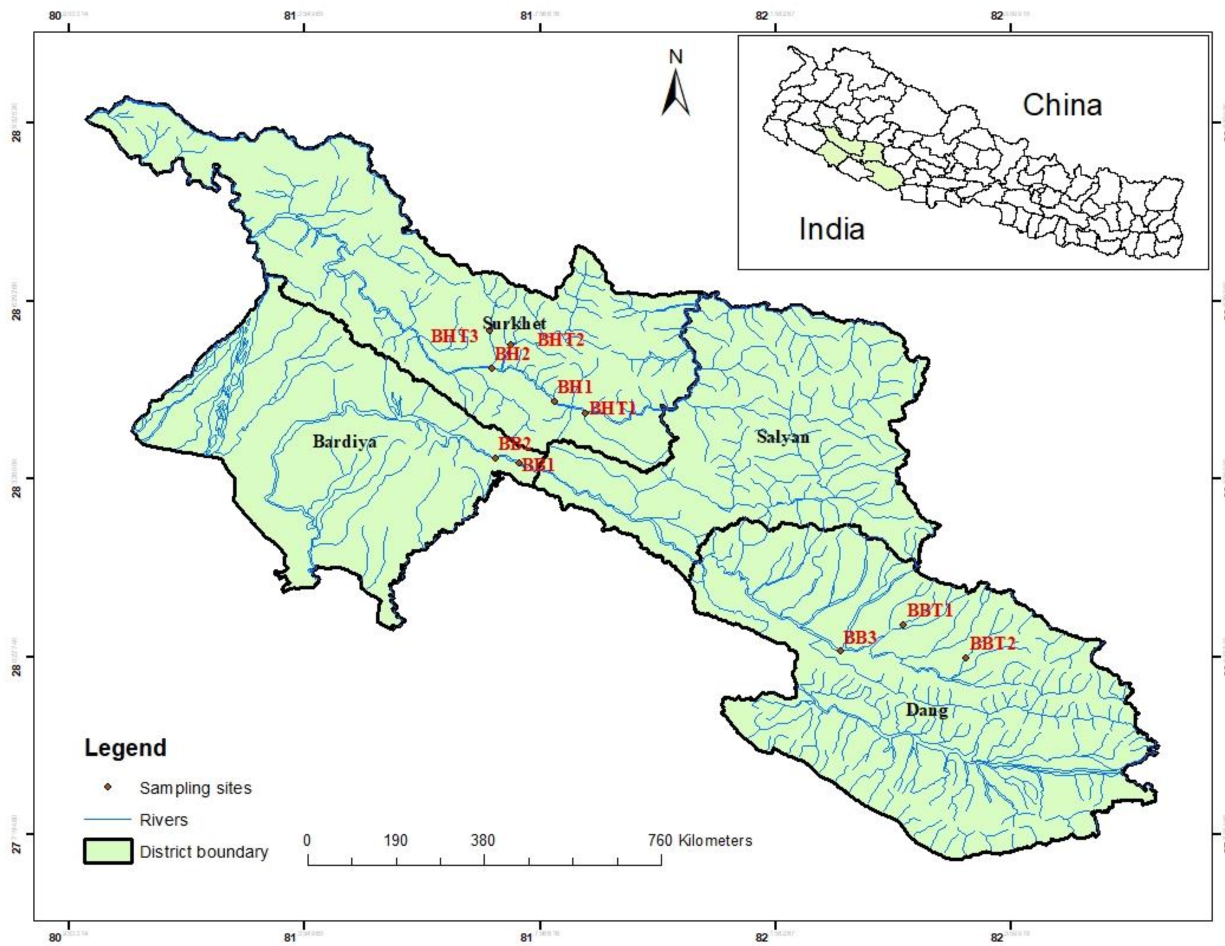


Figure 1 Map showing the different sampling sites

Table 3 Irrigation water quality indices

Index	Formula	Reference
Permeability index (PI)	$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100$	(Doneen, 1954)
Percent sodium (%Na)	$\%Na = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100$	(Wilcox, 1955)
Sodium adsorption ratio (SAR)	$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$	(Richards, 1954)
Residual sodium carbonate (RSC)	$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$	(Richards, 1954)
Magnesium adsorption ratio (MAR)	$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$	(Paliwal, 1972; Raghunath, 1987)
Kelly's index (KI)	$KI = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$	(Kelly, 1940)

Note: all concentrations are expressed in meq/L

In addition, the irrigation water quality index (IWQI) was also calculated following Meireles et al. (2010). In the first step q_i was estimated using the following equation developed by Ayers and Westcot (1994) (Table 4). q_i value is a non-dimensional number and higher qi values indicate better water quality for irrigation and it is calculated on the basis of the values of five irrigation sensitive parameters such as EC, SAR, Na^+, Cl^-, HCO_3^-.

$$q_i = q_{imax} - \frac{[(x_{ij} - x_{inf}) \times q_{iamp}]}{x_{amp}} \text{ ------------------------------(i)}$$

where,

q_i is a quality measurement values
q_{imax} is a maximal value of q_i for the class,
x_{ij} is the observed value of chemical parameters,
x_{inf} is the minimal limit of the class to each parameter belongs,
q_{iamp} is class amplitude and
x_{amp} is the upper limit of the last class of each parameter.

After the calculation of qi, accumulation weights (w_i) were estimated following Meireles et al., (2010) where the total accumulation weights value is equal to 1 (Table 4).

Table 4 Parameter limiting values for quality measurement (q_i) calculation (Ayers & Westcot, 1994) and normalized weights (w_i) for the IWQI calculation (Meireles et al., 2010)

q_i	EC (dS/cm)	SAR $(meq/l)^{0.5}$	Na^+ (meq/l)	Cl^- (meq/l)	HCO_3^- (meq/l)
85-100	0.20 ≤ EC < 0.75	2 ≤ SAR < 3	2 ≤ Na < 3	1 ≤ Cl < 4	1 ≤ HCO_3 < 1.5
60-85	0.75≤EC<1.50	3 ≤ SAR < 6	3 ≤ Na < 6	4 ≤ Cl <7	1.5≤ HCO_3 < 4.5
35-60	1.50≤EC<3.00	6 ≤ EC< 12	6 ≤ Na < 9	7 ≤ Cl <10	4.5 ≤ HCO_3 < 8.5
0-35	EC < 0.20 or EC ≥ 3.00	SAR < 2 or SAR ≥ 12	Na < 2 or Na ≥ 9	Cl < 1 or Cl ≥ 10	HCO_3 < 1 or HCO_3 ≥ 8.5
Weight (w_i)	**0.211**	**0.189**	**0.204**	**0.194**	**0.202**

Finally, irrigation water quality index (IWQI) was calculated according to the following equation:

$$IWQI = \sum_{i=1}^{n} qi \times w_i \text{ -------------------------(ii)}$$

IWQI is the non-dimensional value ranging from 0 to 100; q_i is the quality measurement of the parameter, (i^{th}) a number from (0 to 100) and is a function of its concentration; and w_i is the normalized weight of the i^{th} parameter (Table 4).

The obtained IWQI values fall under five categories (Table 5).

Table 5 IQWI-based classification of water quality

IWQI values and type of restriction	Recommendations for Crops and Soil	
	Plant	Soil
0 ≤ 40 (Severe restriction [SR])	High salt tolerance only	Under normal circumstances, river water cannot be used to irrigate soil.
40 ≤ 55 (High restriction [HR])	Moderate to high salt tolerance	River water can be used for permeable soil without compact layers and with a high irrigation frequency for irrigation water with 2ds/cm and SAR>7(meq/l).
55 ≤ 70 (Moderate restriction [MR])	Moderate salt tolerance	River water can be utilized to irrigate moderately permeable soils and moderate soils leaching processes.
70 ≤ 85 (Low restriction [LR])	Avoid the use of salt sensitive	For light soil textures with high sand concentration and moderate to high permeability, river water can be used.
85 ≤ 100 (No restriction [NR])	No toxicity	River water can be used for all types of soil due to the low risk of soil salinity and sodicity.

Results and Discussion

Results of the assessment of different irrigation water quality parameters and indices from the Bheri and Babai River systems are summarized in Tables 6 and 7.

Table 6 Water quality attributes result of water samples of the Bheri River systems of four major seasons

Site Code	Season	pH	TDS (mg/l)	TH (mg/l)	PI	% Na	SAR	RSC (meq/l)	MAR	KR	IWQI
BH1	Winter	8.59	131.00	143.61	49.28	7.13	0.14	-0.97	41.58	1.29	72.64
	Spring	8.66	144.00	143.67	51.08	7.23	0.14	-0.78	42.99	1.33	70.20
	Summer	8.07	125.33	151.35	52.38	1.19	0.02	-0.73	39.97	1.05	73.60
	Autumn	7.81	185.67	133.56	62.41	4.86	0.09	0.01	43.16	1.22	59.68
		8.28± 0.41	146± 27.26	143.05± 7.29	53.79± 5.89	5.10±2.83	0.10± 0.06	-0.62±0.43	41.93± 1.48	1.22± 0.12	69.03± 6.40
BH2	Winter	8.61	133.00	145.67	51.19	7.21	0.14	-0.78	42.40	1.34	68.59
	Spring	8.85	143.00	147.79	48.30	7.09	0.14	-0.91	44.58	1.42	71.38
	Summer	7.92	127.67	135.13	47.03	1.27	0.02	-1.11	43.78	1.13	80.84
	Autumn	7.45	179.00	135.56	59.43	4.98	0.09	-0.24	42.53	1.22	62.20
		8.21± 0.64	145.67 ±23.11	141.04±6.63	51.49± 5.57	5.14±2.77	0.10± 0.06	-0.76±0.37	43.32± 1.04	1.28± 0.13	70.75± 7.75
BHT1	Winter	8.21	205.00	170.01	61.99	10.00	0.26	0.63	43.60	1.66	36.83
	Spring	8.39	205.67	211.79	46.27	5.38	0.14	-0.66	38.69	1.72	43.35
	Summer	7.37	205.67	217.56	37.63	0.80	0.01	-1.78	32.92	1.24	70.59
	Autumn	7.66	260.00	203.86	49.55	5.39	0.14	-0.37	41.20	1.76	43.35
		7.91± 0.47	219.09 ±27.28	200.81±21.28	48.86± 10.09	5.39±3.76	0.14± 0.10	-0.55±0.99	39.10± 4.58	1.60± 0.24	48.53± 15.02
BHT2	Winter	8.44	115.00	129.48	57.61	8.18	0.17	-0.50	44.84	1.30	68.55
	Spring	8.68	138.00	139.74	52.34	7.08	0.15	-0.72	45.67	1.39	68.89
	Summer	8.30	151.00	170.27	51.47	0.98	0.01	-0.53	43.41	1.33	64.40
	Autumn	8.55	155.67	117.81	64.83	6.80	0.13	-0.03	44.04	1.15	66.44
		8.49± 0.16	139.92 ±18.22	139.33±22.49	56.56± 6.14	5.76±3.24	0.12± 0.07	-0.45±0.29	44.49± 0.98	1.29± 0.10	67.07± 2.08
BHT3	Winter	8.52	121.00	126.03	62.18	10.49	0.23	-0.22	36.59	1.08	65.58
	Spring	8.67	144.00	141.84	54.94	9.12	0.19	-0.54	38.03	1.21	65.90
	Summer	7.76	152.33	166.21	53.19	0.97	0.01	-0.40	35.07	1.09	60.79
	Autumn	7.54	160.33	93.88	74.64	9.76	0.18	-0.03	42.55	0.96	72.17
		8.12± 0.56	144.42 ±16.97	131.99±30.33	61.24± 9.75	7.59±4.45	0.15± 0.10	-0.30±0.22	38.06± 3.23	1.09± 0.10	66.11± 4.67

Table 7 Irrigation water quality attributes result of water samples of the Babai River systems of four major seasons

Site Code	Season	pH	TDS (mg/l)	TH (mg/l)	PI	% Na	SAR	RSC (meq/l)	MAR	KR	IWQI
BB1	Winter	8.53	170.67	183.76	49.81	8.52	0.22	-0.66	43.47	1.74	54.20
	Spring	8.56	160.67	163.79	51.57	7.76	0.18	-0.61	48.77	1.73	60.14
	Summer	7.10	103.33	133.78	65.64	1.72	0.02	-0.23	38.45	0.81	73.58
	Autumn	7.42	227.00	170.01	50.94	6.61	0.16	-0.73	43.60	1.59	58.80
		7.90± 0.75	165.42± 50.65	162.84± 21.09	54.49± 7.47	6.15± 3.06	0.15± 0.09	-0.56±0.22	43.57± 4.21	1.47± 0.44	61.68± 8.33
BB2	Winter	8.68	171.33	175.96	50.29	6.64	0.15	-0.47	48.91	1.83	55.47
	Spring	8.57	162.00	157.67	52.23	9.39	0.22	-0.69	48.05	1.68	62.50
	Summer	8.00	132.33	156.89	56.09	1.22	0.01	-0.31	37.12	1.05	64.29
	Autumn	7.86	236.67	165.66	55.84	7.55	0.18	-0.22	45.73	1.64	52.39
		8.28± 0.41	175.58± 43.99	164.05± 8.88	53.61± 2.83	6.20± 3.51	0.14± 0.09	-0.42±0.21	44.95± 5.39	1.55± 0.34	58.66± 5.65
BB3	Winter	8.28	205.00	229.75	42.67	4.91	0.13	-1.05	46.96	2.24	45.83
	Spring	8.14	201.00	209.59	48.50	9.72	0.28	-0.78	48.53	2.22	45.90
	Summer	8.07	170.67	190.54	49.83	0.73	0.01	-0.49	47.05	1.60	56.82
	Autumn	7.88	273.33	199.93	49.33	6.22	0.16	-0.49	43.05	1.82	45.74
		8.09± 0.17	212.50± 43.35	207.45± 16.78	47.58± 3.32	5.40± 3.71	0.15± 0.11	-0.70±0.27	46.40± 2.34	1.97± 0.31	48.57± 5.50
BBT1	Winter	8.58	151.00	168.01	50.67	5.33	0.11	-0.51	44.12	1.56	58.44
	Spring	8.26	165.00	149.85	53.81	10.87	0.26	-0.77	45.34	1.55	64.61
	Summer	7.56	182.67	209.59	44.16	0.78	0.01	-1.04	39.72	1.48	59.90
	Autumn	7.68	233.33	159.96	55.45	6.66	0.15	-0.32	45.05	1.55	55.20
		8.02± 0.48	183.00± 35.97	171.85± 26.23	51.02± 4.99	5.91± 4.16	0.13± 0.10	-0.66±0.31	43.56± 2.61	1.54± 0.04	59.54± 3.91
BBT2	Winter	8.21	234.00	251.78	38.97	3.95	0.11	-1.47	43.67	2.26	44.41
	Spring	8.02	187.00	187.76	54.98	13.63	0.39	-0.35	42.55	1.84	44.52
	Summer	7.70	257.67	252.56	63.44	1.08	0.01	0.21	55.15	1.48	54.98
	Autumn	7.62	346.33	243.85	43.72	4.71	0.13	-0.76	45.93	2.31	35.63
		7.89± 0.28	256.25± 66.85	233.99± 31.07	50.28± 11.05	5.84± 5.42	0.16± 0.16	-0.59±0.71	46.83± 5.73	1.97± 0.39	44.89± 7.91

pH

pH values ranged from 7.10 to 8.85. The mean value of pH was 8.20 ± 0.44 and 8.04 ± 0.47 in the Bheri and the Babai River system respectively was observed which indicate that river water was neutral to weak alkaline. This indicates a normal range and is suitable for irrigation (Ayers & Westcot, 1994). Alkaline pH has been reported in other Himalayan rivers as well (Paudyal et al., 2016 b; Seth et al., 2016; Matangulu et al., 2017; Sharma et al., 2020). pH values ranging from 6.5 to 8.40 are considered good for irrigation. 12 samples (Tables 5 and 6) had pH values higher than 8.5. Higher pH values are often caused by high carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) concentrations (Ayers & Westcot, 1994).

Total dissolved solids (TDS)

TDS concentration varies from 103.30 mg/l to 346.30 mg/l. The mean concentration value of TDS in the Bheri River system was 159.12 ± 37.00 (mg/l) whereas in the Babai River system was 198.60 ± 55.20 (mg/l). In general, TDS < 450 mg/l is preferred for irrigation; TDS > 450–2000 mg/l and TDS > 2000 mg/l are considered respectively slight to moderately and unsuitable for agricultural purposes (Bauder et al., 2005). In natural waters, TDS is a function of minerals, nutrients and major ions and is resulted from weathering or dissolution of soil and rocks (Singh et al., 2013) and anthropogenic sources such as agrochemicals (Kundu, 2012). Similar TDS values have been observed from the Seti River and the Marshyangdi River (Bishwakarma et al., 2022; Pant et al., 2022; Sharma, 1977; WHO, 2011) and elsewhere (Joshi et al., 2009).

Total hardness (TH)

Total hardness ranged from 93.88 mg/l to 252.56 mg/l with a mean of 151.24 ± 31.99 mg/l in the Bheri river system whereas in the Babai River system it was 188.03 ± 34.96. TH is usually classified as soft (<75 mg/l), moderately hard (75- 150 mg/l), hard (150 – 300 mg/l) and very hard (> 300 mg/l) (Sawyer et al. 1967). The TDS vs TH graph (Fig 2) showed that the samples fall between soft and moderately hard waters. Total hardness along with TDS are functions of geographic and geomorphic conditions, bedrock lithology and human activities (Yuan et al., 2020) which differs in different catchments (Aminiyan et al., 2018; Liu et al., 2020). In natural waters, hardness usually ranges from 10 to more than 500 mg/l and values above 500 mg/l are relatively uncommon in natural waters (USEPA, 1976). A similar observation of total hardness has been observed from rivers originating from Mahabharat range and glacial fed rivers in Nepal (Limbu & Prasad, 2020; Pandey & Devkota, 2016; Paudel et al., 2020; Shrestha & Basnet, 2018) and elsewhere (Bhutiani et al., 2016; Haritash et al., 2016; Tyagi et al., 2020). Hardness in water bodies is resulted from both natural and anthropogenic sources. The former includes limestone and calcareous geology while industrial and domestic wastes include anthropogenic sources (Ojo et al., 2012). Few samples are beyond the range suitable for irrigation (Table 5 and 6) which could be attributed to the predominance of Ca^{2+} and Mg^{2+} (alkaline earths) over Na^{+} and K^{+} (alkali earths) in the river catchment (Eyankware et al., 2018).

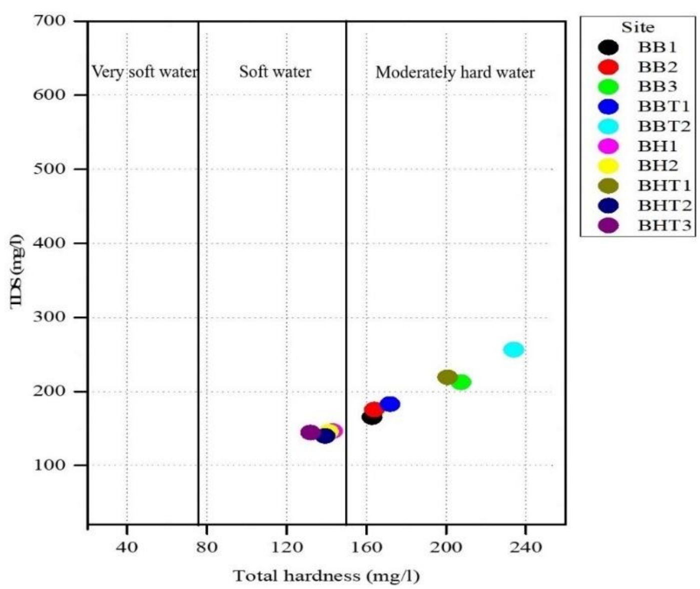


Figure 2 Water types based on TDS vs TH contents for the Bheri and Babai River system

Permeability index (PI)

PI value ranged from 37.63 to 74.64 with a mean value of 54.39±8.16 in the Bheri River system whereas in the Babai River system, this value ranged from 38.97 to 65.64 with a mean value of 51.40±6.44. The permeability index (PI) is one of the widely used parameters used to assess the suitability of water for irrigational purposes. Permeability is the capability of water movement in soil and it is influenced by soil porosity, texture, structure (Tang et al., 2011). However, in arid and semi-arid areas, permeability can be affected by the long-term use of irrigation water and can often result in high concentration of salts in water (Rawat et al., 2018). Decreased permeability causes salt accumulation on topsoil and prevents water adsorption by plants which reduces crop production (Seelig, 2000). Doneen (1975) has categorized water used for irrigation based on PI; Class I with >75% of maximum permeability is considered as suitable; Class II with 25–75% of maximum permeability is considered good while Class III with <25% of maximum permeability is considered unsuitable. Based on PI %, the Doneen's diagram (Fig. 3) showed that the majority of sites belong to Class I and two sites belong to Class II, indicating moderate to a good class water quality for irrigation.

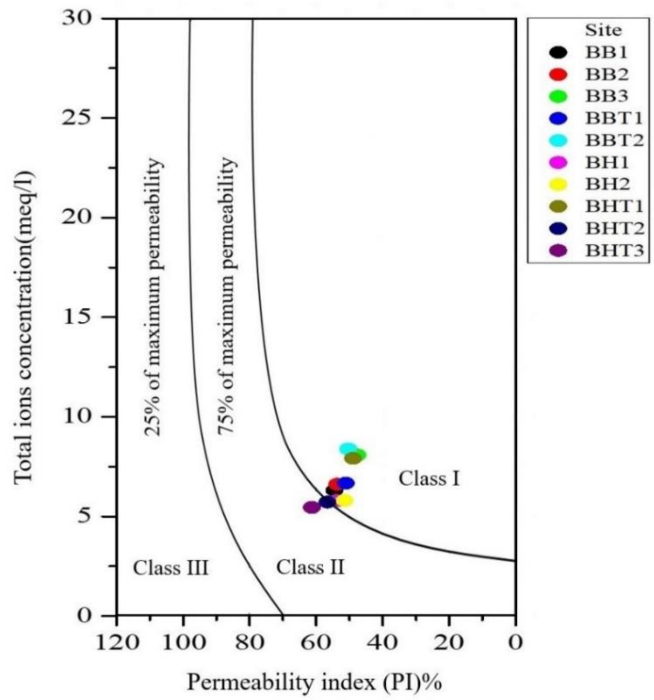


Figure 3 Doneen diagram for water type of the Bheri and Babai River systems

Kelly's index (KI)

KI values ranged from 0.96 to 1.76 with mean value 1.69±0.37in the Bheri River system whereas in the Babai River system, its value ranged from 0.81to 2.31 with mean value of 1.29±0.22. Kelly's index (KI) is an alkali hazard indicator. KI value of <1 indicates deficit of Na^{+} in water and thus indicate suitability of water for irrigation; values between 1 and 2 indicate marginal suitability whereas, values >2 is considered unsuitable for irrigation (Kelly, 1940). Only 4 samples (Table 6) showed values of >2 indicating unsuitable irrigation water quality. The probable reasons for higher KI values could be attributed to agricultural runoff at sites BB3 and BBT2.

Magnesium adsorption ratio (MAR)

MAR values during the study ranged from 32.92 to 55.15. The mean value of MAR was 41.38 ± 3.45 and 45.06 ± 4.06 in the Bheri and the Babai River systems respectively. MAR reflects the relationship between the concentrations of two major alkaline earth metal ions namely Ca^{2+} and Mg^{2+} in water (Ayuba et al., 2013). These ions maintain a state of equilibrium in most waters but high concentrations of Mg^{2+} in water damage the soil quality thereby affecting crop productivity (Salifu et al., 2017). High concentrations of Ca^{2+} and Mg^{2+}in water can cause alkalinity which in turn results in decrease in the availability of phosphorous (Al-Shammiri et al., 2005) thereby affecting soil fertility. High concentrations of transferrable Mg^{2+} ions in the soil may affect infiltration as well (Ayers & Westcot, 1994). MAR values exceeding 50 cause soil alkalinity and is considered to have an adverse effect on crop yields (Paliwal, 1972). Only one site from Babai River system (BBT2) during summer had higher value of MAR.

Residual sodium carbonate (RSC)

The RSC values ranged from -1.78 meq/l to 0.63 meq/l in the Bheri River system and in Babai River system, it ranged from -1.47 meq/l to 0.21 meq/l with a mean values of -0.53±0.50 meq/l and -0.59±0.36 meq/l in the Bheri and Babai River systems, respectively. According to Richards (1954) RSC values of 1.25 meq/l or lower is safe for irrigation; those between 1.25 and 2.5 meq/l is marginal while those above 2.5 meq/l is considered to be of poor quality and deemed unsuitable.

RSC assessment is also important to calculate the required amount of gypsum or sulfuric acid as a remedial measure to neutralize residual carbonates effect in soil. The elevated concentrations of carbonate and bicarbonate is due to the soil's alkaline nature and is deemed unfavorable for agricultural use (Al-Tabbal & Al-Zboon, 2012) as high concentrations of HCO_3^- in soil increases pH value. High levels of RSC are known to cause accumulation of sodium in soil (Murtaza et al., 2021) and induces lime deposition on roots and leaves of the plants (Hopkins et al., 2007). Thus, RSC has implications on soil as well as crops.

Sodium adsorption ratio (SAR)

The mean values of SAR were 0.12±0.07 and 0.14±0.1 in the Bheri and Babai River systems respectively. SAR is an important parameter and one of the most commonly estimated parameters of irrigation water quality (Gholami & Srikantaswamy, 2009). SAR provides information on the potential for infiltration problems due to sodium imbalance in irrigation water. It is used to measure the alkali/sodium level to determine the harmful level of crops (Wagh et al., 2016). SAR also influences the percolation time of water in the soil. Higher SAR values cause serious soil physical problems regarding structure and make water absorption by plants very difficult (Bauder et al., 2011). Leaf burn, scorch and the appearance of dead tissue along the outside edges of leaves on plants are some of the symptoms of sodium toxicity (Ayers & Westcot, 1994) caused by higher SAR values. Thus, it gives a very reliable assessment of water quality of irrigation waters with respect to sodium hazard. Four classes of waters are categorized based on SAR values - value less than 10 meq/l is considered as excellent; values between 10 and 18 meq/l are considered as good; values between 18 and 26 meq/l as doubtful and values greater than 26 meq/l is considered as unsuitable (Richards, 1954). In the present study, SAR values of all sites fall in excellent class (Fig 4). In addition, EC values ranges between 295.00 µs /cm to 526.7 µs /cm indicating all the water samples are within the good class for irrigation. In general, Nepalese rivers and freshwaters are known to be characterize by low SAR values (Gurung et al., 2021; Pant et al., 2018; Sharma et al., 2020) indicating the suitability of these waters for irrigation.

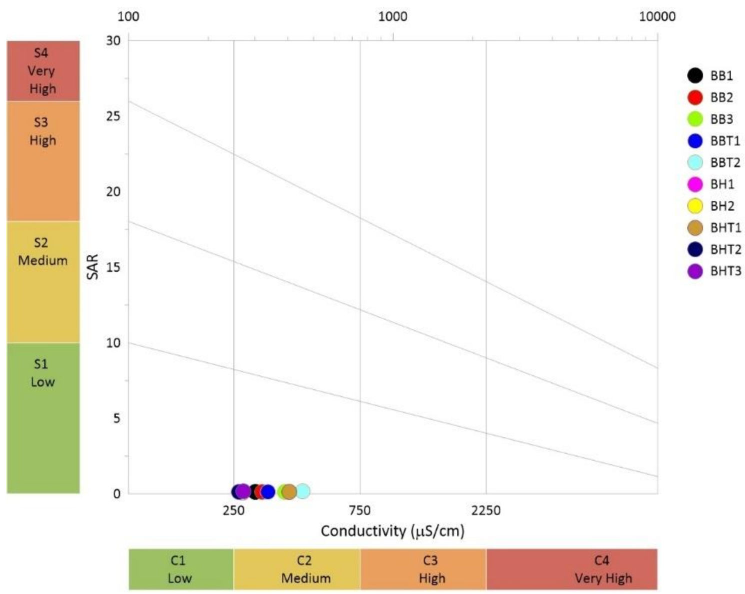


Figure 4 USSL diagram for irrigation suitability according to SAR and EC values

Percent sodium (%Na)

The data in the present study showed that lowest value of %Na was 0.35(during summer) at BB3 and the highest was 2.15 (during spring) at BH1. The mean value of the %Na for all sites is located within the excellent to good classes suitable for irrigation. Sodium percentage (%Na) is another important indicator of sodium hazard and frequently used to assess the suitability of natural waters for irrigation (Richards, 1954). Based on % Na, water is classified into five classes- excellent ($0 \leq \%Na \leq 20\%$); good water ($20 < \%Na \leq 40\%$), permissible ($40 < \%Na \leq 60\%$), doubtful ($60 < \%Na \leq 80\%$) and unsuitable ($80 < \%Na \leq 100$) for irrigation (Wilcox, 1955). % Na is often expressed as Wilcox diagram which illustrates the association between salinity hazards (expressed as EC value in µS/cm) and water sodium content (expressed as Sodium Ratio, %Na). The Wilcox diagram indicates that all the sites fall under excellent to good category (Fig.5). Similar finding was observed from most of the major Himalayan rivers such as Indrawati, Koshi and Gandaki rivers (Sharma et al., 2020). The higher the Na% value, the greater the risk of alkali damage which may affect soil structure, reduce soil permeability, and cause soil compaction, thereby blocking gas exchange between soil and atmosphere (Misaghi et al., 2017).

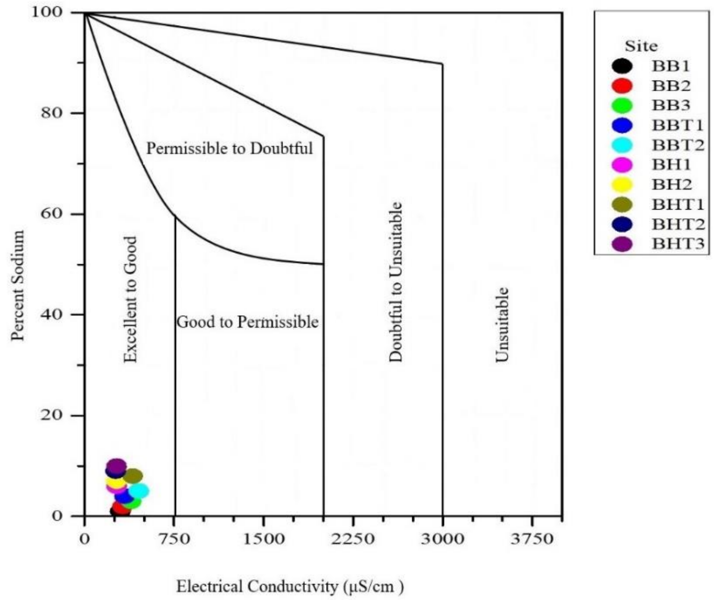
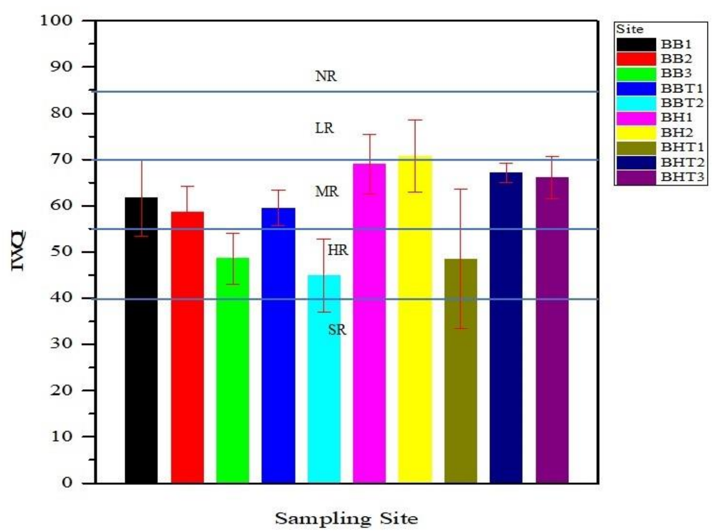


Figure 5 Wilcox diagram for the Bheri and Babai River systems

Irrigation water quality index (IWQI)

IWQI values in the studied area range from 35.63 (during autumn) at site BBT2 and 80.84 (during summer) at site BH2. The IWQI is considered as one of the most effective methods for evaluating irrigation water quality which provides a clear classification for the irrigation water quality based on its impact on irrigated soil and toxicity to plants (Al-Hadithi et al., 2019; Devi & Singh, 2021). Based on IWQI values, freshwaters are classified into five categories - water with severe restriction (SR) (0 ≤ IWQI < 40), high restriction (HR), (40 ≤ IWQI <55) moderate restriction (MR) (55 ≤ IWQI < 70) low restriction (LR) (70 ≤ IWQI < 85) and no restriction (NR) (85 ≤ IWQI < 100) (Meireles et al., 2010) (Table 5). IWQI also provides recommendations on the selection of plant species to be cultivated (Brouwer et al., 1985). In the present study, the samples ranked from low restriction to severe restriction for irrigation (Table 6 and 7). The sites with severe and high restriction IWQI values are located near human settlements and polluted (Fig 6).



Note: SR means Sever restriction; HR High restriction; MR means Moderate restriction; LR means Low restriction and NR means no restriction.

Figure 6 Classification of water sampled based on irrigation water quality index (IWQI) average values of the Bheri and Babai River systems

Conclusions

This study assessed different irrigation water quality parameters from selected stretches of the Bheri and the Babai rivers in west Nepal. All the irrigation water quality parameters viz pH, total dissolved solids (TDS), total hardness (TH), permeability index (PI), percent sodium (%Na), sodium adsorption ratio (SAR), magnesium hazard (MAR), residual sodium carbonate (RSC) and Kelly's index (KI) are within the permissible limit indicating the suitability of waters from both the rivers for irrigation. Based on USSL diagram, the water from both the rivers belongs to the S1 category indicating low sodium hazard. However, IWQI categories of two sites located near human settlements were classified as severe restriction and low restriction for use in irrigation. These results provide baseline data on the suitability of water for irrigation from the Bheri and the Babai prior to inter-basin water transfer from the Bheri to the Babai. Thus, it acts as a crucial reference in assessing the impact of inter-basin water transfer on irrigation water quality.

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Conflict of Interest: The authors declare no conflict of interest.

Data Availability Statement: The data that support the finding of this study are available from the corresponding author, upon reasonable request.

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