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RESEARCH ARTICLE

Index Based Irrigation Suitability of Ramsar Sites (Rara and Ghodaghodi) in Western Nepal

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Abstract

The present study highlights the water quality of two important Ramsar sites of western Nepal (Ghodaghodi and Rara lakes) in terms of irrigation use. Based on land use patterns and location accessibility, 13 sites in Ghodaghodi and 18 in Rara were considered and the samplings were performed in the pre-monsoon and post-monsoon seasons. Different physicochemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), major cations, and anion (Na^+, K^+, Ca^{2+}, Mg^{2+}, and HCO_3^-) were measured. The calculated indices were permeability index percentage (PI), sodium percentage (%Na), sodium adsorption ratio (SAR), magnesium hazard ratio (MAR), residual sodium carbonate (RSC), and Kelly's index (KI). Major ions were analyzed using ion chromatography including field and procedural blanks to maintain quality standards, whereas on-site parameters were measured by using standard multi-meter probes. The studied irrigation water quality parameters (pH, EC, TDS, TH) and indices (PI, MAR, RSC, KI, SAR, and %Na) fall within the permissible limit in both lakes, indicating the suitability of such water for irrigation purposes. In addition, based on the SAR vs. EC plot, all the results from both the lakes fall in the S1 category, signifying low sodium hazard. Concerning EC, most of the samples demonstrate the C1 category and few are in the C2 category (in Ghodaghodi) whereas the C1 category predominates for Rara. According to IWQI, all water samples in both lakes fall in the class I category, which supports the results of other indices indicating the suitability of water for irrigation purposes.

Keywords: *Irrigation water quality, major ions, Ramsar sites, wetlands*

Introduction

Wetlands are regions where water is the main aspect governing the environment and the related plant and animal life [1]. They are the most dynamic ecosystems that provide unique ecological functions and economic values such as water storage, groundwater recharge, and discharge, water purification, retention of nutrients, and biodiversity conservation. Wetlands provide great economic benefits, which include water supply including drinking water, water for irrigation and other purposes; fisheries; maintenance of water tables and nutrient retention in floodplains; and providing products from plant and animal resources [2].

Water quality is the appropriateness of water for a specific purpose, depending upon different physicochemical and biological parameters [3]. Water quality is different depending on the purpose for which it is to be used [4]. Various factors as natural/ geogenic factors, anthropogenic factors and climate change activities affect the water quality. Various water quality indices and standards are used globally as the WHO standard for drinking water quality [5], EPA standard for drinking water quality [6], FAO standard for irrigation water quality [7], BIS standard for drinking water quality [8]; and also, locally as Nepal drinking water quality standard [9], Nepal standard for aquaculture and irrigation [10]. These standards are for different purposes such as drinking, irrigation, aquaculture, etc. Irrigation water quality depends basically upon the concentration of major ions [11]. Different indices are used to calculate the water quality for irrigation purposes [7,11,12].

Nepal is rich in freshwater resources [13], and has 5358 lakes in total [14]. Out of 10 wetlands of international importance (Ramsar sites), nine are classified under lakes and reservoirs [14]. According to studies, there are an estimated 225 billion cubic meters (BCM) of surface water available in Nepal, of which 15 BCM are now being utilized. Around 95.9% of this 15 BCM is in use for agricultural purposes [13]. Therefore, study of the water quality used for agricultural purposes is necessary. There are fewer studies regarding the environmental status and water quality of different aquatic bodies of Nepal. The most studied region is the eastern and central regions of Nepal. For example, the study of organic pollutants and mercury pollution in the Everest region [15]; the study regarding outcomes on the limnology of high-altitude lakes (Gokyo and Gosainkunda) ([16, 17]; study related to mercury pollution in fishes from Lake Phewa [18]; study of major cations and anions in the Nepalese rivers and their water quality [19, 20]. Despite these studies, information on the water quality particularly for irrigation purposes is still limited, mainly in western Nepal.

In this study, two Ramsar sites from western Nepal, viz., Lake Ghodaghodi (Ghodaghodi hereafter) and Lake Rara (Rara hereafter) were included. Ghodaghodi is a lowland lake while Rara is a high mountain lake. These lakes fall in the category of lacustrine [2] wetlands. Our observations comply with previous studies [21,22] that the Ghodaghodi water is used for irrigation purposes and local people consume fish products from the lake. Whereas, the outlet of Rara is called Khatyad Khola, which is also used for irrigation purposes by locals. The main objective of this work is to study the suitability of waters from Ghodaghodi and Rara for irrigation purposes.

Materials and Methods

Study area

Ghodaghodi complex (28º41'17"N, 80º 56'47" E) is located in the Kailali district of far western Terai in Nepal. It occupies an area of 2,563 ha and is situated at an elevation of 205 m above the sea level. It is present on the lower slopes of the Siwalik Hills [23]. It was recognized as a Ramsar site in August 2003. It is dominated by forest and cultivated land. The land use pattern consists of forest (1420 ha), cultivated land (810 ha), water bodies (80 ha), grassland (110 ha), sandy area (45 ha), bush and shrubs (30 ha), and swamp (3 ha) [24]. The lake complex comprises of a network of approximately 14 large and shallow oxbow lakes and ponds having finger-shaped projections with marshes, meadows, streams and swamps [25]. One of the major lakes of the complex is Ghodaghodi Lake which covers an area of 138 ha. The region has a sub-tropical monsoonal type of climate where winter is dry and summer is rainy. The lake is fed by atmospheric inputs (direct precipitation during monsoon) and surface flows [22]. There are two outlets along the Mahendra highway. The water level of Ghodaghodi varies from 1 m to 4 m in depth [25]. It is 1-2 m deep during the dry periods and 3-4 m deep during the monsoon [21]. According to the natives of Ghodaghodi are, during dry season, the surrounding farms are irrigated using lake water that is pumped from it. This wetland provides agriculture, traditional fishing, timber and other resources to the local people [25, 26].

Rara (29°32'45"N, 82°05'35"E) is situated at an altitude of 2990 m above sea level [27]. It has a surface area of about 9.8 km^2 [28] and is about 167 m in depth. It is the largest and deepest freshwater lake in Nepal [29] which was established as a Ramsar site in September 2007. It is located in the Rara National Park, Mugu district, Karnali province of Nepal. The lake and its catchment area are located within the subalpine climatic zone. The temperature ranges from -4^0C in winter to 27^0C in the summer. Over 30 small streams flow into this lake as inlets, but there is only one outlet on the western shore called as Khatyad Khola which finally mixes into the Karnali River [28].

Sampling and analyses

This study was conducted in the year 2019. In early June (pre-monsoon season) and November (post-monsoon season), water sample collection was done at 13 different sites in Ghodaghodi Lake and 18 different sites in Rara Lake (Figure 1). Based on a variety of land-use patterns, accessibility, and stresses, the sampling sites were chosen. From each site, two replicate samples were collected. pH, electrical conductivity (EC), and total dissolved solids (TDS) were measured on-site with a Multimeter probe ("Consort bvba" Parklaan 36, B-2300 Turnhout, Belgium). Specific electrodes were selected for parameters planned to be investigated. Before the measurement, the electrodes were calibrated by the standard procedure. Details of sampling techniques are described elsewhere [30].

20 mL ultraclean HDPE (high-density polyethylene) vials were used for water sample collection. The sample was passed through a 0.45 µm polypropylene membrane filter. Before collecting the samples, the bottles and vials used for sampling were washed three times with lake water. The water samples were collected from a depth of approximately 0.25 m. Before the laboratory analysis, each sample bottle was labeled, sealed in a polyethylene zip-lock bag, and stored in a refrigerator at 4^0 C. The samples for major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) were investigated by Dionex DX-600 ion chromatograph. This chromatograph has an IonPac CS12A analytical column, IonPac CG12A guard column, 20 mmol//L methanesulfonic acid (MSA) eluent, and CSRS 300 continuous self-regeneration cation suppressor. Bicarbonate concentration was computed by applying ion balance of total cations and anions [31]. Total

Hardness (TH) was calculated using values of calcium and magnesium ions [32].

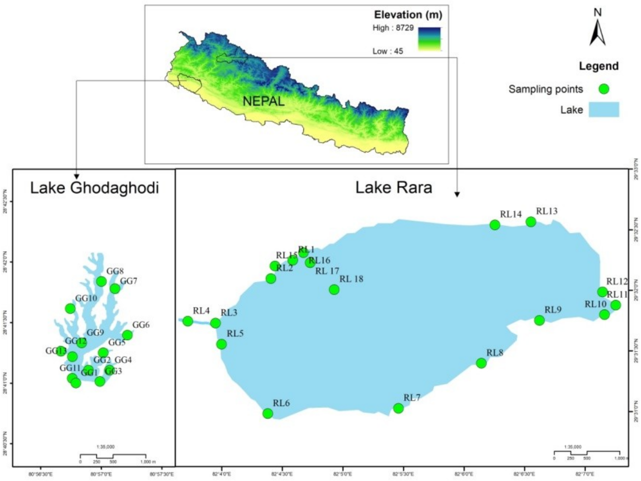

Figure 1: Diagram illustrating the figure of the study area indicating the location of the sampling sites (n= 13 in Ghodaghodi and n=18 in Rara) [30]

Quality assurance / quality control

To prevent contamination, masks and nonpowder vinyl clean gloves were used during the sampling process. Deionized water was used as field blanks, which were taken in the field during sample collection and stored in the same environment and finally were analyzed in the laboratory for the major cations. The method detection limits were determined as three times the standard deviation of replicated blank measurements. The detection limits for the ions Na^+, K^+, Ca^{2+} and Mg^{2+} are respectively as 0.0003 mg/L, 0.0009 mg/L, 0.0006 mg/L and 0.0008 mg/L.

Data analysis

The various parameters and indices used for the assessment of water quality for irrigation purposes are pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), permeability index percentage (PI), soluble sodium percentage (SSP or %Na), sodium adsorption ratio (SAR), magnesium hazard ratio (MAR), residual sodium carbonate (RSC), Kelly's index (KI), and Irrigation water quality Index (IWQI).

Permeability index percentage (PI) was calculated following [33]. Based on the permeability index, the author has developed a criterion for determining the suitability of water for irrigation, equation (1).

$$PI = \frac{Na^{+}+\sqrt{HCO_3^-}}{Ca^{2+}+Mg^{2+}+Na^{+}} \times 1 \qquad (1)$$

Soluble sodium percentage, SSP, (or %Na), was calculated using equation (2) following the method described in [34] and used by [19], where concentrations are expressed in meq/L.

$$SSP = \frac{Na^{+}}{Ca^{2+}+Mg^{2+}+K^{+}+Na^{+}} \qquad (2)$$

Sodium adsorption ratio (SAR) is the calculation of the sodium hazards in relation to calcium and magnesium concentrations [35] and was calculated using equation (3)

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+}+Mg^{2+})/2}} \qquad (3)$$

Where, Na^+,Ca^{2+}, Mg^{2+} represents concentration of ions in meq/L unit.

Magnesium hazard ratio (MAR) was calculated using equation (4) following [36].

$$MAR = \frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}} \times 100 \qquad (4)$$

Residual sodium carbonate (RSC) was calculated based on equation (5) [37].

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \qquad (5)$$

Kelly's index (KI) was calculated using [38], which is represented in equation (6)

$$KI = \frac{Na^{+}}{Ca^{2+}+Mg^{2+}} \quad (6)$$

Different plots as TDS vs. TH diagram, SAR vs. EC and SSP vs. EC were drawn using Origin 2016 software wherever necessary to explain the data.

In addition, with the objective to determine whether lake water is suitable for irrigation or not, irrigation water quality index (IWQI) was calculated using the standard three-step methodology [11,19], considering following parameters (i.e., pH, EC, TH, SAR, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}). This was done after calculating the percent compliance of our data with the FAO guidelines.

Initially, each parameter was given a weight (wi) as a relative significance for overall water quality based on percentage of samples within the FAO allowed limits [39]. In the second step, using equation (7), the relative weight (Wi) was determined for each parameter. In the third stage, equation (8) was used and the quality rating scale (qi) was calculated for each parameter. Finally, on the basis of equation (9), the sub-index of water quality (SIi) was computed for each parameter which was then added together to calculate the final IWQI using equation (10).

$$Wi = \frac{wi}{\sum wi} \quad (7)$$

Where, *Wi* is the relative weighting, wi is the weight of individual parameter and Σwi is the sum of all parameters

$$qi = \left(\frac{Ci}{Si}\right) \times 100 \quad (8)$$

Where, qi is the quality rating scale,

Ci is the concentration of each parameter. *Si* is the FAO guideline of each parameter.

$$SIi = Wi.qi \quad (9)$$

$$IWQI = \sum SIi \quad (10)$$

Where, SIi denotes subindex of water quality, Wi denotes the relative weighting, qi denotes the quality rating scale and IWQI stands for irrigation water quality index.

The calculated IWQI values were then categorized into four classes: Class I (<150), class II (150-300), class III (300-450), and class IV (>450) and entitled respectively as "none", "slight", "moderate" and "severe" restrictions for irrigation use [11].

Results and Discussion

The results of different physicochemical parameters and indices used for the evaluation of water quality for irrigation purposes for lakes Ghodaghodi and Rara are given in Table 1. Units for the different cations (Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}) and anions (HCO_3^{-}, CO_3^{2-}) while calculating the different irrigation water quality indices was milliequivalent per liter.

Water Chemistry

Mean pH for Ghodaghodi was 8.68±0.46 in pre-monsoon season and 8.14±0.99 in post-monsoon season (Table 1) while mean pH for Rara was 8.47± 0.13 and 8.05±0.27 (Table 1) in pre-monsoon and post-monsoon seasons, respectively. Data indicates that both the lake waters are alkaline in nature, and have pH values higher than 8. Alkaline pH has been reported in several aquatic bodies of Nepal [29,40]. According to Ayers and Westcot [7] the suitable pH range for irrigation water is 6.5 – 8.4, some of the water samples from both lakes Ghodaghodi and Rara have pH more than 8.4. High concentrations of carbonate and bicarbonate often result in higher pH level [41].

Ion concentration in water is measured by electrical conductivity, which is a function of the volume and mobility of ionic species [42, 43]. The mean EC values for Ghodaghodi were 192.26±87.97 µS/cm in pre-monsoon and 139.61±63.17 µS/cm in post-monsoon seasons (Table 1). For Rara, the EC values were 194.57±16.43 µS/cm and 202.05±22.98 µS/cm in pre-monsoon and post-monsoon seasons, respectively (Table 1). The overall concentration of dissolved salts in waters can be used to categorize irrigation water classes such as low-class C1 (EC ≤ 250 µS/cm), medium-class C2 (250–750 µS/cm), high-class C3 (750–2250 µS/cm) and very high-class C4 (2250–5000 µS/cm) salinity zones [19,35]. For Ghodaghodi, most of the samples fall in low class salinity zone, few samples fall in medium class salinity zones. For Rara, all the samples fall in the low-class salinity zone.

The mean values of TDS in Ghodaghodi were 95.68±44.37 mg/L and 91.37±42.34 mg/L in pre-monsoon and post-monsoon seasons respectively. The post-monsoon season has a lower value for both EC and TDS; it may be due to the dilution effect after the rainfall [43, 44]. For Rara, the values of TDS for pre-monsoon and post-monsoon seasons were 124.21±11.56 mg/L and 134.76±10.43 mg/L, respectively.

The sum of concentrations of bicarbonate, carbonate, chloride, and sulfate of calcium and magnesium determines the total hardness of water. The mean value of total hardness for Ghodaghodi is 72.06±40.92 mg/L in pre-monsoon and 50.12±23.60 mg/L in post-monsoon season. For Rara, values of total hardness in pre-monsoon and post-monsoon seasons were 97.00±15.23 mg/L and 86.75±11.43 mg/L, respectively. According to U.S. Geological Society, the broader classification of waters based on hardness is as soft (0 to 60 mg/L), moderately hard (61 to 120 mg/L), hard (121 to 180 mg/L), and very hard (more than 180 mg/L) [45]. For Ghodaghodi, the Total Dissolved Solids vs. Total Hardness graph (Table1; Figure 2) revealed that the majority of the samples fell between soft and moderately hard water except a sample in post-monsoon was hard and a sample in pre-monsoon was very hard. In Rara, all the samples fall in between soft and moderately hard category (Table 1; Figure 2). In natural waters, hardness usually ranges from 10 to < 500 mg/L and values exceeding 500 mg/L are relatively not common in natural waters [46]. The lakes and rivers of Nepal have shown a similar observation of total hardness [47-49].

Table 1: *Irrigation water quality parameters and indices for Lakes Ghodaghodi and Rara*

Parameters	Lake Ghodaghodi				Lake Rara			
	Pre-monsoon		Post-monsoon		Pre-monsoon		Post-monsoon	
	Mean ±SD	Range	Mean ±SD	Range	Mean ±SD	Range	Mean ±SD	Range
pH	8.68±0.46	7.9-9.4	8.14±0.99	7.2-10.8	8.47±0.13	8.27-8.73	8.05±0.27	7.45-8.51
EC (µS/cm)	192.26±87.97	127.7-422.3	139.61±63.17	86.83-332.33	194.57±16.43	174.23-225.00	202.05±22.98	172.20-241.10
TDS (mg/L)	95.68±44.37	63.3-211.3	91.37±42.34	55.7-218.9	124.21±11.56	107.67-146.33	134.76±10.43	122.77-149.03
TH (mg/L)	72.06±40.92	42.90-185.45	50.12±23.60	21.03-121.14	97.00±15.23	53.51-108.04	86.75±11.43	66.37-100.88
PI	98.25±16.95	62.03-116.05	104.97±22.69	72.20-169.57	74.47±7.89	69.59-97.64	78.38±5.36	72.09-88.28
%Na	12.39±2.32	7.49-16.83	7.41±4.18	1.74-19.38	1.47±0.29	1.22-2.37	1.71±0.55	1.32-3.55
SAR	0.24±0.07	0.17-0.40	0.13±0.07	0.03-0.26	0.03±0.01	0.02-0.05	0.03±0.01	0.02-0.07
MAR	15.91±3.42	11.90-25.83	17.70±5.34	11.93-29.39	43.83±2.95	37.27-52.50	53.05±3.23	46.09-59.85
RSC(meq/L)	0.27±0.15	0.15-0.68	0.17±0.07	0.06-0.36	0.07±0.04	0.02-0.21	0.07±0.02	0.04-0.13
KI	0.15±0.03	0.09-0.21	0.09±0.06	0.02-0.29	0.02±0.003	0.01-0.02	0.02±0.01	0.01-0.04

Permeability index percentage (PI)

Permeability is the water movement ability in soil which is affected by the extended use of irrigation water with a lot of salts having various ions as sodium, calcium, magnesium and bicarbonate [50, 51]. In Ghodaghodi, the mean values of PI were 98.25±16.95 and 104.97±22.69 in pre-monsoon and post-monsoon seasons, respectively (Table 1); whereas Rara had respective mean values of 74.47±7.89 and 78.38±5.36 (Table 1).

In Ghodaghodi, most of the water fall in the Class I category, i.e., PI > 75 except in GG4 (Class II). In Rara, the water belongs to class I and II categories. No any samples fall in class III category (Table 1). According to Donnen's classification, Class I and Class II refer to excellent and good for irrigation while class III is unsuitable for irrigation [52]. Low permeability causes restricted infiltration which prevents water adsorption by soil, and rainwater will be lost as runoff [53].

Table 2: *Irrigation water quality index (IWQI) of Lakes Ghodaghodi and Rara*

Site	Season	Irrigation water quality index (IWQI)			
		Mean ±SD	Range	Class	Restriction
Ghodaghodi	Pre-monsoon	53.05±15.37	31.56-89.41	I	None
	Post-monsoon	57.17±10.26	39.93-84.75	I	None
Rara	Pre-monsoon	36.16±1.65	31.01-37.78	I	None
	Post-monsoon	20.14±1.40	17.42-22.54	I	None

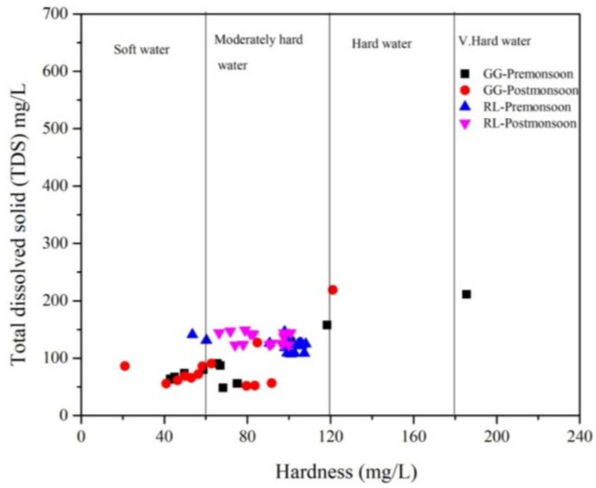

Figure 2: *Classification of Ghodaghodi and Rara lake water based on Total dissolved solid (TDS) vs. Total hardness (TH)*

Magnesium adsorption ratio (MAR)

The magnesium adsorption ratio (MAR) gives relationship between the concentrations of calcium and magnesium in water [54]. MAR value higher than 50 is said to be causing an adverse effect on crop yields [50]. In addition, soil having high levels of exchangeable magnesium is considered to be causing infiltration problem [7]. In Ghodaghodi, the mean MAR ratio was 15.91 ± 3.42 and 17.70±5.34 respectively in pre-monsoon and post-monsoon seasons (Table 1). All the sites of Ghodaghodi show MAR < 50 which indicates the suitability of water for irrigation purposes. Lake Rara also showed MAR < 50 in almost all water samples in pre-monsoon 43.83±2.95 except RL3, indicating suitability for irrigation purposes, while most of the samples from post-monsoon season showed values higher than 50 (mean MAR 53.05±3.23).

Residual sodium carbonate (RSC)

One of the factors influencing appropriateness of water for irrigation purposes is the concentration of bicarbonate and carbonate. It is assumed that under certain circumstances, water containing elevated concentration of bicarbonate ions creates a tendency for calcium and magnesium to precipitate as carbonates. Based on which, the idea of residual sodium carbonate (RSC) for the estimation of high carbonate waters was proposed by Eaton in 1950 [35, 55]. It is mentioned that RSC value < 1.25 meq/L is safe, value from 1.25 to 2.5 meq/L is of marginal quality and value > 2.5 meq/L is inappropriate for irrigation [35, 55]. The range of RSC in Ghodaghodi (0.06 to 0.68) as well as Rara (0.02 to 0.21) (Table 1), were considered safe for irrigation.

Kelly's index (KI)

Kelly's index is used to categorize water for irrigation which depends on sodium, calcium and magnesium ions. The water suitability is defined as two classes, KI < 1 is suitable and KI > 1 is unsuitable [38]. In this study, the KI value ranged from 0.02 to 0.29 in Ghodaghodi and 0.01 to 0.04 in Rara (Table 1), indicating the appropriateness of lake waters for irrigation in both lakes.

Sodium adsorption ratio (SAR)

The sodium adsorption ratio (SAR) or sodium or alkali hazard denotes elevated concentrations of sodium compared to the entire concentrations of calcium and magnesium. The sodium or alkali hazard increases with an increased proportion of sodium or with an increased SAR value [34]. Based on SAR values, waters are classified into four classes: value < 10 is considered as excellent; 10-18 as good; 18-26 as doubtful, and > 26 is as unsuitable [34, 35]. In the present study, SAR value ranged from 0.03 - 0.4 in Ghodaghodi and 0.02 - 0.07 in Rara (Table 1) which can be interpreted as excellent. The national standard given by Nepal Government for SAR is < 2 [10], and all the samples from both the lakes have SAR values < 2.

We constructed a sodium absorption ratio (SAR value) versus electrical conductivity plot (Figure 3) to know the suitability of lake water for irrigation purposes [34]. The water of Ghodaghodi (Figure 3) shows that the lake has low SAR values (S1) in all seasons coupled with low EC values (C1). Although a few samples showed medium EC value (C2), overall results indicated the suitability of lake waters for irrigation purposes. Rara Lake water shows low SAR value (S1) and low EC value C1 (Figure 3) suggesting suitability for irrigation purposes. Similar results having low SAR values were also reported in different water bodies of Nepal [19,56,57,58]. One of the factors for low SAR values in these locations might be due to being far from the oceans because surface waters near the ocean may have greater SAR values as suggested by one of the studies in Bangladesh by Shammi et al. [59].

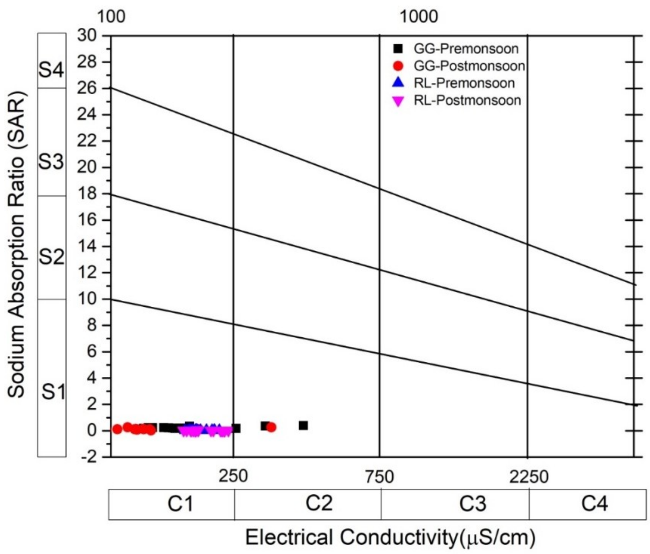

Figure 3: *Figure showing classification of irrigation water on the basis of SAR and EC. Ghodaghodi lake water shows low SAR value (S1) while low to medium EC value (C1 to C2).Rara lake water shows low SAR value (S1) and low EC value C1.*

Soluble sodium percentage or Percent sodium (%Na)

Sodium percentage (%Na) is also one of the indicators of sodium hazard and commonly used for the evaluation of the appropriateness of water for irrigation [34,35,60]. Based on % Na value, irrigation water is classified into five categories: excellent (< 20), good (20 to 40), permissible (40 to 60), doubtful (60 to 80) and unsuitable (> 80) [60].

In the present study, the %Na in Ghodaghodi ranged from 1.74 to 19.38, while in Rara it ranged from 1.22-3.55 (Table 1) indicating excellent water quality in both lakes. We also plotted %Na versus EC (Wilcox diagram, Figure 4) which indicates an excellent category of lake waters in terms of % Na. A similar result was found to be reported by Sharma et al. [19] for three rivers -Indrawati, Dudh Koshi and Gandaki from Nepal.

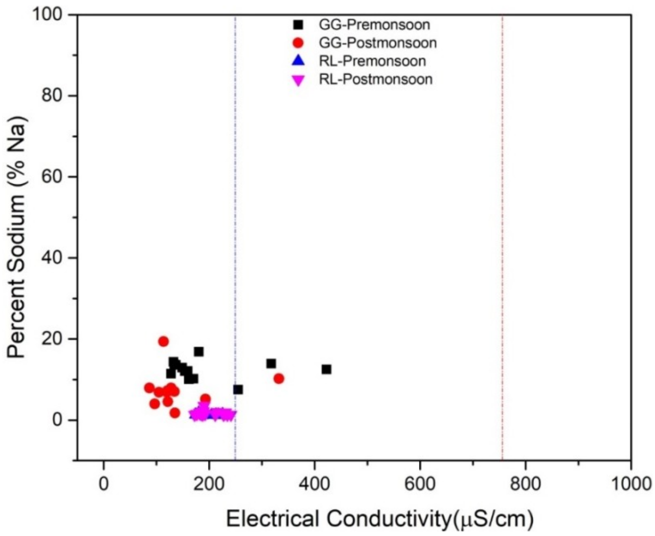

Figure 4*: Categorization of lake water on the basis of percent sodium versus EC values. The value of %Na is excellent in both the lakes Ghodaghodi and Rara. The EC value in water is used to categorize irrigation water class, as low (EC ≤ 250 μS/cm), medium (250–750 μS/cm), high (750–2250 μS/cm) and very high class (2250–5000 μS/cm) salinity zones.*

Irrigation water quality index (IWQI)

The irrigation water quality index (IWQI) is regarded as one of the most efficient ways for estimating irrigation water quality providing a clear image for the classification on the basis of its influence on irrigated soil and toxicity to plant [61]. Based on IWQI, irrigation water is classified into four classes: class I, II, III and IV [11]. All IWQI values in the present study fall under class I, indicating no restricted use of water for irrigation purposes (Table 2; Figures 5,6).

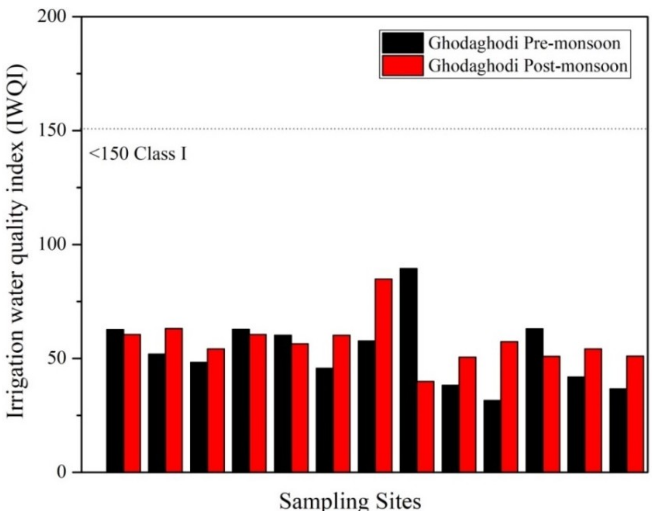

Figure 5*: Water quality index calculated for all water samples from Lake Ghodaghodi. All of the water samples fall in Class I.*

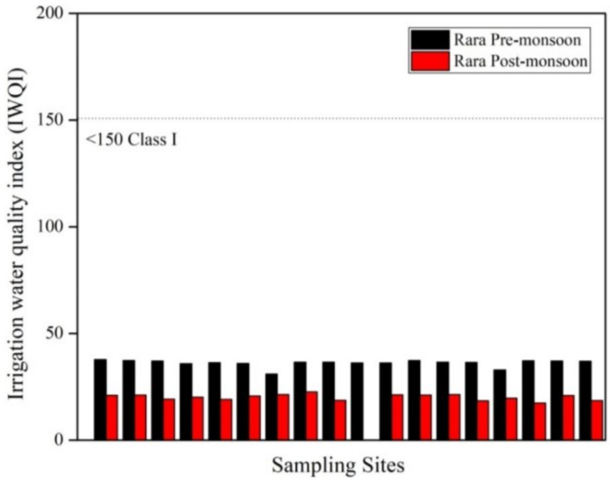

Figure 6*: Water quality index calculated for all water samples from Lake Rara. All of the water samples fall in Class I.*

Conclusions

The water quality parameters and indices (pH, EC, TDS, TH, PI, MAR, RSC, KI, SAR, and %Na) studied in lakes Ghodaghodi and Rara fall within the permissible limit which indicates the suitability of such water for irrigation purpose. Moreover, SAR vs. EC plot also indicated low sodium hazard. Additionally, the overall irrigation water quality index also indicates the good quality of water of both lakes for irrigation purposes.

Acknowledgements

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