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A Comparative Study of Physico-Chemical Parameter in Glacial Melt Water, Ponkar Glacier, Nepal

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Abstract

We conducted a detailed study in comparing physico-chemical parameters of glacier melt water between two years (2016 & 2019) in upstream sites with an elevation ranging from 4100 m to 3550 m above sea level of Ponkar glacier, Manang district, Nepal. We conducted onsite testing of physical parameter like pH, electrical conductivity, total dissolved solids, turbidity by using multiprobes and chemical parameters like anions, cations, total silica and heavy metals were analyzed following standard methods from APHA, AWWA, WEF (2012). The mean concentration of total silica was found to be higher in upstream sites than downstream. The elemental ratio Ca/Si was found to be higher in glacial melt water with low elemental values for K/Na, Na/Cl and K/Cl. The average concentration of parameters like electrical conductivity, turbidity, total hardness in glacier melt water was recorded to be higher in year 2019 than 2016. The mean concentration of anions and heavy metal was recorded to be higher in year 2016 than 2019. This study has provided a baseline information in comparing physico-chemical parameters in glacial melt water of Ponkar glacier and will be helpful in mitigating adverse impacts of climate change in Nepal's glacier.

Subject Areas

Environmental Sciences, Natural Geography, Oceanology

Keywords

Glacier, Physico-Chemical Parameters, Concentration, Ions, Upstream, Downstream

1. Introduction

Glaciers function over a number of temporal and spatial scales as water reservoirs of fresh water (Jansson *et al.* 2003) [1] and provide downstream consumers with water during times of low precipitation (Kaser *et al.* 2010 [2]; Viviroli *et al.* 2011 [3]). The Hindu Kush Himalaya covers eight countries including Afghanistan, Bangladesh, Bhutan, China, India, Nepal, Myanmar and Pakistan (Bajracharya *et al.* 2011) [4] and is probably the most significant "water tower" in the world, being the source of ten of the largest rivers in Asia and the largest amount of ice and snow outside the Arctic and Antarctica and thus is popularly "known as the third pole". The Himalayan range extends for approximately 2400 km within the 3500 km length of the Hindu Kush-Himalayan ranges, and has about 33,000 sq.km of the estimated 110,000 sq.km of the glaciated area. The Himalayas of Nepal occupy 800 km of the central part of the Himalayan range (ICIMOD, 2011) [5]. These Himalayas can be used as climate change proxies with an approximate rise of 0.04˚C - 0.09˚C/year as they are highly vulnerable to climate change and continuously display the signs of diminishing and retreating that have been rising in recent decades resulting into the rapid melting of glaciers thereby reducing the glacier area by fragmenting the glacier with increase in glacier number (Bajracharya *et al.* 2008) [6]. As chemical weathering rates are strong and anthropogenic consequences are mostly so small, glaciered areas are an excellent place to study water-rock interaction (Brown, 2002) [7]. The chemical composition of the underlying rocks in the glacier depends on precipitation and chemical composition (Vasilchuk, 2009) [8].

One of Nepal's dominant water supplies, which the country relies on for drinking water, irrigation and hydropower, is melting water from mountain glaciers in the Himalayas. The main water supplies in Nepal derive from glaciers in the Himalayas that melt rapidly due to continued increase in earth temperature causing hydrological changes in the headwater of the river (Bhatt *et al.* 2016) [9]. However, as a result of global climate change, accelerated glacial retreats may have major influence on hydrological regimes, resulting in a decline in water resources, quality and quantity (IPCC, 2007 [10]; Moore, 2009 [11]).

The complex weathering dynamics functioning in the glaciated river catchments is yet to understand, so the research on melt water hydrochemistry of glaciers is critical for water supply management in the Himalaya, and also for the study of the impacts of global climate change on these glaciers. In contrast, the rising demand for freshwater for drinking, agricultural and hydropower purposes as well as the ecological climate in downstream stretches has made the hydro-chemical analysis of Himalayan glaciers extremely imperative (Singh *et al.* 2012) [12]. Mountain melt water hydrochemistry is strongly influenced by the chemical structure of atmospheric deposition and by the features of the atmosphere (Gibbs, 1970 [13]; Nijampurkar *et al.* 1993 [14]). To determine the consistency of melt water and also to classify the origins of dissolved ions in the glacier environment, hydro-geochemical characterization of glacier melt water with respect to dissolved ion components is very useful. It is important to provide baseline knowledge on the physico-chemical characteristics of melting waters from the glacier in order to fill the gaps that exist in the hydrochemistry study of glaciers in Nepal.

2. Materials and Methods

Study Area

We carried our study in Ponkar glacier, a debris covered glacier with thickness of 134.05 m, having area of 28.509 km^2 and located in an elevation of 5679 m above sea level (ICIMOD, 2010) [15]. The glacier is located in Bhimthang Valley, Manang District of Gandaki Province in Nepal (**Figure 1**). It lies between 28˚35'00'' to 28˚45'00'' latitude and 84˚25'00'' to 84˚30'00'' longitude.

Sampling and Analysis

A total of 16 water sampling stations were established in Ponkar glacier (**Figure 1**) with an altitude of PG1-4100 m to PG16-1930 m. The stations PG1 through PG16 correspond to decreasing altitudes 4100 m to 1930 m as already described in our previously published paper in Thapa *et al.* 2019 [16]. We have considered water sampling sites from PG1-4100 m to PG7-3650 m as upstream sites (**Figure 1**) and PG8-3583 m to PG16-1930 m as downstream sites (**Figure 1**). After the end of glacier terminus, the glacier melt water mix with river, which we have considered those sites as downstream sites where water finally mix into big Marsyandhi river basin.

The water samples were collected in Pre monsoon season (2017 and 2018), then stored in freezer and analyzed within 2 weeks in Department of Environmental Engineering and Science Laboratory, Kathmandu University, Nepal and the laboratory of Environment and Public Health Organization (ENPHO), Nepal. Physical water quality parameters for each of the sample stations were measured using calibrated standardized probes: electrical Conductivity, pH and total dissolved solids (TDS) were measured using Multiprobe HI 98194 while turbidity was measured by using turbidity meter: Model no HI 98713 and both instruments were calibrated before taking data. The cations, anions, total silica and heavy metals of glacier melt water were analyzed using following method from APHA, AWWA, WEF (2012) [17]: Calcium-2500 Ca B; Magnesium-3500 Mg B; Sodium-3500 Na B; Potassium-3500 K B; Total silica-4500 SiO_2C; Iron-3111 B; Zinc-3111 B; Manganese-3111 B; Alumunium-3500 Al B.; HCO_3^--Titrimetric; Chloride-Titrimetric; Nitrate and Total Phosphorus-Ultraviolet Spectrophotometric Screening method. A comparative study of different physico-chemical parameters like pH, electrical conductivity, total solids, total dissolved solids, total hardness, turbidity, anions and heavy metals in upstream sites of Ponkar glacier was done between the data we collected (published in our previous paper Thapa *et al.* 2019 [16]) and data collected by Shrestha, 2016 [18] (B.Sc thesis 2016, unpublished data) at the same sample stations. This comparison will help us predicting the effect of climate change in the physico-chemical parameters of

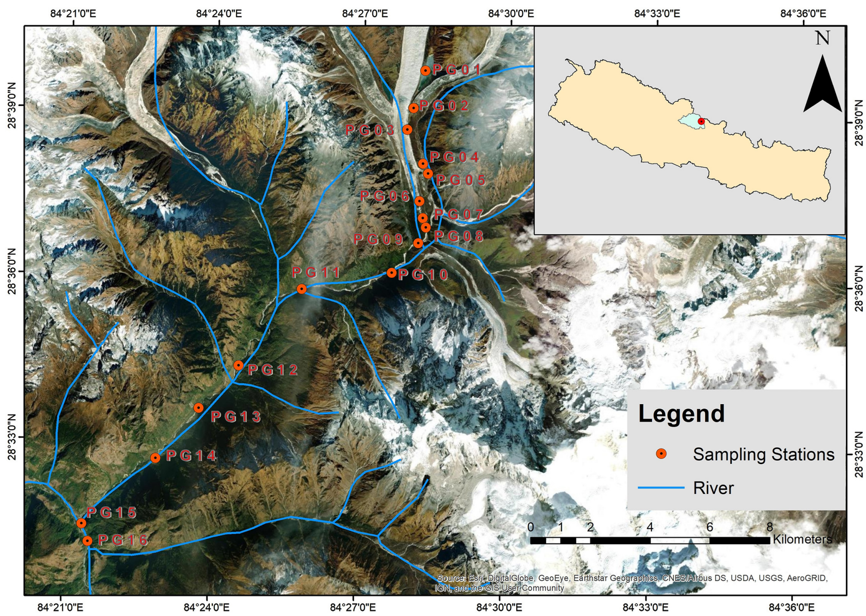

Figure 1. Map of study area showing sampling points.

glacier melt water of Ponkar glacier over years. Further we have analyzed our previously published data to study the dependence of physical parameters at different altitudes in Ponkar glacier. We performed our data analysis using simple statistical parameters like mean, standard deviation and t-test to check the statistical significance of the data obtained in Microsoft excel.

3. Results and Discussion

We have already published the data of physico-chemical analysis of glacier melt water of Ponkar glacier, Manang district, Nepal in our paper Thapa *et al.* 2019 [16]. Further, we conducted analysis of our data that would help boarder understanding of glacier melt water chemistry of Ponkar glacier. We calculated Charge balance errors by the formula $(TZ^+ - TZ^-/TZ^+ + TZ^- \times 100)$ (Freeza and Cherry, 1979) [19] and the result were found to be less than 10%.

The TDS/EC ratio was 0.430, demonstrating the efficiency and consistency of the analytical performance. Taking altitude as dependent variable, different physico-chemical parameters as pH, electrical conductivity, turbidity, total solids, total dissolved solids were plotted as independent variables for Thapa et al 2019 [16]. The results showed that pH is almost same throughout the upstream and downstream of the glacier (**Figure 2(a)**). Thus we see that average pH is neutral with respect to melting water of Ponkar glacier. In contrary total hardness (TH) is somewhat seen to increase with altitude. But, the plot of hardness versus altitude was not a perfect linear fit ($R^2 < 0.9$) (**Figure 2(b)**) indicating that even if the altitude of the glacier affects total hardness of water but $R^2 = 0.5164$. Further we did not see any linear dependence of other parameters as turbidity, total solids, total dissolved solids and electrical conductivity with respect to altitude in the Ponkar glacier.

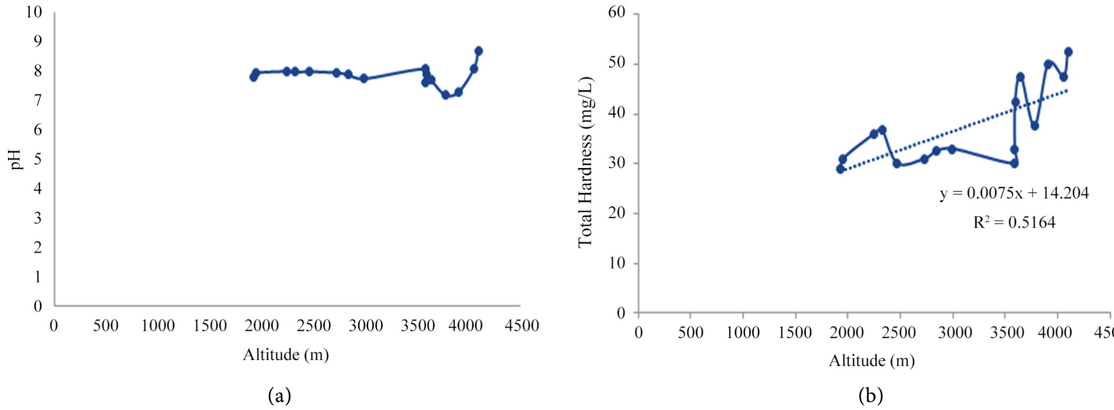

Figure 2. (a) Relationship between pH and altitude; (b) Relationship between TH and altitude.

The cumulative silica present in the water consists of "Reactive Silica" and "Unreactive Silica." We have analyzed total silica concentration of glacier melt water in downstream sites in altitude 3583 m (PG 8) to1930 m (PG 16) and recorded mean concentration to be 6.33 ± 1.13 mg/L (**Figure 3**). The highest concentration of total silica was found to be 8.78 mg/L in downstream sites and was recorded in 2323 m (PG 13). Shrestha, 2016 [18] recorded mean concentration of total silica to be 1.12 ± 0.74 mg/L in upstream sites of Ponkar glacier and recorded highest concentration in 4100 m (PG 1). The total silica is considerably higher in melt water of Ponkar glacier than other glaciers due to higher deposition from granite rock fragments composed of moraine sediments (Shrestha, 2016) [18].

We measured the concentration of cations, anions and heavy metals in glacial melt water of Ponkar glacier, as published in our previous paper Thapa *et al.* 2019 [16]. Further, based on these data from Thapa *et al.* 2019 [16], we have calculated the elemental ratios of melt water of Ponkar glacier as seen in **Table 1**. The overall Ca/Si ratio is believed to be higher in glacial waters due to preferential carbonate weathering and sluggish silicate weathering (Tranter, 1993) [20]. The hydrochemistry of the glacier melt water is likely to be determined by combining two components of carbonate and silicate dissolution, and the relative importance of these two sources can be explained by the cationic abundance and its ratios (Singh *et al.* 2005) [21]. The elemental ratio of K/Na was found to be 0.0053 and in general, average K/Na ratio is slightly higher in glacial runoff than the non-glacial runoff owing to the preferential weathering of K-mica minerals resulting in high K concentrations (Anderson, 1997) [22]. The average ratio of Na/Cl and K/Cl was similar to that of seawater (Na/Cl = 1.0 and K/Cl = 0.2). These ratios suggested a significant contribution from atmospheric precipitation to the detected dissolved ions in the glacier melt water. However, the release of dissolved ions to the glacier streams is governed by the rock–water interaction, bed rock mineralogy, weathering reactions, composition of atmospheric deposition and rate of water flow in the glacier catchment (Singh and Hasnain, 1998) [23].

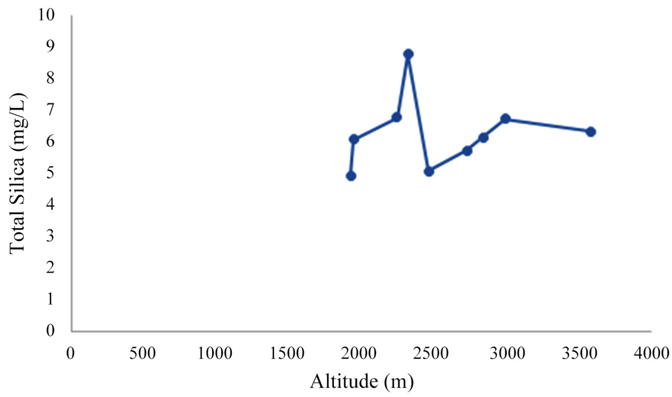

Figure 3. Concentration of Silica in different altitudes of downstream sites.

Table 1. Elemental Ratio in melt water of Ponkar glacier.

	Minimum	Maximum	Mean	Std. Deviation
Ca/Si	1.187	4.555	3.065	0.829
K/Na	0.053	0.649	0.354	0.173
Na/Cl	0.197	0.731	0.349	0.153
K/Cl	0.012	0.244	0.116	0.057

Shrestha, 2016 [18] conducted study in physico-chemical parameters of glacier melt water of Ponkar glacier in upstream sites (PG1-PG7) and Thapa *et al.* 2019 [16] also conducted study in physico-chemical parameters (analyzed cations which was not done by Shrestha, 2016) from the same water sample stations of upstream sites. The differences in concentrations of physico-chemical glacier melt water between the two sampling years (Shrestha, 2016 [18] and Thapa *et al.* 2019 [16]) in the Ponkar glacier recorded similar concentration for pH, total solids and total dissolved solids however, Thapa *et al.* 2019 [16] recorded higher concentration of electrical conductivity, turbidity and total hardness in glacier melt water compared to Shrestha, 2016 [18] (**Figure 4**). Statistical analysis shows that the electrical conductivity (p value = 0.034) and turbidity (p value = 0.04) have increased significantly in 2 years using one tail t test. However there is no statistical significance in total hardness (p value = 0.059). The significant increase (p value < 0.05) in these physical parameters over the course of time can be correlated with the impacts of climate change. Also no statistical significance in pH value of this water glacier indicates that pH of water is not affected by the increase in chemical weathering of glacial rocks over years.

We found differences in the concentration of anions between two years in Ponkar glacier (**Figure 5**). Shrestha, 2016 [18] recorded mean concentration of HCO_3^- with a value of 194.2 mg/L while Thapa *et al.* 2019 [16] recorded mean concentration of HCO_3^- to be 42.09 mg/l. Similarly, Shrestha, 2016 reported 55.70 mg/L of chloride, but in comparison to that, Thapa *et al.* 2019 [16] recorded 9.59 mg/L of chloride. Shrestha, 2016 [18] found the mean concentration of sulphate 11.53 mg/L but mean concentration of 6.3 mg/L of sulphate was recorded in upstream sites by Thapa *et al.* 2019 [16]. Nitrate was not detected in seven sampling stations of upstream sites carried by Thapa *et al.* 2019 [16]. However, the mean concentration of 1.0 mg/L of nitrate was recorded by Shrestha, 2016. The concentration of anions is in the order of HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > TP-PO_4^{3-} for both years of study (Shrestha, 2016 [18]; Thapa *et al.* 2019 [16]). The overall comparative analysis of anions in the upstream sites of Ponkar glacier indicates that the contact period of melting water with sediment below the glacier and the weathering rate of Ponkar glacier is higher in the study performed by Shrestha, 2016 [18] than that of Thapa *et al.* 2019 [16]. We did not compare the concentration of anions as Shrestha, 2016 [18] did not measure anions for the upstream sites.

Similarly, comparing the heavy metals concentrations in glacier melt water for upstream sites between two successive years, Shrestha, 2016 [18] recorded high amounts of aluminum and iron compared to Thapa *et al.* 2019 [16] (**Figure 6**). The mean concentration of manganese was found equal in both years (Shrestha, 2016 [18] and Thapa *et al.* 2019 [16]). But mean concentration of zinc recorded was higher in Thapa *et al.* 2019 [16] than recorded by Shrestha, 2016 [18]. Studies carried by Tuladhar *et al.* 2015 [24] in Lirung glacier Nepal, recorded increase in concentration of major cations, anions and heavy metals in glacier melt water compared to previous year. However, our comparative study recorded high concentration of anions and heavy metals higher for Shrestha, 2016 [18] than Thapa *et al.* 2019 [16]. There is decrease in the concentration of total Phosphorus and nitrate concentration as recorded by Thapa *et al.* 2019 [16] than Shrestha, 2016 [18]. Anthropogenic impacts would increase in the concentration of total Phosphorus and Nitrate in glacier melt water (Bhandari *et al.* 2015 [25]; Tuladhar *et al.* 2015 [24]). However, it shows that there is less influence of anthropogenic activities in upstream sites of Ponkar glacier. Recent, climate change impacts have increased temperature of Himalayas in Nepal by 0.06˚C resulting in increase in chemical weathering and recording higher concentration of anions, cations and heavy metals in glacier melt water in recent years (Chalise *et al.* 2006 [26]; Tuladhar *et al.* 2015 [24]).

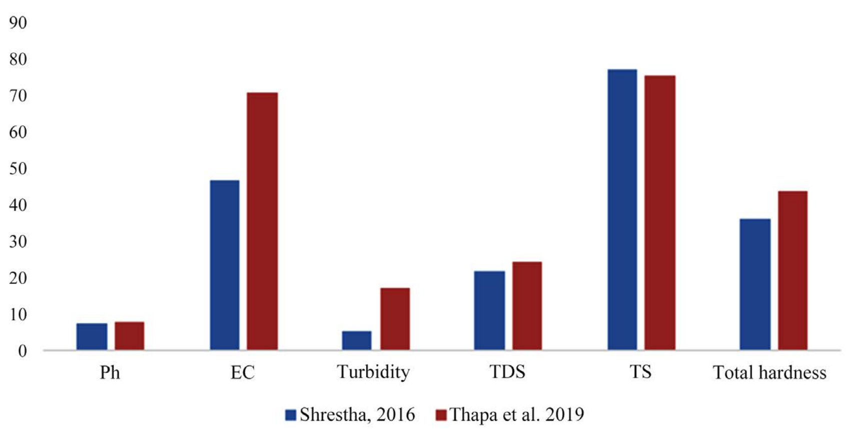

Figure 4. Comparative concentration of physical characteristics of melt water of Ponkar Glacier.

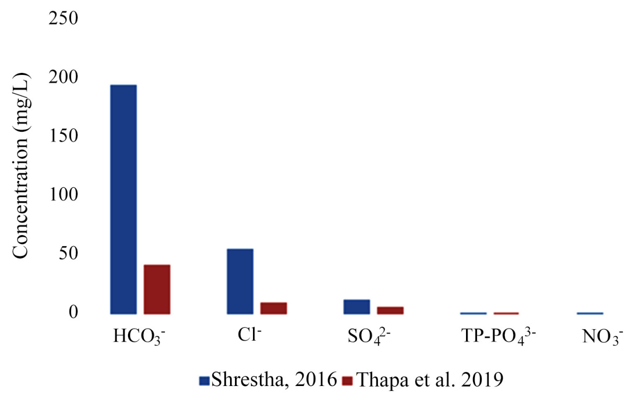

Figure 5. Comparative concentration of major anions in meltwater of Ponkar Glacier.

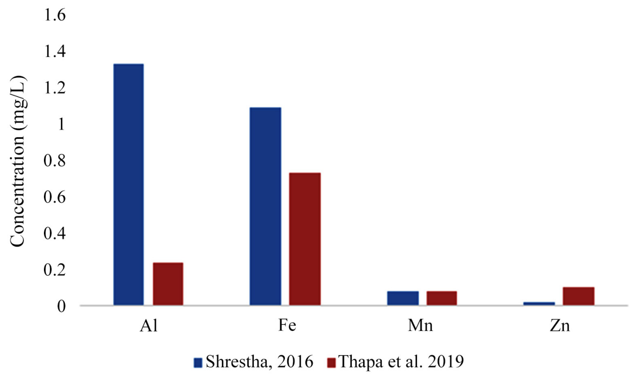

Figure 6. Comparative concentration of heavy metals in melt water of Ponkar Glacier between two years.

4. Conclusion

This study has compared physico-chemical parameters data from two different years in melt water draining from the Ponkar Glacier, Manang, Nepal. The comparative study of the Ponkar glacier in relation to the previous year reveals that the mean concentration physical parameters like electrical conductivity, turbidity and total Hardness were higher in 2019 than 2016. In both the studies, the concentration of anions is in the order of $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- >$ $TP\text{-}PO_4^{3-}$. The elemental ratios (Ca/Si and K/Na) were typical of glacial melt water and the low Na/Cl and K/Cl ratios indicated major contribution from atmospheric precipitation to the observed dissolved ions of melt waters. It is expected that further studies will be conducted to mitigate the rising global temperatures, which would eventually lead to intensify chemical weathering and increase concentrations of anions, cations and heavy metals in the melting water of the glacier in coming years.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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