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MAJOR ION CHEMISTRY OF RIVER BHAGIRATHI AND RIVER KOSI IN THE UTTARAKHAND HIMALAYA

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ABSTRACT

The chemistry of river water is governed by supply of various elements from natural (chemical weathering and rain) and anthropogenic (sewage, mining effluents etc.) sources. Major ions of glacial melt streams and sulphur spring, located in the Bhagirathi valley were studied separately to observe the contribution of these sources to the ionic abundance in River Bhagirathi. Ionic composition in glacial melt streams was found to be as; Mg > Ca > Na > K > NH_4 (cations) and Cl > HCO_3 > SO_4 >NO_3 (anions). On the other hand, sulphur spring water was characterized by high concentration values with altogether a different composition of cations i. e. Na > Mg > K > Ca > NH_4, whereas, anion composition followed the same pattern as for glacial melt water. The average ionic composition of River Bhagirathi towards downstream was found to be as; Ca > Mg > Na > K > NH_4 (Cations) and HCO_3 > SO_4 > Cl > NO_3 (Anions). However, sulphate ion predominates over rest of the anions in the upstream i. e. in the Gangotri valley. Some local streams such as Nagun Gad and Syansu Gad, which contributes substantial quantity to River Bhagirathi in the downstream near Uttarkashi are characterized by high levels of HCO_3 and Total Dissolved Solids (TDS). At two damming areas namely Maneri and Tehri, the concentration levels of cations and anions were increased as compared to flowing river stretch. These results were compared with ionic abundance of comparatively low altitude spring fed Himalayan River Kosi, where the ionic concentration levels were comparatively low at the origin and consistently increased towards downstream. The average ionic composition of River Kosi all through its length was similar as River Bhagirathi in the downstream reaches, which in fact is the composition of rain water over the Himalaya region. It is also observed during the study that biological life in the form of benthic fauna is also influenced by the ionic environment at sediment - water interface.

Key words: Ion composition, Water quality, River Kosi, River chemistry

INTRODUCTION

The study of chemical composition of river waters is important not only for

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determining erosion rates, but also to learn about sources of elements to rivers, mineral weathering and elemental mobility. In addition, information on river chemistry is essential to assess water quality for domestic, agricultural and industrial usage. Chemical weathering of rocks and minerals determines the flux of dissolved materials carried by rivers, whereas physical weathering regulates the particulate transport. This makes the study of dissolved and particulate components of rivers important to characterize and quantify weathering and erosion. Chemistry of river waters in the Himalayan region is predominantly governed by the lithology of the basin and less commonly by other sources like, sewage, industrial waste, agricultural run offs and rains. River Bhagirathi is an important Himalayan river in Garhwal Himalaya, originating from Gaumukh in Gangotri glacier at an altitude of 3892 MSL. Starting from Gangotri, the river passes through thickly populated towns like Uttarkashi, Tehri and Devprayag. At Devprayag, it meets the River Alaknanda and from the confluence downstream, it is called the River Ganga. Flowing initially over medium to high grade metamorphic rocks in higher Himalayas, the Bhagirathi and its tributaries predominantly drain over shales, slates, carbonates, quartzite, granites, greywacke, evaporites and calcsilicates. Consequently, it annually delivers 0.74 M tons of dissolved and 7.77 MT of suspended load to the River Ganga at Devprayag[1]. About 225 km stretch of River Bhagirathi has a steep gradient with an altitudinal difference of 3048 MSL from Gangotri to 475 MSL at Devprayag[2]. Due to this reason, the river has been extensively harnessed for generation of hydroelectric power in the last few years. As a result, the entire stretch of River Bhagirathi is undergoing continuous transformation of its natural substratum and flow. Such transformations of natural substratum, flow, temperature and some other physical and hydrological factors have an integrated impact on the chemical, biological and ecological status of River Bhagirathi. The river on its way from Gangotri to Uttarkashi is joined by sulphur springs and several glacial melt streams. Sulphur spring water was reported to be characterized by domination of Na and HCO_3 ions, whereas glacial melt streams are characterized by domination of Mg and HCO_3 ions. Studies carried out on major ion chemistry of the Ganga source water – the Bhagirathi, the Alaknanda and their tributaries to assess the chemical weathering processes in the high altitude Himalayas, indicated Ca, Mg, HCO_3 and SO_4 were among the most abundant ions in these rivers[3]. Studies have also revealed weathering of carbonate rocks, calcsilicates and albite by carbonic and sulphuric acid dominated in these drainage basins[2]. It has been reported that coupled reactions involving sulphide oxidation and carbonate dissolution are mainly controlling solute acquisition processes and sediment transfer in a high elevation river basin, suggesting combination of calcium, bicarbonates and sulphates in river water. The dominance of carbonate rock weathering in the upland Himalayan rivers has also been reported earlier by Singh and Hasnain[4,5]. Comparison of leachate chemistry with stream chemistry in the Caimgorm Mountains of Scottland, indicated that snowpack melt water contributes directly to stream water. Temperature observations of different altitudes within the catchments supported this interpretation[6]. Studies on major ion chemistry of Yamuna River system has also shown temperature dependence and CO_2 consumption impacting on chemical weathering in Himalayas[7]. Silicate weathering and its relation to CO_2 consumption and sulphuric acid interaction in the Bhagirathi basin has been reported earlier. It is also reported that Ca and Na among cations and SO_4 and Si among anions were most abundant ions in River Bhagirathi in Gangotri valley[8]. Like River Bhagirathi, River Kosi is another important spring fed Himalayan river originating from Rudradhari of district Almora (Uttarakhand) at an altitude of 1830 MSL, meets River Ramganga in the downstream, which ultimately joins River Ganga in Uttar Pradesh. The ionic composition of River Kosi was found similar to River Bhagirathi, however, the concentration increases progressively towards down stream. Present study throws some light on the ionic distribution pattern of glacial origin and spring origin water quality of River Bhagirathi and River Kosi, respectively. Table 2a and 2b shows the comparative data of both the rivers. Present study also deals with the identification of sources of major ions to River Bhagirathi and their impact upon the diversity of benthic fauna which are indicators of water quality. Table 3 shows the variation in genus levels of benthic macro-invertebrates among the two rivers. Benthic fauna which are bound to sediment-water interface are directly exposed to ionic concentration of water.

Water chemistry

There can be three important sources of ions to the rivers:

Rain/precipitation

The primary source of water to rivers is rainfall and snow melt, which makes their composition an important component of river water chemistry. Rain water composition is location dependent, Na^+ and Cl^- are the dominant components of coastal rains, this changes to Ca^{+2}, HCO_3^- and SO_4^{2-} inland.

Chemical weathering in drainage basins

Chemical reactions occurring in the drainage basins are the primary source of solutes to rivers. These reactions are of two types :

$$CaSO_4 \rightarrow Ca^{2+} + SO_4^{2-} \quad ...(1)$$

$$CaCO_3 + (CO_2 + H_2O) \leftrightarrow Ca^{2+} + 2\,HCO_3^- \quad ...(2)$$

$$\begin{aligned} 2\ \mathrm{NaAlSi_3O_8} + 2\ \mathrm{CO_2} + 11\ \mathrm{H_2O} &\leftrightarrow 2\ \mathrm{Na^+} + 4\ \mathrm{Si(OH)_4} \\ \text{(Albite)} + \mathrm{Al_2Si_2O_5(OH)_4} &+ 2\ \mathrm{HCO_3^-}\ \text{(Kaolinite)} \end{aligned} \quad ...(3)$$

The reaction type (1) can be important source of ions to rivers draining terrains containing evaporites and saline/alkaline soils, whereas reactions type (2) and (3) require protons for initiation. The most common source of protons (H^+) in rivers is carbonic acid generated by solution of CO_2 from atmosphere in rains and from soil gas in river waters. Another source of protons for these reactions is sulphuric acid from the oxidation of pyrites (FeS_2). In regions, where there are abundant pyrites and other sulphides, there can be significant production of H_2SO_4.

Anthropogenic input

Major ion abundances in rivers can be modified by anthropogenic inputs such as discharge of sewage, industrial and mining effluents, supply from fertilizers, etc. This input can be an important source for Na, Cl (NaCl in sewage, mining of sodium salts, solution of road salt, etc.), SO_4 (fertilizers, mining of pyrites, industrial wastes, atmospheric deposition from fossil fuel burning, etc.) and nutrients (nitrogen and phosphorus compounds, mainly from fertilizers). There can be two other potential suppliers of major elements to rivers. One is organic matter, which during their growth incorporate elements such as N, P and K. Decay of organic matter can release these elements to rivers. Among these, the nutrients (N and P) are recycled and are generally reconverted to organic matter by plant uptake. Potassium, concentrated in plant leaves is from weathering of silicates.

Another supplier of major elements to rivers is springs/groundwater. Many rivers receive water from springs and groundwater, particularly during lean stages of their flow. The primary source of major ions to spring and groundwater is chemical weathering of aquifer rocks. The importance of springs/groundwater on the abundances of major ions in rivers, though is recognized, it is difficult to quantify.

Sources of various dissolved elements to the rivers

Na	Rain, halites, saline/alkaline soils, anthropogenic, silicate
K	Rain, silicates, biogenic, fertilizers
Ca	Silicates, carbonates, evaporites, fertilizers
Mg	Silicates, carbonates

HCO_3	Silicates, carbonate weathering, CO_2
Cl	Rain, halites, anthropogenic
SO_4	Rain, evaporites, pyrites, fertilizers
N species	Rain, fertilizers

EXPERIMENTAL

Water samples of River Bhagirathi were collected from Gangotri to Devprayag. Altogether, 8 locations on River Bhagirathi were selected such as; Gangotri, Maneri Reservoir, Upstream Uttarkashi Town, Downstream Uttarkashi Town, Upstream Tehri at Malideval, Tehri Reservoir, Zero point and Devprayag. Samples were also collected from glacial melt streams located nearby Gangotri and sulphur spring at Gangnani about 53 km downstream from Gangotri. Similarly 8 locations were selected on River Kosi from its origin to its confluence to River Ramganga, which are as, Rudradhari, Totaciling, U/s Someshwar, Dadimkhola, River Swal, River Ramgad and River Kosi at Ramnagar. For ionic composition of water quality, sodium, potassium, calcium, magnesium and ammonium ions as major cations and sulphate, chloride, bicarbonate and nitrate as major anions were analyzed. The concentration values were converted to milli equivalent per liter from milli gram per liter for ionic balance. Since the pH of water quality was less than 8.2 at all the locations, concentration of bicarbonate ions was calculated from total alkalinity values. Percent difference ratio of total anions and total cations in most of the samples were observed less than 10%, except for pure glacial melt streams and sulphur spring, where this ratio falls between 20-30%. These values are generally confirming the reliability of the analytical results[5]. Benthic macro-invertebrates were collected from all the selected sampling locations and identified up to family/generic level of taxonomic precision to find out their specificity to minimum and maximum levels of cation and anion.

RESULTS AND DISCUSSION

The results obtained for River Bhagirathi and River Kosi were compared to find out the difference in ionic distribution pattern of high altitude glacial fed and comparatively low altitude spring fed river. Tables 2a and 2b show the concentration pattern of individual ions in both the rivers. The results of glacial melt streams and sulphur spring were also compared (Table 1) to observe the contribution of these sources to water quality of River Bhagirathi. Influence of major ions of sulphur spring was observed during winter and that of glacial melt water during summer season. Johanessen and Henriksen[11] have demonstrated laboratory and field lysimeter experiments to indicate that 50-80% of the pollutant load is released with the first 30% of the melt water.

Table 1: Total ion distribution in River Bhagirathi and Sources

Sampling locations	Altitude (MSL)	Total anions (meq/L)	Total cations (meq/L)	TDS (mg/L)	Total alkalinity (mg/L)
Glacial melt stream at 3 km from Gangotri Temple	3038	0.6765	1.0287	48	22
Sulphur spring at Gangnani	2133	24.2867	12.7103	772	560
Gangotri	3048	1.0155	1.1697	113	19
Maneri Reservoir	1298	1.4730	2.1320	117	38
Upstream Uttarkashi	1219	1.1370	1.7883	129	31
Downstream Uttarkashi	1036	1.4327	1.0132	85	25
Tehri Reservoir	755	1.5283	1.7423	73	46
Zero point	595	1.6328	1.3531	74	46
Devprayag	475	1.5063	1.4790	72	47

Anions

Total anion concentration of 1.015521361meq/L was observed in River Bhagirathi at Gangotri, located at an altitude of 3048 MSL (Table 1). Anion levels were found to be elevated to 1.472966814 meq/L at Maneri Reservoir located at 1298 MSL, about 82 km downstream from Gangotri. It is observed that anion concentration in glacial melt streams are generally unfavorable for benthic fauna and thus support low diversity of these animals in River Bhagirathi at high altitude[13]. However, after reaching to comparatively lower altitude of around 755 MSL at Tehri Reservoir, the anion concentration levels gradually increased to 1.528286385meq/L. Sulphate ions, which were dominant in the Gangotri valley were replaced by HCO_3 in the down stream. Studies on stream water chemistry, clearly showed preferential elution of sulphate and nitrate over chloride, hydrogen and other cations durig the early melt of 1988 in Caimgorm mountains of Scottland[6].Sulphur springs contribute high level of anions (24.286 meq/L) to River Bhagirathi at upstreams.

Table 2(a) : Anion distribution in glacial fed and spring fed rivers

Range	Sulphate (meq/L)		Chloride (meq/L)		Bicarbonate (meq/L)		Nitrate (meq/L)	
	Bhagirathi	**Kosi**	**Bhagirathi**	**Kosi**	**Bhagirathi**	**Kosi**	**Bhagirathi**	**Kosi**
Avg.	0.457	0.250	0.210	0.201	0.648	1.194	0.004	NT
Min.	0.375	NT	0.112	0.140	0.160	0.380	NT	NT
Max.	0.562	0.479	0.253	0.281	1.000	2.120	0.005	NT

NT – Not Traceable

Table 2(b): Cation distribution in glacial fed and spring fed rivers

Range	Sodium (meq/L)		Potassium (meq/L)		Calcium (meq/L)		Magnesium (meq/L)		Ammonium (meq/L)	
	Bhagirathi	**Kosi**	**Bhagirathi**	**Kosi**	**Bhagrathi**	**Kosi**	**Bhagirathi**	**Kosi**	**Bhagirathi**	**Kosi**
Avg.	0.176	0.136	0.066	0.018	0.815	0.878	0.457	0.470	NT	NT
Min	0.130	0.043	NT	NT	0.650	0.250	0.823	0.246	NT	NT
Max	0.217	0.217	0.102	0.025	1.000	1.700	0.987	0.576	0.002	NT

NT – Not Traceable

In sulphur spring, the anion levels are increased due to bicarbonates (12.819 meq/L) and sulphates (8.739 meq/L) followed by chlorides (2.647 meq/L). Consequently, bicarbonates dominated in the down stream and increased to maximum at Tehri Reservoir and downstream. Sulphate level was highest at Maneri reservoir with a continuous input from sulphur spring located at some 21 km upstream. An analytical study of major ions of the glacier fed Alaknanda River and its tributaries, indicated bicarbonate to be most dominant anion (78%) with minor contribution from sulphate (19%) and chloride (3%). The range of anion concentration in glacial fed River Bhagirathi (1.015521361 to 1.632831286 meq/L) differed from spring fed River Kosi (0.52084507-2.880856808 meq/L). Anion distribution in low concentration stretch of River Bhagirathi followed a sequence of SO_4 > HCO_3 >Cl >NO_3, however, at high concentration stretches this pattern is changed to HCO_3 >SO_4 > Cl > NO_3. The pattern of anion distribution at low concentration stretches of River Kosi, was found to be HCO_3 > Cl > SO_4 and for high concentration stretches, it was HCO_3 > SO_4 > Cl. Sulphates were below detection limit at the origin of River Kosi. Among total anions in River Kosi, bicarbonates contributed maximum in the range of 0.38 to 2.12 meq/L, supporting diversity of benthic fauna. Previous study has indicated large variation of HCO_3 concentration from 110 to 1320 micromoles/L, in the Himalayan rivers caused by the flow of rivers in the silicate terrains granites and gnesisses (low HCO_3) and in carbonate terrains (high HCO_3) and a mixing of the two (intermediate HCO_3 concentrations)[10]. It is reported that bicarbonate and Chloride ion predominates among major anions in Class 'A' (Clean) to Class 'C' (Moderate pollution) biological water quality, whereas, increase in sulphate ion concentration indicated pollution of water quality in rivers[12]. Camargo and Tarazona[9] observed an acute toxicity of fluoride ion (F^-) to freshwater benthic macroinvertebrates.

Cations

Total cation levels were comparatively low (1.169670983) at the origin of River Bhagirathi at Gangotri (Table 1). However, these were increased to 2.131968702 meq/L at Maneri Reservoir as sulphur stream joining at Gangnani, upstream of Maneri. Further downstream at Tehri Reservoir, cation levels were found in the range of 1.47 to 2.272 meq/L, which are primarily due to the inundation of large area in the valley. Glacial melt streams contributed less cation levels (1.028 meq/L) to River Bhagirathi compared to the levels contributed (12.71 meq/L) through sulphur spring. High levels of cation in sulphur spring are mainly due to sodium concentration (8.739 meq/L). Cation levels in River Bhagirathi is mainly due to calcium ion (0.65 - 1.0 meq/L). However, in glacial melt streams the contribution of magnesium ion (0.82 meq/L) is more compared to calcium ion (0.35 meq/L). Calcium and magnesium were reported to be major cations accounting for 85% of the total cations in glacier fed Alaknanda River and its tributaries[5]. As a result, at low ionic concentration stretches of River Bhagirathi, cation distribution followed a dominance sequence of Mg > Ca > Na > K > NH_4 and at comparatively high concentration stretches the pattern was slightly different i. e. Ca > Mg > Na > K > NH_4. Range of total cations in glacial fed river Bhagirathi was 1.015521361-1.931968702 meq/L, supporting low diversity of benthic fauna compared to spring fed River Kosi having higher range of total cation (0.540391841 to 2.519164017 meq/L). Dominance sequence was similar in minimum and maximum concentration zones for cations in River Kosi i. e. Ca > Mg > Na > K > NH_4. Ionic levels specially, major cations of sodium, calcium and magnesium were minimum at the origin, which gradually increased in the downstream reaches. On the contrary, ionic concentration levels were high towards upstream of glacial fed river Bhagirathi. Semwal and Akolkar[12] have indicated lack of benthic fauna in River Revathi.

CONCLUSIONS

In River Bhagirathi, bicarbonate, sulphate and chloride constitute the bulk anions and calcium, magnesium and sodium the bulk cations. Sulphur spring water is the major source of sulphate, chloride and sodium ions to River Bhagirathi, whereas, magnesium ions were significantly contributed through glacial melt streams. Impoundment of river on account of damming activities causes inundation of large part of the land/rocks, resulting in elevation of ionic concentration in water quality of River Bhagirathi. In spring fed River Kosi, there is a natural eluding of ions throughout its length and no direct source such as glacial streams, sulphur spring etc. is impacting on it. Hence, the trend of ionic distribution is consistent without any abrupt change. However, the major ions remain the same as for River Bhagirathi. It can be concluded from the observations that natural sources governed the elemental mobility in both the Himalayan rivers and anthropogenic inputs are insignificant. Thus, the ionic composition is characteristic of the basin lithology. It is also observed that the concentration value of each ion studied is well below the permissible limit as prescribed by BIS for drinking water supply. It is also observed during the study that extreme levels of ionic concentration (minimum or maximum) in water quality do not favors biological establishment in the form of benthic fauna. Although, a numbers of investigations have been carried out on ionic distribution pattern in high altitude rivers, however, the role of major ions for establishment of diverse species of benthic fauna in river waters requires much attention and further investigation.

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