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ORIGINAL ARTICLE

Major ions and trace elements of two selected rivers near Everest region, southern Himalayas, Nepal

Rukumesh Paudyal[1,2,3,4] · **Shichang Kang**[1,5] · **Chhatra Mani Sharma**[3,4,6] · **Lekhendra Tripathee**[3,7] · **Jie Huang**[7] · **Dipesh Rupakheti**[2,7] · **Mika Sillanpää**[4]

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Abstract During pre-monsoon of 2013, water samples were collected from 30 sites of two major rivers, viz. Dudh Koshi and Indrawati to assess the river water quality on the southern side of the Nepalese Himalayas. The physical parameters such as pH, EC, turbidity and water temperature were measured in the field and major ions (Na^+, NH_4^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, and NO_3^-) and element concentrations (Li, Sc, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, As, Rb, Sr, Cs, Ba, Pb, U, Y, Zr, Nb and Cd) in the water samples were analyzed in the laboratory. The result indicated river waters were neutral to mostly alkaline with pH ranging from 6.57 to 8.81 and EC ranging from 10.5 to 321 μS/cm. The lower values of turbidity were recorded in the pristine tributaries of Dudh Koshi, whereas the main rivers had the higher values with a range of 0.51–515 NTU. Bicarbonate (HCO_3^-) showed a significant correlation with Ca^{2+} and Mg^{2+}, suggesting carbonate weathering as the dominant geochemical process in the region. Furthermore, the Gibbs plot also suggested the dominance of rock weathering. Very low concentration of trace elements was found in most of the samples which were within the WHO guidelines. In addition, the concentrations of toxic elements such as As and Pb were below the detectable limits in most of the samples. Furthermore, the analysis of PCA suggests that most of the elements originated from natural weathering; however, there were some evidences of anthropogenic effect on water quality which may not be critical issue at present but can be of concern in future.

Keywords Dudh Koshi · Indrawati · Trace elements · Major ions · Nepal

Introduction

The Himalayan arc extends about 2400 km of which 800 km extends in the Nepal Himalayas (Gansser 1964). The glaciers in these regions are also known as the "Water Towers" as they play a vital role in the hydrological cycle providing significant amount of melt water (Immerzeel et al. 2010). The southern side of the Himalayas, especially Mount Everest region, is one of the biggest areas covering the glaciers in the central Himalayan regions (Scherler et al. 2011; Salerno et al. 2013). However, these glaciers are experiencing intensive shrinkage and reduction both in length and area (Anthwal et al. 2006; Bolch et al. 2012; Yao et al. 2012). These changes have raised a great concern

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✉ Shichang Kang
shichang.kang@lzb.ac.cn

[1] Present Address: State Key Laboratory of Cryospheric Sciences, Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI), Chinese Academy of Sciences, Donggang West Rd. 320, Lanzhou 730000, China

[2] University of Chinese Academy of Sciences, Beijing 100049, China

[3] Himalayan Environment Research Institute (HERI), Kathmandu, Nepal

[4] Laboratory of Green Chemistry, Lappeenranta University of Technology, Sammonkatu 12, 50130 Mikkeli, Finland

[5] CAS Center for Excellence in Tibetan Plateau Earth Sciences, Chinese Academy of Sciences, Beijing 100101, China

[6] Department of Environmental Science and Engineering, School of Science, Kathmandu University, Kavre, Nepal

[7] Key Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100101, China

during the last decades due to its potential implications in water supply and sea level rise (Jacob et al. 2012). It was believed that the Himalayas are one of the most pristine and uncontaminated areas in the world. However, some past studies indicated changes in the water chemistry of Nepal mainly due to bedrock, land use change, altitudinal effects and terrace–agriculture practices (Jenkins et al. 1995; Reynolds et al. 1995; France-Landlord et al. 2003). It should also be taken into consideration that the Himalayas of Nepal is sandwiched between China and India, the two largest emitters of atmospheric pollutants in Asia (Kurokawa et al. 2013). These pollutants could be long range transported to the pristine Himalayan atmosphere from heavily polluted south Asian regions (Tripathee et al. 2014a, b, Sharma et al. 2015) and could be deposited as snow and rain into the river. In addition, the existing information on snow and ice samples also indicated the contribution of air mass from Indian subcontinent to these areas (Valsecchi et al. 1999; Marinoni et al. 2001; Shrestha et al. 2002; Balestrini and Polesello 2014).

The sources of most of the rivers in Nepal are glacier fed. Intense studies on larger rivers of south Asia such as Ganges, Indus, and Brahmaputra have been conducted by many researchers (Raymahasay 1970; Abbas and Subramanian 1984; Sarin et al. 1990, 1992; Zhang et al. 1990, 1995; Jain and Sharma 2001; Huang et al. 2008, 2009). This area lies in a seismic zone and is prone to tectonic movement. A recent study in Yangtze River of China (Qu et al. 2015) indicated that the tectonic instability and chemical process play role in the chemical composition of the river. However, studies on the chemistry of Nepalese rivers (head waters of Ganges) till date have been limited in spatial scale. Due to the energy crisis in Nepal and high topographic relief in these Himalayan rivers, there is a high potential of hydropower generation. Hence various studies are undergoing for the generation of energy but the research on water quality is limited, because of its extreme terrain and limited transportation facilities (Hannah et al. 2005). Nevertheless, some studies on rivers of Nepal have been undertaken (Galy et al. 1999; Kannel et al. 2007; Bhatt and Gardner 2009; Bhatt et al. 2014), especially on the urban areas. Therefore, there is a need for exploring and understanding the physical and chemical compositions in the Himalayan Rivers from Nepal.

In the present work we analyze the spatial distribution of major ions and trace elements to set up the base line data for the water quality of the Himalayan rivers. Moreover, this work also aims to improve the understanding of weathering and geochemical processes in high altitude river basins. In addition, the study also assesses the possible sources of pollutants in the rivers and effects of long-range transport of atmospheric pollutants to the rivers on the southern slopes of the Himalayas.

Materials and methods

Study area

The study was conducted in two rivers from Koshi River Basin on the southern side of the Nepalese Himalayas, viz. Dudh Koshi River (Everest region) and Indrawati River. The River Dudh Koshi originates from melting of Ngozumpa Glacier and the outlet of Gokyo Lake. It is of major importance as many tourists travel to Everest region along the river inside the Sagarmatha National Park (SNP). The SNP is also highest protected mountain area in the world. In 2008 alone, over 30,000 tourists travelled to the SNP (Salerno et al. 2013). The study site of Dudh Koshi stretches 60 km from the outlet of Gokyo Wetlands (Ramsar site) at 4665 m above sea level (a.s.l.) to Juving at 1482 m asl (Fig. 1) with 7 sampling points in main stream and 9 in its tributaries. The head water of Dudh Koshi River is known as Khumbu region. Seventy percent of this area is covered with bare rock and soil that are eventually covered with snow, ice or glacier (Bajracharya et al. 2010). The Khumbu area lies in the Higher Himalayan region that consists of gneiss (para-gneiss and ortho-gneiss) as well as migmatite and leucogranite (Baral et al. 2015). The Indrawati River is located in on the eastern slope of Kathmandu valley, the capital city of Nepal. It meets Bhote Koshi River at Dolalghat and flows downwards as Sunkoshi River. The stretch of the studied river is about 44 km with 8 sampling points in the main stream and 6 in its tributaries. The climate in this region is dominated by Asian and Indian summer monsoon. Indrawati River lies in Sub tropical zone. The annual precipitation is about 1000–1500 mm per year. There are widely distributed igneous and metamorphic rocks such as granite gneiss, granite amphibolites gneiss, migmatite, etc.

Sampling and laboratory analysis

Water samples were collected from both the Koshi river sub-basins during May 2013 (pre-monsoon) for the analysis of major ions and trace elements. Altogether 30 sampling sites were used for the study including main rivers and their tributaries (Fig. 1). In situ measurements were taken for pH, conductivity, temperature and turbidity. The details of these instruments are presented in Table 1. Water samples were collected into 20 mL ultra-clean HDPE (high-density polyethylene) bottles through 0.45 µm polypropylene membrane filter. The sampling bottles were rinsed with river waters thrice, before the actual samples were taken. All samples were taken at a depth of approximately 30 cm below water surface. The sampled bottles were packed inside the double polyethylene zip-lock bags

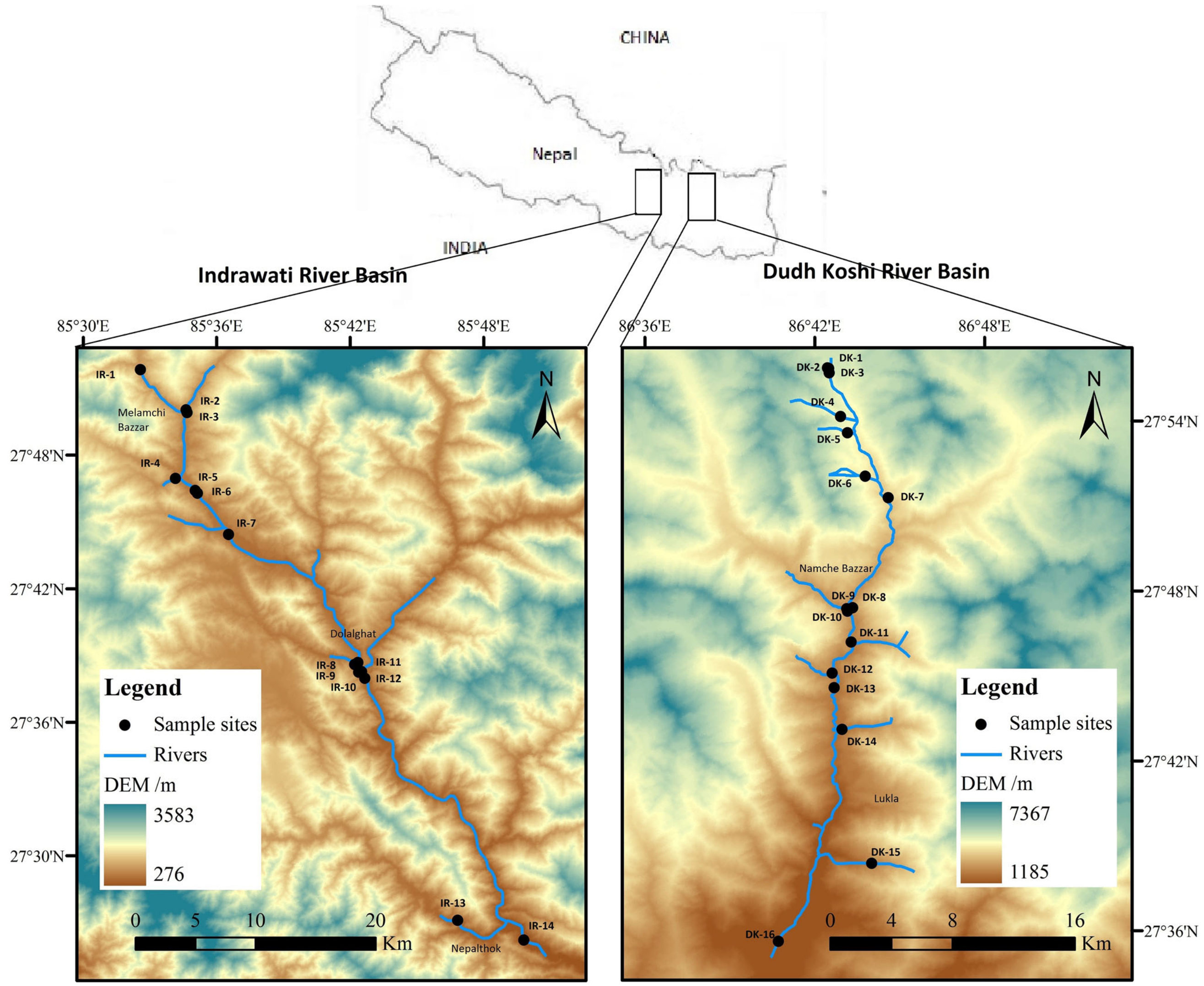

Fig. 1 Map of the study area showing the sampling points in Dudh Koshi River and Indrawati River

Table 1 Details of pH meter, conductivity meter, and turbidity meter

Instruments	Description	Error
Potable pH meter	Wagtech pH meter WAG-WE30200)	±0.01
Conductivity and TDS meter	Wagtech Conductivity Meter (WAG-WE30210)	±1 %F.S. +1 digit
Turbidity meter	Turbidity meter (WAG-WE30210)	±2 % of reading for 0–500 NTU 3 % of reading for 501–1000 NTU

and kept in refrigerator at 4 °C until the laboratory analysis. All samples for trace elements were acidified to $pH < 2$ with ultra-pure HNO_3 before analyses in order to dissolve the trace elements and to prevent their adsorption on the walls of the bottles.

Collected samples were taken to the Institute of Tibetan Plateau Research, Chinese Academy of Sciences (ITP-CAS), Beijing, and organized for different laboratory analysis. Samples were analyzed for 21 elements (Li, Sc, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, As, Rb, Sr, Cs, Ba, Pb, U, Y, Zr, Nb and Cd) using inductively coupled plasma-mass spectrometry (ICP-MS, X-7 Thermo Elemental) at ITP-CAS. The samples for major ions (Na^+, NH_4^+, K^+, $Ca^{2+,}$ Mg^{2+}, Cl^-, SO_4^{2-}, and NO_3^-) were analyzed at State Key Laboratory of Cryospheric Sciences, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences (CAREERI-CAS). Major cations were analyzed by Dionex ISC 2000 ion chromatograph using an IonPac CS12A column, 20 mM methanesulfonic acid eluent, and CSRS300 suppresser. Major anions were analyzed by Dionex ISC 2500 ion chromatograph using an IonPac AS11-HC column, 25 mMNaOH eluent, and ASRS300 suppresser. Four major ions samples (IR-4, IR-6, IR-8, and IR-12) from Indrawati were contaminated so they were not considered for analysis.

Quality control assurance, ionic balance and data analysis

Special care was taken during field sample collection as well as laboratory analysis by wearing non-powder vinyl clean room gloves and masks to avoid contamination. All samples were kept in frozen state in the laboratory until analysis. Three field blanks were prepared with deionized water and taken in the field and were analyzed for trace elements and major ions. Results of blank samples showed very negligible contamination during sampling, storage and transportation of the samples. The ion balance between anions (F^-, Cl^-, SO_4^{2-} and NO_3^-) and cations (K^+, Na^+, Ca^{2+}, Mg^{2+} and NH_4^+) was evaluated by regression analysis. The result for Dudh Koshi and Indrawati are $\sum\text{anions} = 0.21 \times \sum\text{cations} + 0.02$ ($R^2 = 0.74$) and $\sum\text{anions} = 0.23 \times \sum\text{cations} + 0.02$ ($R^2 = 0.94$), respectively, suggesting an acceptable data quality. Bicarbonate was determined by charge balance from other ions (Li et al. 2007; Tripathee et al. 2014a). In the Himalayan Rivers, this method was found to be efficient as suggested by different researchers (Wu et al. 2008; Huang et al. 2009). Principal Component Analysis (PCA) was performed using SPSS 16 software.

Results and discussion

Major ions composition

Mean ion concentrations of samples from the selected two rivers are presented in Table 2; including comparisons with rivers from India, Tibet and other parts of the world (Huang et al. 2009; Singh and Hasnain 1998; Bartarya 1993). With the exception of NO_3^- in Indrawati, concentrations of most of the ions were extremely low. However, it is comparable and shows similar concentration with the head water of Ganges in India (Singh and Hasnain 1998; Bartarya 1993).

Relative proportions of major anions and cations on an equivalent basis are plotted in piper diagram (Fig. 2). This plot shows that all rivers are located in a corner indicating HCO_3^- as the major constitutes among the anions (60–90 %), followed by SO_4^{2-} (up to 25 %), NO_3^- and Cl^-. Cationic composition also suggests that, most of the rivers are located in Ca^{2+} corner. On an average Ca^{2+} accounted for 50–90 % of total cations, followed by Mg^{2+} (up to 40 %), Na^+ (4–12 %) and K^+ (2–6 %).

There are various sources of ions in river water such as rock weathering, precipitation, minor contribution from cyclic sea salt, wind-blown dust/aerosols and pollution (Berner and Berner 1987). Relative proportions of ions in the surface water depend mainly on parent materials. The correlation between Na^+ and Cl^- in Indrawati ($r^2 = 0.034$) and Dudh Koshi ($r^2 = 0.03$) were poor, indicating Sodium and Potassium alumino-silicate weathering and anthropogenic emission. On the contrary, the correlation between Ca^{2+}, Mg^{2+} with SO_4^{2-} are good [Indrawati r^2 (Ca^{2+}/SO_4^{2-}) = 0.82; r^2 (Mg^{2+}/SO_4^{2-}) = 0.97; Dudh Koshi r^2 (Ca^{2+}/SO_4^{2-}) = 0.67; r^2 (Mg^{2+}/SO_4^{2-}) = 0.37], indicating their common source. Sulfate ions are often suspected of having anthropogenic origin in addition to dissolution of evaporates such as gypsum and atmospheric inputs (Han and Liu 2004). The source of HCO_3^- is from weathering of carbonate and silicate. Dudh Koshi and Indrawati rivers are basically glacier fed; therefore, it is possible that the chemical weathering is taking place underneath the glacier (Reynolds and Johnson 1972; Collins 1979). Bicarbonate (HCO_3^-) in surface water is mainly derived from dissolution of atmospheric carbon dioxide (CO_2) in water (Garrels and Mackenzie 1971). Source of dissolved ions in the river basin can be evaluated by observing the associations among them. The positive correlation of HCO_3^- with Ca^{2+} ($r^2 = 0.97$) and Mg^{2+} ($r^2 = 0.95$) in Dudh Koshi suggests that they were derived from a common source, i.e., by dissolution of carbonates. In carbonate weathering reactions, carbonate-derived calcium and magnesium (Ca^{2+}+Mg^{2+}) should be equal to the carbonate-derived HCO_3. Analysis shows that the total calcium and magnesium is not very different from total carbonate. The plot between Ca^{2+} and Mg^{2+} against HCO_3^- in Fig. 3a suggests that most of them were from a common source and the slight excess of ($Ca^{2+} + Mg^{2+}$) should be balanced by SO_4^{2-} and Cl^-. Average equivalent ratio of total cations (TZ^+) and ($Ca^{2+} + Mg^{2+}$) was 1.19 (Fig. 3b), suggesting Ca^{2+} and Mg^{2+} had high concentration of cations. High contribution of ($Ca^{2+} + Mg^{2+}$) to TZ^+, high ($Ca^{2+} + Mg^{2+}$)/(Na^++K^+) ratio (7.07), and low (Na^++K^+)/TZ^+ ratio of 0.14 (Fig. 3c) indicate that carbonate weathering was the major source of solutes in these rivers; which is also supported by the results Alaknanda River of India (Singh and Hasnain 1998; Table 2).

The variation of weight ration of Na^+/(Na^++Ca^{2+}) as a function of total dissolved solids (TDS) has been plotted as to find the mechanism controlling water chemistry (Gibbs 1970). Figure 4 indicates that Dudh Koshi, Indrawati and their tributaries are basically dominated by magnesium and

Table 2 Ionic concentrations of Indrawati River and Dudh Koshi River in the southern side of the Nepalese Himalayas (mean value of all the samples in the catchment) compared to those in rivers of Tibetan Plateau, Head water of Ganges in India and other parts of the world expressed in mg/l

River studied	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-	Na^+	K^+	Mg^{2+}	Ca^{2+}
Indrawati[a]	2	4	9	58	4.2	1.1	3.4	15
Dudhkoshi[a]	0.6	1.2	3.7	22	0.8	0.7	0.4	7.9
Salween[b]	5	0	31	66	3	1	7	24
Mekong[b]	14	0	69	138	12	1	14	49
Yangtze[b]	64	0	53	108	38	2	12	40
Ganga (at Rishikesh)[d]	1.47		15.5	61.2	3.32	1.57	5.7	15.9
Alakananda(India)[c]	0.67		8.9	58.1	1.91	2.33	4.1	16.1
Asia[b]	9	1	8	79	6	4	6	18
Africa[b]	12	1	14	43	11	–	4	13
North America[b]	8	1	20	68	9	1	5	21
South America[b]	5	1	5	31	4	2	2	7
World[b]	8	1	11	58	6	2	4	15

[a] Present Study

[b] Huang et al. (2009)

[c] Singh and Hasnain (1998)

[d] Bartarya (1993)

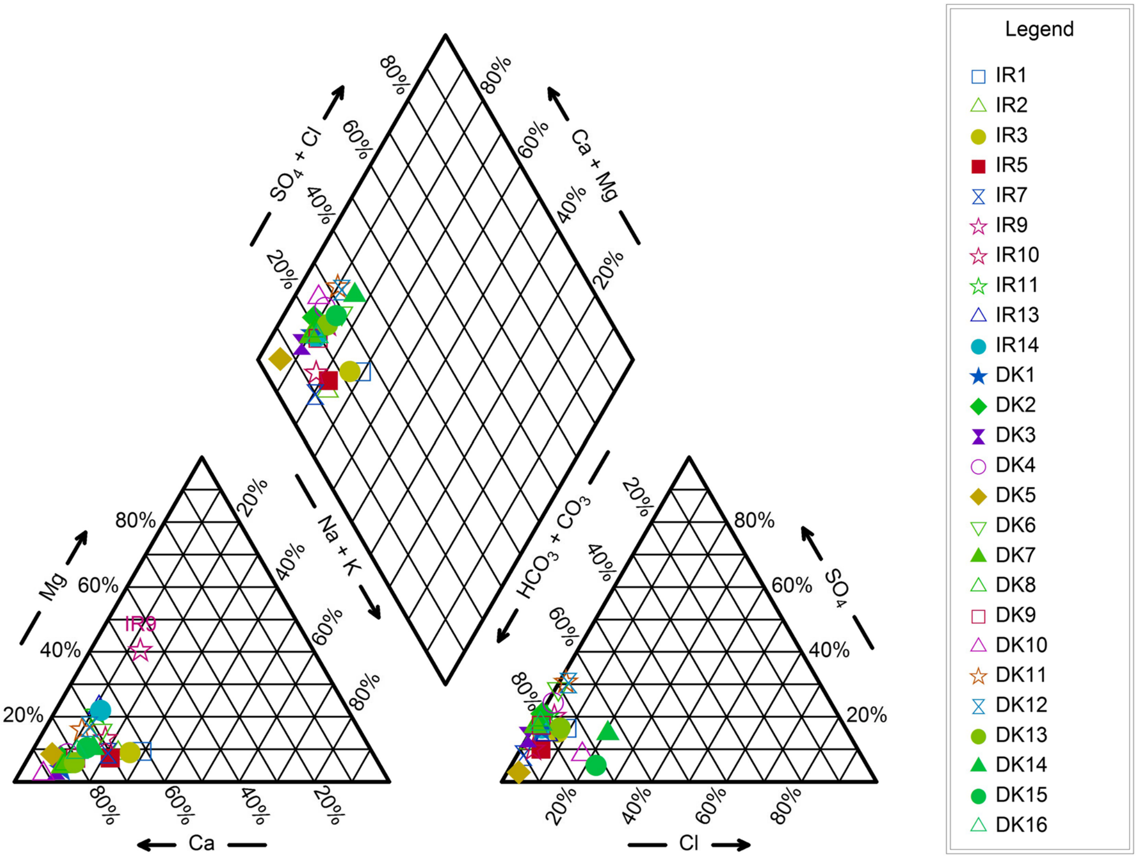

Fig. 2 Piper diagram of dissolved major anions and major Cations on an equivalent concentration (μeq/L) basis in Indrawati Dudh Koshi and their tributaries

calcium minerals; however, the major ion chemistry of DK-5 and DK-15 was precipitation dominant. In summary the mechanism controlling the river water includes rock weathering, atmospheric precipitation, evaporation-crystallization and anthropogenic activities in the present study.

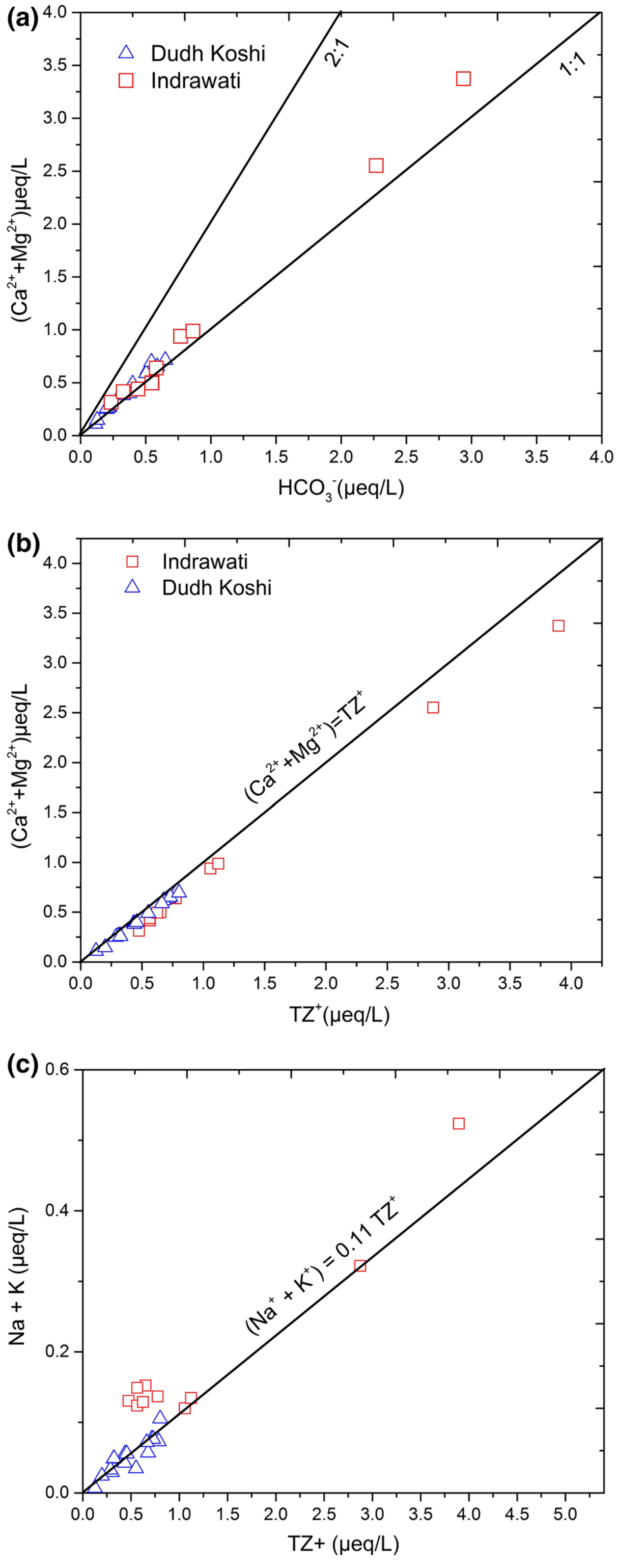

Fig. 3 Scattered plots between **a** $(Ca^{2+}+Mg^{2+})$ Vs Bicarbonate **b** $(Ca^{2+}+Mg^{2+})$ Vs total cations (TZ^{+}); and **c** $(Na^{+}+K^{+})$ Vs total cations (TZ^{+})

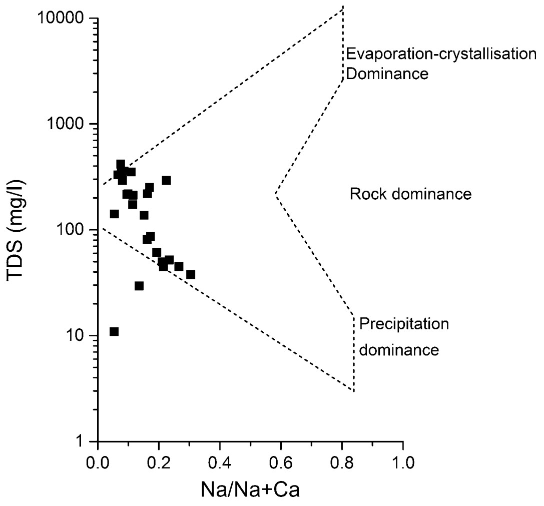

Fig. 4 Variation of the weight ratio of $Na^{+}/(Na^{+}+Ca^{2+})$ as a function of TDS

Elemental concentration

General

Mean metal concentrations of the two selected rivers are grouped and listed in Table 3. The pH ranged from 6.57 at TokTok (DK- 12) to 8.81 at the outlet of Ngozumpa glacier (DK-1) and EC from 10.5 µS/cm (DK-15) to 321 µS/cm (IR-13). Similarly, turbidity ranged from 0.51(DK-12) to 515(DK-13) Nephelometric Turbidity Units (NTU). It should be noted that pre-monsoon season receives very few atmospheric precipitation inputs when the main source of elements could be chemical weathering. High turbidity recorded in main stream of Dudh Koshi River could be due to high amount of chemical weathering and physical erosion because these processes are higher in the Himalayan region (Colin et al. 1999; Dalai et al. 2002; Singh et al. 2005). On the other hand, low turbidity was recorded from the pristine tributaries of Dudh Koshi River which receive melting snow/ice as the only source of water. In general, the data given in Table 3 show low concentrations of most of the elements compared with WHO guidelines for drinking water (WHO 2011).

Dudh Koshi and its tributaries

Gokyo lake outlet is the first tributary of Dudh Koshi. It mixes with main stream immediately after Ngozumpa Glacier. The pH and content of dissolved salt was 8.03 and 56.1 µS/cm, respectively. Most of the elemental concentration was very low. However, Zn (25.54 µg/L) and Mn (31.05 µg/L) were the notable elements. The source of Zn

Table 3 Mean, maximum and minimum elemental concentration (μg/L), pH, EC (μS/cm) and Turbidity (NTU) in Dudh Koshi River, Indrawati River and their Tributaries in the southern side of Himalayas

Parameters	Indrawati			Dudh Koshi			WHO guidelines for drinking water
	Maximum	Minimum	Average	Maximum	Minimum	Average	
pH	8.59	7.58	8.18	8.81	6.57	7.52	6.5–8.5
EC	321	37.7	104.08	60.7	10.5	37.61	
Turbidity	30.2	2.49	12.81	515	0.51	155.63	5
Li	4.15	0.22	1.53	58.75	0.12	14.26	
Sc	5.12	0.44	1.77	8.13	0.34	2.14	
V	3.38	0.29	1.26	16.17	0.18	3.63	
Cr	3.33	0.32	1.34	13.69	0.34	3.10	50
Mn	37.87	3.32	14.26	125.20	0.75	28.24	400
Co	2.02	0.05	0.50	3.94	0.00	0.80	
Ni	7.24	0.40	2.77	14.15	0.10	2.74	20
Cu	7.08	0.00	3.53	8.33	0.00	1.78	2000
Zn	26.24	0.00	7.12	62.56	0.00	16.74	3000
Ga	2.50	0.11	0.52	4.60	0.03	1.02	
As	0.00	0.00	0.00	15.57	0.00	3.68	10
Rb	17.59	1.09	4.42	57.63	1.13	13.47	
Sr	232.00	10.23	42.29	26.28	2.11	12.38	
Cs	0.53	0.01	0.17	13.74	0.01	2.90	
Ba	76.92	2.59	13.21	40.95	0.35	9.49	700
Pb	3.30	0.00	0.69	7.83	0.00	1.82	10
U	3.40	0.06	0.75	21.86	0.07	4.42	1000
Y	0.758	0.03	0.18	0.89	0.03	0.23	
Zr	0.374	0.02	0.07	0.09	0.01	0.04	
Nb	0.191	0.004	0.05	1.95	0.002	0.477	
Cd	0.053	0.005	0.02	0.04	0.002	0.009	3

could be traffic pollution that might have been carried by atmospheric circulation (Adachi and Tainosho 2004), whereas Mn might have originated from industrial emission (Zayed et al. 2003).

The main upstream tributaries of Dudh Koshi River are Machhermo, Luza and Dole located at about 4, 5 and 8 km downstream from Ngozumpa Glacier, respectively. Compared to Luza (1.88 NTU) and Dole (2.9 NTU), Machhermo had a high turbidity (40.3 NTU). Except for Zn in Machhermo, which was 21.8 μg/L, concentrations of all other elements were negligible.

Bhote Koshi is the biggest tributary meeting Dudh Koshi near Namche Bazaar, the gateway to the Everest region. The confluence of Bhote Koshi and Dudh Koshi is about 18 km below the Ngozumpa Glacier. It was the most turbid river among the tributaries of Dudh Koshi having pH and EC readings 7.7 and 32 μS/cm, respectively. The elemental concentrations of this river were also very low. However, the concentration of Zn (18.89 μg/L), Li (8.97 μg/L), and Mn (9.03 μg/L) was higher than other tributaries. This slightly higher concentration of Zn, Li and Mn might be due to the waste produced by tourist in the small villages like Thamu, Kisibook, Phurte, and Namche Bazaar. However, the concentrations of these elements were within the WHO guidelines for drinking water (WHO 2011).

Monjo, TokTok, Kusum, and Payon were the other studied tributaries of Dudh Koshi which appeared pristine as there were no settlements upstream. The pH of these rivers ranged from 6.57 to 7.49 that are within the WHO guidelines (WHO 2011). EC ranged between 10.5 and 25.1 μS/cm. The concentration of Zn was 23.78 μg/L in Kusum River; otherwise, the elemental concentrations were extremely low in all other tributaries.

Along the main stream of Dudh Koshi, pH was generally alkaline in the high altitude and had fairly high buffering capacity for acid rain. It decreased gradually downstream from 8.81 to 7.14. Similarly, EC ranged from 35.9 to 60.7 μS/cm. Although appeared low, elemental concentrations in the main river were high as compared to its tributaries. The main reason behind this scenario might be due to the high discharge rate causing high chemical weathering and erosion compared to the tributaries. This also indicates that, apart from chemical weathering and erosion, there could be very limited input from atmosphere. Average concentration of Cr was 5.68 µg/L, which is higher than Lhasa River during both monsoon and non-monsoon seasons (Li et al. 2014), but lower than YarlungTsangbo, Indus and Ganges (Zhang et al. 2014), whereas the average concentration of Mn (51.08 µg/L) was extremely lower than YarlungTsangbo and about three fold lower than Indus (Zhang et al. 2014). Average concentration of As (7.35 µg/L) was lower than head water of YarlungTsangbo, Indus, Ganges (Zhang et al. 2014) and Lhasa river during non-monsoon (Li et al. 2014). However, it was comparable with upper Ganges River (Chakrapani 2005).

Indrawati and its tributaries

Indrawati River originates from eastern part of Langtang National Park of Sindhupalchok district (Fig. 1). The pH in the whole basin ranged from 7.85 to 8.59. Turbidity was generally low in this river with most turbid water found in Indrawati at Melamchi Bazaar. The EC ranged from 37.7 to 321 µS/cm (Table 3).

Melamchi River also originates from the southern slope of Langtang National Park (Fig. 1). It is one of the important Rivers for Kathmandu Valley as this river will supply drinking water to the valley in future after the completion of Melamchi Drinking Water Project. Melamchi confluences Indrawati near the place known as Melamchi Bazaar. The pH, EC and turbidity read at 7.82, 48.3 µS/cm and 5.69 NTU, respectively. Concentrations of all elements were extremely low. SinduKhola, DhadKhola and ChaKhola are small tributaries of Indrawati before it mixes with Bhote Koshi at Dolalghat, about 25 km downstream from Melamchi. The pH and EC in these tributaries ranged from 7.71 to 8.38 and 37.7 to 204 µS/cm, respectively. Although these rivers flow through the small plots of agricultural fields, the concentrations of toxic elements such as Pb, As, and Cd were extremely low (in fact the concentration of Pb and As were below the detectable limits). The pH and EC were 8.23 and 109.5 µS/m in Bhote Koshi. The elemental concentrations were very low; and concentrations of As, Pb and Zn were below the detectable limits.

Roshi Khola mixes with Sun Koshi about 20 km downstream of Dolalghat (Fig. 1). This river was overexploited by extraction of riverbeds (mainly sand and stones) with the use of crusher plants. The high levels of EC (321 µS/cm) and pH (8.5) in Roshi Khola compared to the main stream and other tributaries might be due to severe impact of crusher plants to extract sands and stones from the river. The crusher plants have had effects not only on the physical parameters but also on the elemental concentration. It was also observed that the concentrations of most of the elements were higher in this stream compared to the average of rest of the samples in the basin. The concentration of toxic element like Pb (3.3 µg/L) was also high in this stream compared to other streams and rivers in this basin. However, this value is still within the permissible limit of WHO guidelines (WHO 2011).

The pH in main stream of Indrawati and Sun Koshi was alkaline (7.58–8.59), EC increased gradually from upstream to downstream (55.2–112.1 µS/cm) and turbidity was low (2.48 to 30.2 NTU). Most of the elemental concentration of toxic elements such as As and Pb were below the detectible limit. The concentration of Cr and Ba was less than Dudh Koshi, YarlungTsangbo, Indus and Ganges (Zhang et al. 2014); however, it was comparable with Lhasa River (Li et al. 2014). Lower concentration of crustal elements such as Rb, U, Zr, Mn, Ba, Nb, Cr might be due to low gradient in Indrawati compared to Dudh Koshi hence lower physical and chemical weathering. However, the concentration of Cr, Ba, and Rb was comparable to the upper Ganges River (Chakrapani 2005).

Varimax rotated PCA results are presented in Table 4. In most of the samples, concentrations of As, Zn, and Mg were either low or below the detectible limits so they were not considered in PCA analysis. According to the results of PCA, first three components account for 94.43 % of the total variance explained. The first component (73 %) was

Table 4 Principal component analysis (PCA) of elements in river waters

Elements	Component		
	1	2	3
Li	0.92	−0.38	−0.050
Sc	0.95	0.10	−0.036
V	0.96	−0.24	−0.00
Cr	0.97	−0.21	0.04
Mn	0.97	−0.15	0.01
Co	0.97	0.05	0.02
Ni	0.91	0.11	0.15
Cu	0.69	0.48	0.34
Ga	0.99	−0.02	−0.09
Rb	0.97	−0.19	−0.05
Sr	0.31	0.88	−0.30
Cs	0.92	−0.37	−0.01
Ba	0.78	0.55	−0.23
U	0.88	−0.26	−0.02
Y	0.93	0.21	−0.06
Zr	0.45	0.83	−0.16
Nb	0.88	−0.37	−0.11
Cd	0.41	0.37	0.77
% of variance	73.088	16.034	5.310
Cumulative %	73.088	89.122	94.432

loaded with crustal elements (Li, Sc, Mn, Rb, Cs, U, Nb, Cr, Co, V and Ni). However, the source of elements such as Cr, Co, V and Ni could also be of anthropogenic origin because of fossil fuel combustion and solid waste dumping (Pacyna et al. 1984; Barałkiewicz and Siepak 1999; Teng et al. 2006; Wise et al. 2009). In addition, this might be due to the local sources caused by burning of waste (deposited by travelers in the Everest regions) as suggested by Balestrini and Polesello (2014). Furthermore, recent studies (e.g., Tripathee et al. 2014a; Sharma et al. 2015) indicated the possibilities of long-range transportation of elements to the high altitude fresh waters of Nepal. The second component (16 %) was mostly loaded with Sr, Ba and Zr suggesting chemical weathering of parent rock materials, where as the third component (5.3 %) was mainly loaded with anthropogenic sources (Cu and Cd). This analysis shows that most of the elements could be derived from the crustal origin; however, there were evidences of some anthropogenic emissions too. This PCA analysis only shows possible sources of the elements, and the quantitative estimation is unknown, which need further modeling analysis in the future.

Conclusions

This study provides a baseline information and spatial distribution of water quality of two major rivers on the southern side of the Nepalese Himalayas. As river water chemistry was largely determined by soil constituent in the catchment, the trace element concentrations in these areas were mainly governed by the weathering of soil parent materials. However, there are some evidences of long-range transportation of pollutants from the southern urban areas deposited in the region. In case of Indrawati River, some human activities (extraction of sand and stones) also played role in determining the pollutant levels in river waters. Nevertheless, the concentrations of elements are still within the guidelines of WHO. In general, data suggests that the chemical concentrations in all the rivers were mainly controlled by carbonate weathering, with Ca^{2+} and HCO_3^-being the dominated ions. Overall results showed that the river waters in these areas were undisturbed despite some agricultural and anthropogenic impacts. The effect of some anthropogenic activities on river water quality may not be an issue at present; however, it can be of major concern in future as millions of population is directly or indirectly dependent on these water resources. Therefore, a further study of quantitative modeling analysis is required in order to quantify the source of different elements.

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