Hindawi Publishing Corporation
Journal of Chemistry
Volume 2016, Article ID 6025905, 13 pages
http://dx.doi.org/10.1155/2016/6025905

Research Article

Variations of the Physicochemical Parameters and Metal Levels and Their Risk Assessment in Urbanized Bagmati River, Kathmandu, Nepal

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Received 14 July 2016; Revised 14 September 2016; Accepted 13 October 2016

Academic Editor: Franco Tassi

During post-monsoon 2013, surface water samples were collected form 34 sites from the Bagmati River and its tributaries within the Kathmandu Valley to assess the river water quality. The physical parameters were measured on site and major ions (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}, and NO_3^-) and 17 elements in water were analyzed in the laboratory. Conductivity ranged from 21.92 to 846 μS/cm, while turbidity ranged from 2.52 to 223 NTU and dissolved oxygen (DO) ranged from 0.04 to 8.98 mg/L. The ionic and elemental concentrations were higher in the lower section where the population density is high compared to the headwaters. The large input of wastewater and organic load created anoxic condition by consuming dissolved oxygen along the lower belt of the river. The concentration of the elements was found to be in the order of Mn > Zn > Ti > Rb > Cr > Cu > Sc > Ni > V > Li > Co > Mo > Cd > Y > Ga > Be > Nb. The concentration of Mn, Cd, Cr, Co, and Zn was particularly higher in urban and semiurban sections. Enrichment factor (EF) calculations for Cd, Co, and Zn showed their highly enriched values indicating that these elements originated from anthropogenic sources. Preliminary risk assessments were determined by the hazard quotient (HQ) calculations in order to evaluate the health risk of the metals. The $HQ_{ingestion}$ values of elements were found to be in the order Sb > Mn > Cr > V > Co > Cd > Cu > Zn > Ni > Li > Mo with all averaged HQ values less than 1, indicating no or limited health risk of metals from the river to the local residence. However the values of Sb in some parts of the Bagmati were close to unity indicating its possible threat. Anthropogenic activities like industrial activities, municipal waste water, and road construction besides the river appear to control the chemical constituent of the river water. Overall the river was highly polluted with elevated concentrations of major ions and elements and there is a need for restoration projects.

1. Introduction

Metal contamination in fresh water has been global problem because of its toxicity, abundance, and persistence [1–3]. The rate of heavy metals release to the rivers worldwide is increasing rapidly mainly due to the rapid growth of urban population and increased industrial and agricultural production [4–7]. Furthermore, their distribution and accumulation in the environment have been increasing at an alarming rate affecting human and other aquatic organisms [8, 9]. Many anthropogenic activities like disposal of industrial and domestic wastes, agriculture, construction of roads and buildings, and deforestation are known to affect water chemistry [10–13]. Similarly, increase in ions concentration could be a result of increased population, for example, in the United States [14], France, and Germany [15–17].

Water resources from the Bagmati River System are important for small scale hydroelectricity and irrigation and as drinking water sources. About 82% of water volume is extracted daily from the surface water sources for drinking water supply in the Kathmandu Valley. On the other hand, these rivers are extensively being used as dumping sites for solid wastes, outlets for domestic sewerage, and industrial and agricultural effluents. Also, the river banks are being encroached upon by slum dwellers without any restrictions from the government. Furthermore, due to heavy traffic in the city, the demands of new road channel are increasing; hence construction of roads by the banks of river without proper study is common these days. All these negative approaches in addition to uncontrolled and mismanaged growth of urban population are affecting the balance of the riverine ecology in the valley. In addition, the uncontrolled quarrying of sand has tremendously affected the self-treatment capacity of the rivers.

In this paper we focus on the contribution of chemical load from the tributaries of Bagmati into its main stream. In the past, there have been few studies about the water chemistry of main stream of Bagmati River which have focused mainly on nutrients, major ions, and trace elements with limited sampling points [18–23]. However, there is a lack of information on the chemistry of the tributaries of Bagmati River, their possible sources within the valley, and trace metals induced human risk assessments. This study, for the first time, provides the detailed information from the tributaries of Bagmati, water quality health assessment in the Bagmati River during the current state of rapid urbanization, and socioeconomic development including the risk assessment from trace metals.

2. Materials and Methods

2.1. Study Area

2.1.1. Geological Settings. This study was conducted in the Bagmati River and its tributaries in the Kathmandu Valley, Central Nepal (Figure 1). Kathmandu lies in the middle mountain region of Nepal. It is roughly circular bowl-shaped valley with diameter of about 25 to 30 km [24]. It covers an area of approximately 650 km^2 with an average altitude of 1340 m [25]. The Bagmati is not a snow-fed river and most of its water is contributed by runoff. The origin of Bagmati is at Shivapuri and surrounding mountain range. There are 24 main tributaries originating from Mahabharat and Siwalik range which feed the Bagmati River [26]. The Bagmati River system drains about 3,500 km^2 before crossing the boundary of India and eventually draining into the Ganges [23]. The Bagmati river system consists of three major rivers flowing through the Kathmandu Valley, namely, Bagmati, Bishnumati, and Manahara. Kathmandu Valley was a lake during Plio/Pleistocene times and silted up by lacustrine and deltaic river sediments [27]. The basin filled sediments are mainly loam and composed of unconsolidated clay, silt, sand, and gravels. The headwaters of Bagmati river contain mica gneiss and biotite schist with muscovite, whereas the southern part of the river consists of thick clay formation and basal gravel [28] and the bed rock downstream contains fine grained phyllite, quartz containing argillaceous limestone, slates, shales, claystones, and mudstones [29, 30]. In this study we consider samples from 5 major tributaries (Manahara, Dhobi, Tukucha, Bishnumati, and Balkhu Khola) and some minor tributaries (Mahadev Khola, Hanumante, and Godavari). The study stretch in the main stream of Bagmati River is about 37 km in length from Sundarijal to Khokana.

2.1.2. Land-Use. There have been rapid urbanization in Kathmandu Valley as it is the capital city and center of attraction to the Nepalese population. In 1976, the total urban/built-up area in Kathmandu was about 17%, but in 2009 the percentage increased to almost 67%. In the same period the Forest Cover area was reduced from 14% to 2.3% [31]. This can have an immense effect on the river water quality.

The climate of Kathmandu Valley is subtropical cool temperate with maximum temperature of 35.6°C in April and minimum of −2.5 in January and 75% annual average humidity. The temperature on average is 19°C to 27°C in summer and 2°C to 20°C in winter; the average rainfall is 1400 millimeters, most of which falls during monsoon. Monsoon is generally observed during June–September.

Kathmandu Valley comprises three districts, Kathmandu, Lalitpur, and Bhaktapur. The valley encloses the entire area of Bhaktapur, 85% of Kathmandu, and 50% of Lalitpur District. The total population of Kathmandu Valley is more than 2.5 million according to the population census of 2011.

2.2. Sampling and Laboratory Analysis. Water samples were collected from the Bagmati River and its tributaries during October 2013 (after monsoon). The analyses were performed for trace elements and major ions. Alltogether, 34 samples were collected from different tributaries of Bagmati river basin. In situ measurements were carried out for air temperature, water temperature, pH, conductivity, turbidity, DO, and TDS. A WagTech pH meter (WAG-WE30200), WagTech conductivity meter (WAG-WE30210), and turbidity meter (WAG-WE30210) were used in the field for in situ measurements. Water samples were collected into 20 mL ultraclean HDPE (High Density Polyethylene) bottles after filtering through 0.45 μm polypropylene membrane filters. The sampling bottles were rinsed with river waters thrice before the original 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 and kept in refrigerator at 4°C until the laboratory analysis [32].

All samples for trace elements were acidified to pH < 2 with ultrapure HNO_3 before analyses in order to dissolve the trace elements and to prevent their adsorption on the walls of the bottles. The samples were organized for the different laboratory analysis. Samples were analyzed for 17

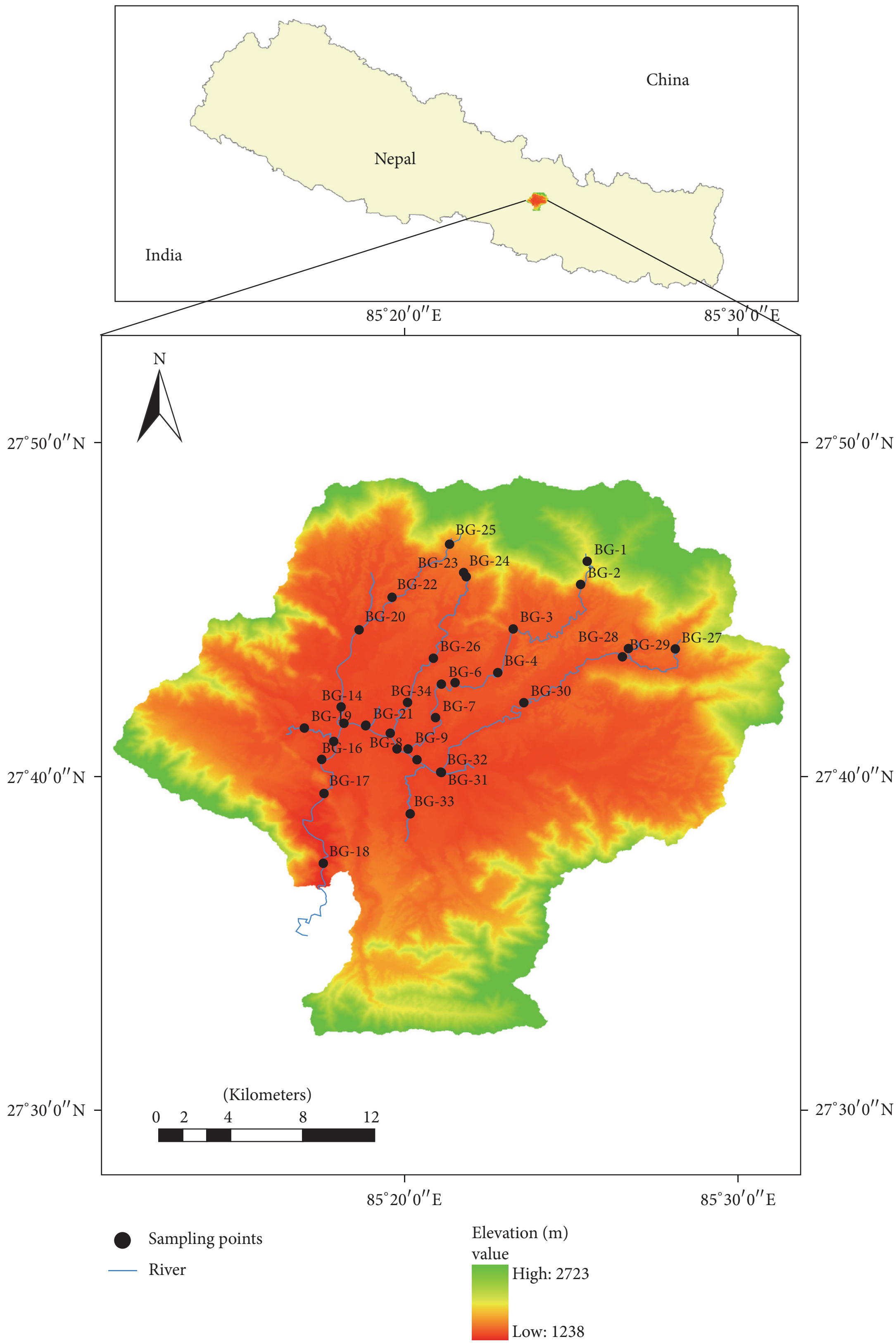

Figure 1: The map of the study area showing the sampling points in Bagmati and its tributaries within the Kathmandu Valley.

elements (Li, Be, Sc, Ti, V, Mn, Cr, Co, Ni, Cu, Zn, Ga, Rb, Y, Nb, Mo, and Cd) directly by inductively coupled plasma-mass spectrometry (ICP-MS, X-7 Thermo Elemental) at the Institute of Tibetan Plateau Research (ITP-CAS). The samples for major ions (Na^+, NH_4, K^+, Mg^{2+}, Ca^{2+}, Cl^-, $SO_4{}^{2-}$, and $NO_3{}^-$) were analyzed at the 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 mM NaOH eluent, and ASRS300 suppresser. The detection limits were less than 1 μg/L [33].

2.3. Quality Control, Ionic Balance, and Data Analysis. Special care was taken during the field sample collection and laboratory analysis. Nonpowder vinyl clean room gloves and masks were worn to avoid the possible contaminations in the field as well as in the Laboratory. All the samples were kept frozen 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. The field blank samples showed very negligible contamination during sampling, storage, and transportation of the samples. The ionic balance between anions (F^-, Cl^-, $NO_2{}^{2-}$, $SO_4{}^{2-}$, and $NO_3{}^-$) and cations (Na^+, $NH_4{}^+$, K^+, Mg^{2+}, and Ca^{2+}) were evaluated by regression analysis, $\sum \text{anions} = 0.26 \times \sum \text{cations} - 80.74$ ($R^2 = 0.78$), suggesting an acceptable data quality. Details of sampling, analysis, and quality control have been explained elsewhere [32–35]. Some statistical analysis like Pearson's correlation and Principle Component Analysis (PCA) were performed using IBM SPSS19 statistics.

2.4. Enrichment Factor. Enrichment factor (EF) is considered as an effective tool to evaluate the magnitude of contaminants in the environment from anthropogenic influence [36–38]. EF calculations for the trace elements have been previously found to be efficient for the study of precipitation [35] and surface water [39] in Nepal. EF can be calculated using the following equation:

$$\mathrm{EF}_x = \frac{(C_x/C_r)\ \text{riverwater}}{(C_x/C_r)\ \text{soil}}, \tag{1}$$

where x represents the element of interest; EF_x is the enrichment factor of x; C_x is the concentration of x; and C_r is the concentration of a reference element. Generally, Al, Li, Fe, Sc, and Zr are considered as reference elements. Li was selected as the reference element for calculating EF, as it is not subject to anthropogenic enrichment. For this study top soil composition of Tibet was considered [40] because of its proximity to the study area instead of upper continental crust (UCC) [41]. Tripathee et al. [35] also considered soil composition of Tibet to calculate EF and found that it was effective for the regions. However, recent study by Tripathee et al. [42] has suggested that both UCC and Tibetan top soil could be used for EF calculations in the southern Himalayas, Nepal. Elements with EF close to 1 are considered as having strong natural influence. Samples having EF > 1.5 are considered indicative of human influence [43], an EF value higher than 4 indicates some anthropogenic sources [37] and elements having EF greater than 10 are regarded to be severely affected by anthropogenic origin.

2.5. Risk Assessment. Some of the important pathways of trace metals entering into human body include ingestion, dermal adsorption, and inhalation in surface water environment [44–46]. Using ingestion and dermal pathways, hazard quotients (HQs) associated with corresponding metals were assessed via a risk assessment model. The exposure dose is calculated as modified from the US Environmental Protection Agency [47] using

$$\begin{aligned} D_{\text{ingestion}} &= \frac{C_w \times \mathrm{IRW} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}}, \\ D_{\text{dermal}} &= \frac{C_w \times \mathrm{SA} \times K_p \times \mathrm{ET} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{CF}}{\mathrm{BW} \times \mathrm{AT}}, \end{aligned} \tag{2}$$

where C_w is average concentration of trace metals in water. IRW is drinking water ingestion rate (2 L/day). EF is exposure frequency (350 days/year). ED is exposure duration (30 years). BW is body weight (70 kg). AT is average time for noncarcinogens and carcinogens (10950). SA is exposed skin area (2800 cm^2). K_p is dermal permeability constant, cm/hr, C is 0.0004, Ni is 0.0002, Zn is 0.0006, and Cr is 0.002 for other metals: 0.001. ET is exposure time 0.6 h/day. CF is unit conversion factor; for water, it is equal to 1 L/1000 cm^3.

However the hazard quotient (HQ) is calculated as follows:

$$\mathrm{HQs} = \frac{D}{\mathrm{RfD}}. \tag{3}$$

RfD is the reference dose for different analytes expressed in μg/kg/day, which is based on US risk based assessment [48]

3. Results and Discussion

3.1. Physical Parameters and Major Ions Concentration. The average concentration of ions and physical parameters in the headwaters and semiurban and urban stretch of the river for all the samples are presented in Table 1. The concentration of every parameter except pH and dissolved oxygen showed much higher concentration in urban and semiurban areas compared to the headwaters of Bagmati river basin. pH ranged from 6.07 at Balkhu (BG-15) to 8.05 in headwater of Dhobi Khola at Chapali (CG-23). BG-15 sample was collected near the vegetable market of Balkhu, which is one of the most polluted sections of Bagmati river basin. However the range of pH value along the Bagmati river system is within a typical river water value (4.5–8.5), as suggested by McCutcheon et al. [49]. Lowest conductivity, total dissolved solids, and highest dissolved oxygen were found in Sundarijal Bazzar (BG-2), one of the main headwaters of Bagmati River with high flow rate. On the contrary, high conductivity, high TDS, and low

Table 1: Variation of measured major ions (μeq/L), conductivity (μS/cm), turbidity (NTU), DO (mg/L), and TDS (mg/L) in three different sections of the Bagmati River basin within Kathmandu Valley. Values in brackets indicate standard deviation.

Parameters	Headwater		Semiurban		Urban	
	Range	Average (SD)	Range	Average (SD)	Range	Average (SD)
F^-	6.67–12.64	9.71 (2.22)	8.05–50.02	17.00 (12.31)	12.40–1122.89	152.72 (300)
Cl^-	3.04–44.20	22.15 (13.6)	15.19–320.41	138.41 (118.96)	117.59–1035.45	392.41 (249.4)
SO_4^{2-}	1.58–23.40	11.01 (7.44)	7.4–72.17	33.48 (20.71)	13.79–189.50	70.49 (39.34)
NO_3^-	12.16–69.13	43.60 (24.08)	0–488.51	94.93 (144.55)	0–382.62	86.36 (123.9)
Na^+	101.14–259.99	202.19 (61.56)	73.35–1115.69	472.49 (366.28)	467.19–2573.30	1124.38 (647.1952)
NH_4^-	23.13–131.29	79.32 (39.50)	47.02–557.40	221.74 (178.79)	177.10–1146.64	595.05 (300.89)
K^+	8.47–34.07	25.10 (10.07)	11.09–196.91	85.29 (70.92)	59.78–493.18	218.31 (139.76)
Mg^{2+}	4.57–48.56	30.40 (17.36)	14.41–409.76	151.80 (137.51)	76.21–361.23	203.27 (88.67)
Ca^{2+}	30.94–301.60	172.84 (95.24)	88.71–1752.57	668.38 (569.01)	261.04–1116.36	779.18 (262.47)
pH	7.07–8.05	7.49 (0.31)	6.52–7.7	7.16 (0.377)	6.07–7.62	7.06 (0.41)
Conductivity	21.92–255	83.36 (65.97)	63.10–538	259.93 (183.3)	174–846	491.38 (205.67)
Turbidity	2.52–18.67	6.95 (5.37)	14.39–223	50.65 (63.11)	13.32–222	57.96 (52.51)
Dissolved oxygen	5.21–8.98	6.76 (1.07)	0.37–6.29	3.63 (2.26)	0.04–4.7	1.80 (1.53)
TDS	11.8–129	42.06 (33.36)	31.5–265	130.10 (91.06)	87.5–418	248.16 (98.26)

Table 2: Pearson correlation matrix among some major ions in the water samples from Bagmati drainage system within Kathmandu Valley.

	F^-	Cl^-	SO_4^{2-}	NO_3^-	Na^+	NH_4^-	K^+	Mg^{2+}	Ca^{2+}
F^-	1								
Cl^-	.74**	1							
SO_4^{2-}	.01	.63**	1						
NO_3^-	−.12	−.10	−.07	1					
Na^+	.72**	.97**	.58**	−.07	1				
NH_4^-	.62**	.92**	.65**	−.25	.94**	1			
K^+	.71**	.95**	.57**	−.11	.99**	.96**	1		
Mg^{2+}	.46**	.79**	.59**	.22	.83**	.74**	.83**	1	
Ca^{2+}	.33	.67**	.53**	.36*	.71**	.61**	.70**	.96**	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

dissolved oxygen were found in the urban section of Dhobi Khola at Buddha Nagar (BG-11) and Maitidevi (BG-34). Conductivity of the river was found to increase from headwaters to the area downstream due to the increased intensity of anthropogenic activities downstream. Furthermore, turbidity ranged from 2.52 at Sundarijal above Dam (BG-1) to 223 at Bagmati Nagar (BG-5). Bagmati Nagar is a suburban section of the Bagmati river basin. The high turbidity must be due to high sediment loading in the downstream.

All the measured major ions showed an increasing trend from headwaters to semiurban to urban section except for nitrate ions. Nitrate ions decreased from semi urban to urban mainly due to the high population density in the urban section of the river. The major ions compositions in equivalent per litre in headwaters were $Na^+ > Ca^{++} > NH_4^+ > NO_3^- > Mg^{2+} > K^+ > Cl^- > SO_4^{2-} > F^-$, suburban was $Ca^{2+} > Na^+ > NH_4^+ > Mg^{2+} > Cl^- > NO_3^- > K^+ > SO_4^{2-} > F^-$, and urban stretch of the river was $Na^+ > Ca^{2+} > NH_4^+ > Cl^- > K^+ > Mg^{2+} > F^- > NO_3^- > SO_4^{2-}$, respectively. The concentration of NO_3^-, Ca^{2+}, Na^+, SO_4^{2-}, Mg^{2+}, NH_4^+, K^+, F^-, and Cl^- was 2, 4, 5, 6, 6, 7, 8, 15, and 17 times higher, respectively, in urban stretch compared to the headwaters. Correlations among ions are presented in Table 2. Chlorine ion is highly correlated with many ions like F^-, Na^+, NH_4^+, K^+, and Mg^{2+}, suggesting their common source of origin. High amount of Cl^- ions is mainly from anthropogenic sources [16, 20, 50], which might have originated from domestic effluents, roads, and industries in the river system. Moreover, the high value of Cl^- concentration is an indicator of unforested land and is considered as good indicator of human disturbance [51]. The possible sources of K^+ are domestic wastes and fertilizers. On the other hand, low sulfate concentrations in comparison to chloride might be due to sulfate reduction to sulfide occurring as a result of high organic load. Nitrate concentrations were very low in the samples with low DO concentrations suggesting lack of oxygen limits nitrification which enhances denitrification [17, 52, 53]. Figure 2 shows the variation of conductivity, DO, and TDS along the distance in the main stream of Bagmati River. Generally, DO showed a decreasing trend with distance (Figure 2(b)); however in some of the lower reaches of Bagmati River, DO was relatively

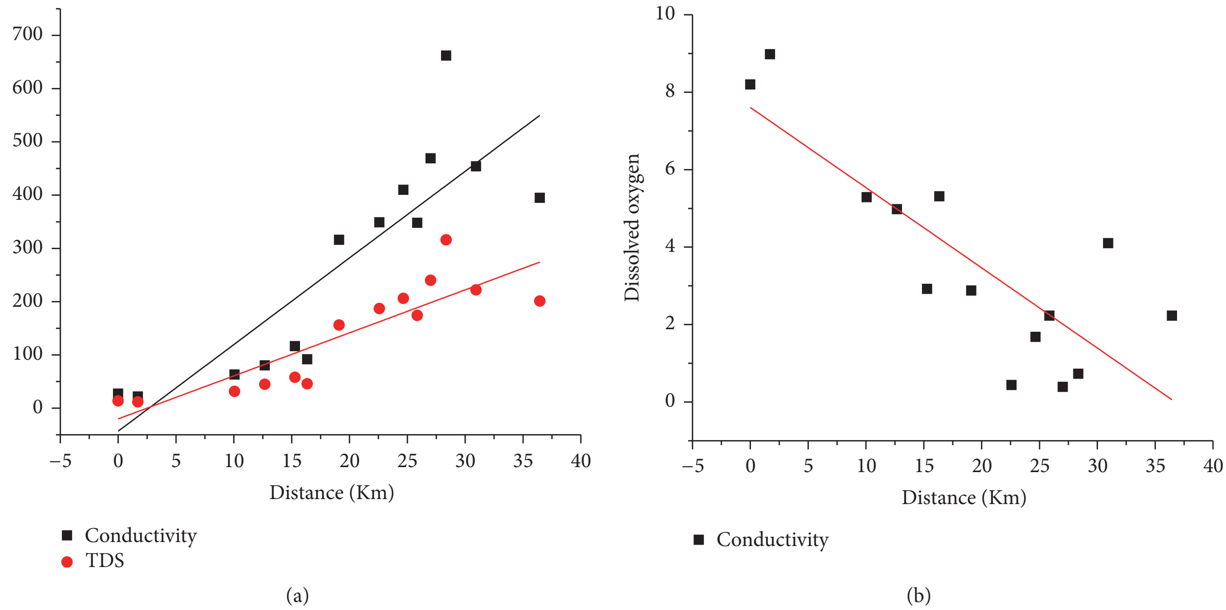

Figure 2: Variation of (a) conductivity (μS/cm), TDS (mg/L), and (b) dissolved oxygen (mg/L) along the Bagmati River within the Kathmandu Valley (the distance was measured from the headwater).

high due to good mixing. In such samples, the concentration of nitrate was high suggesting nitrification in the presence of oxygen. In addition, variation of conductivity and TDS was also plotted with distance (Figure 2(a)), which showed an increasing trend with distance suggesting high input of ions in the downstream river with high population density. Ammonium had a good correlation with chloride, potassium, and sodium, suggesting their common sources in the river systems. High concentration of NH_4^+ appears to be released by anthropogenic sources such as untreated domestic sewage and agricultural and industrial effluent. The concentration of NH_4^+ was extremely high in semiurban and urban region of the Bagmati basin. The use of chemical pesticides and fertilizers has been common in the agriculture lands of the Kathmandu Valley, which has high contribution in the Bagmati nutrient load [54]. Similarly, carpet, garment, and other small scale industries also play a significant role in the contribution of chemical loads.

3.2. Elemental Composition. Average concentrations of elements in headwaters and semiurban and urban sites are shown in Table 3. The concentration of Mg and Zn appeared to be higher than other elements. All the elements showed a high concentration in urban areas and semiurban areas. The increase in concentration of elements like Mn, Cd, Cr, Co, and Zn was particularly high from headwaters to the urban sites. The concentration of Cd was not detected in the headwater but, however, was observed in the semiurban and urban stretches of the river (Table 3). The concentration of Cd was higher than observed in the previous study in the Bagmati [23], suggesting increase of such anthropogenic metal levels in the river. The high value of Cd might be attributed to industrial activities downstream. On the other hand, the concentration of Zn is lower in headwater and suburban water compared to the data reported by Bhatt et al. [23] suggesting the natural restoration in the upper zone. However, in the urban section the concentration of Zn was high in our study. Such a result is an indication that other tributaries must be contributing to more Zn downstream. The sources of Zn are domestic construction, car related waste, and untreated waste water [55]. The concentration of Cr was 3 μg/L, 8 μg/L, and 17 μg/L, respectively, in headwaters and semiurban and urban section of the river. These values are higher than in Buriganga [9] and lower compared to the Korotoa River [3] in Bangladesh and Orge River in France [56]; both are urban rivers. However, the values were still higher than the WHO guidelines of 5 μg/L [57] in semiurban and urban sections. Similarly, the concentration of Ni, Cu, and Cd was 14-, 5-, and 21-fold lower than those found in River Korotoa in Bangladesh [3]. The concentration of cobalt was 0.0092 μg/L, 0.2 μg/L, and 0.38 μg/L in headwaters and semiurban and urban areas, respectively. These values were lower than Orge River in France [56]. Interestingly, these concentrations were comparable to Indrawati (0.12 μg/L) and Dudh Koshi (0.8 μg/L) which are remote rivers of Nepal with limited anthropogenic pressure in the surroundings and the only source of pollutants is long range transport [32]. Similarly, the concentration of Ni was slightly lower in the Bagmati compared to the Indrawati and Dudh Koshi indicating that there is limited source of cobalt and nickel in the Bagmati River [32]. Furthermore, the concentration of Mn, Co, Ni, Zn, and Cd was lower in our study compared to Guamaxung-chu near Lhasa [58], which is a stream with high impact of mining activities, indicating that the elements like Mn, Co, Ni, Zn, and Cd are more influenced by mining than municipal waste. Previous studies [15, 20, 22] have suggested

Table 3: Variation of average concentration (expressed in μg/L) of the elements in three sections of the Bagmati River basin within the Kathmandu Valley.

	Detection limit	Headwater				Semiurban				Urban			
		Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD
Li	0.024	1.98	0.47	0.98	0.50	2.35	0.28	1.18	0.62	3.00	0.60	1.66	0.72
Be	0.004	0.05	0.01	0.02	0.01	0.06	0.00	0.03	0.02	0.06	0.00	0.03	0.02
Sc	0.012	6.29	2.63	4.68	1.05	7.49	1.68	4.52	1.71	7.99	1.83	5.37	2.01
Ti	0.064	8.02	1.59	5.13	2.07	29.00	2.00	11.29	7.95	39.90	7.03	21.64	10.70
V	0.007	1.83	0.28	1.21	0.55	3.74	0.26	1.28	1.05	2.50	0.65	1.63	0.58
Mn	0.005	29.60	0.52	11.05	10.54	257.00	23.00	95.97	77.66	233.00	70.50	158.71	56.58
Cr	0.03	4.99	0.75	2.90	1.41	20.90	0.63	8.67	8.01	29.80	1.00	17.27	8.98
Co	0.008	0.22	0.04	0.12	0.06	0.73	0.18	0.42	0.20	0.86	0.28	0.58	0.19
Ni	0.017	0.52	0.02	0.29	0.20	2.63	0.33	1.20	0.75	4.13	0.93	2.18	1.06
Cu	0.079	3.60	0.18	1.25	1.25	20.80	0.58	3.96	6.38	36.60	1.27	11.29	9.10
Zn	0.034	13.60	4.14	6.51	3.33	40.90	6.02	12.71	10.74	96.70	7.13	37.05	25.25
Ga	0.003	0.08	0.01	0.04	0.02	0.17	0.03	0.08	0.04	0.24	0.06	0.13	0.05
Rb	0.005	3.09	0.51	1.85	0.89	31.60	1.65	9.58	9.52	48.70	6.20	22.98	15.55
Y	0.0002	0.28	0.01	0.14	0.10	0.42	0.02	0.20	0.13	0.58	0.11	0.29	0.14
Nb	0.002	0.02	0.01	0.01	0.01	0.08	0.00	0.02	0.02	0.09	0.01	0.04	0.02
Mo	0.002	0.16	0.04	0.09	0.04	0.68	0.06	0.26	0.22	1.17	0.19	0.49	0.29
Cd	0.003	0.02	0.00	0.01	0.01	1.21	0.00	0.20	0.43	2.42	0.02	0.38	0.62

that the Bagmati River is one of the most polluted rivers in the world; however, the concentration of some heavy metals is lower than Seine River, Korotoa River, and Orge River mostly because of differences in the industrial inputs. The major anthropogenic sources of the Bagmati are untreated domestic waste, urban development, landfill sites along the bank of the river, and some small scale industrial activities.

The concentration of all the measured elements in the main stream of Bagmati River showed an increasing trend with distance for 25 km from the first sampling site. However, for the samples downstream, the elemental concentration did not show any specific pattern mainly due to the variability in input of chemical load from other tributaries like Tukucha, Bishnumati, Balkhu, and also inputs from domestic and industrial effluents. Figure 3 shows that the elements concentration was very low at Guheshwori (BG-6). The elemental concentration reaches very low values mainly because of the presence of water treatment plant (WTP) just before the sampling point. This water treatment plant was established because of the presence of holy Hindu temple named Pashupatinath. The concentration of elements starts to increase and the highest peak for all the elements was found near the Kritipur (below the suspension bridge). This may be due to the presence of dumping site in the area. The concentration of elements reduces when it reaches Chovar, the exit of Bagmati River from the Kathmandu Valley suggesting the high gradient as the river passes through a small channel, increasing the flow velocity, hence resulting in low residence time of the elements. In general, the concentration of elements shows an increasing trend along the river channel downstream. The population density is generally high in lower section of the basin, indicating population density as the major factor for elemental concentration.

3.3. Contribution of Chemical Load from Each Tributary to Main Stream. Samples from six tributaries before the confluence to the main stream were observed in order to identify the contribution of chemical load to the main stream. As the tributaries Dhobhi Khola and Bishnumati flow through highly urbanized and densely populated areas of Kathmandu Valley, the elemental concentrations were high. The average concentration of elements such as Mn, Cr, Ni, Cu, Zn, Rb, Mo, and Cd was highest in the Dhobhi Khola followed by Bishnumati. Similarly, for major ions, Cl^-, SO_4^{2-}, Na^+, and NH_4^- were highest in the Dhobhi Khola whereas F^- and NO_3^- were highest in the Bishnumati. The elemental and ionic concentrations were relatively lower in the Bagmati and Manohora. Therefore, the elemental and the major ions concentrations were found to be high in the section with high population density, suggesting the major sources were from anthropogenic inputs into the river system.

3.4. Enrichment Factor and Source Identification. The EF of Bagmati River has been shown in Figure 4. The elements showed substantially different EF; lowest value was detected for Ga (0.133, 0.199, and 0.22) and highest for Cd (3755.29, 38007.99, and 59322.45) in headwaters and suburban and urban sections of the river, respectively. The elements can be divided into three groups: the first group includes nonenriched elements (EF < 4) such as Be, V, Mn, Cr, Co, Zn, Ga, Rb, and Y in headwater, Be V, Co, Ga, Rb, and Y in semiurban areas, and Be, V, Co, and Y in urban areas indicating crustal origin. The second group has intermediately enriched elements (EF between 4 and 10) such as Zn in headwater, Mn, Cr, Cu, and Zn in semiurban areas, and Mn, Cr, and Rb in urban areas. The third group has highly enriched elements (EF > 10) such as Sc and Cd in

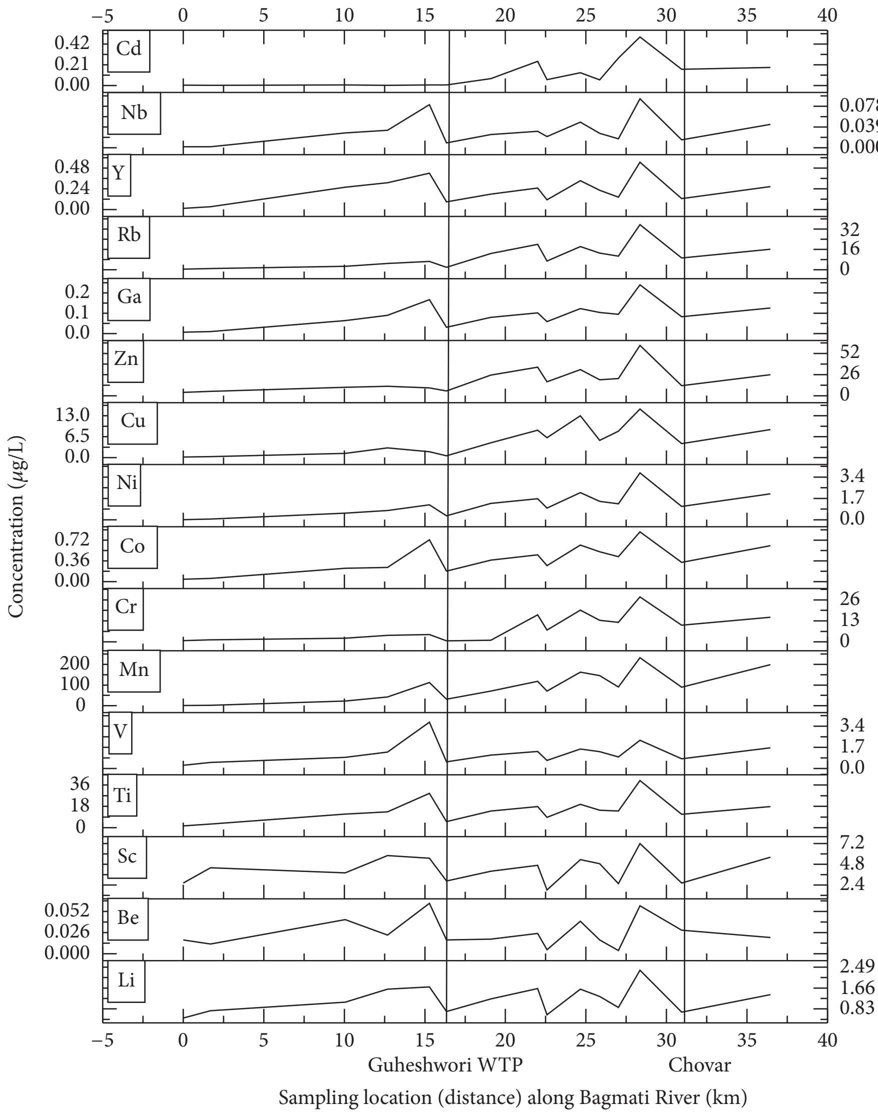

Figure 3: Changes in chemical composition of the Bagmati River from Sundarijal (headwater) to the area downstream (urban area) about 37 km at Khokana, within the Kathmandu Valley, where the concentration of elements is expressed in μg/L.

headwater and semiurban areas and Sc, Cu, Zn, and Cd in urban areas indicating anthropogenic origin. The EF of Cd was extremely high in all the samples. Higher Cd value might have been attributed to industrial activity, fuel burning, and traffic [59–62] and also leachates from defused NI-Cd batteries and Cd plated items. The other highly enriched elements (e.g., Sc, Zn, and Co), were also highly enriched in urban section compared to the headwaters. Such a result may be because of high human population in urban areas where the major role is played by sewage effluent, untreated domestic waste, industrial activities, mining, traffic pollution, and landfill sites at the river banks [63, 64]. Similarly, Mn was intermediately enriched in semiurban and urban section of the Bagmati river basin in Kathmandu Valley. The sources of Mn could be from combustion of unleaded gasoline and industrial activities [65].

Furthermore, PCA analysis was applied for the results of trace elements from the Bagmati River water to understand the elemental associations and their origins based on factor loadings [36, 66, 67]. Three principal components (PCs) were extracted from 17 elements. The PC1 has high loadings of Nb, Y, V, Be, Ga, and Ti; PC2 has Mn, Co, Ni, Cr, and Mo; and PC3 has Cd, Cu, and Zn (Table 4). The total principal component together explained 91% of variance (PC1, 69.3%; PC2, 12.83%; and PC3, 8.8%). The elements in the first component are from the weathering of catchment rocks and soils mainly due to construction of roads and buildings beside the river. Construction of roads beside the river has become very popular in the city. The source of V may be from tar which is used for the construction of roads. All elements in PC2 (Mn, Co, Ni, Cr, and Mo) are potentially harmful metals. High concentration of these metals is believed to be associated with anthropogenic origin partially due to discharge of untreated sewage into the river water while some are from the garment, carpet, and other factories. These elements could also have originated from burning of

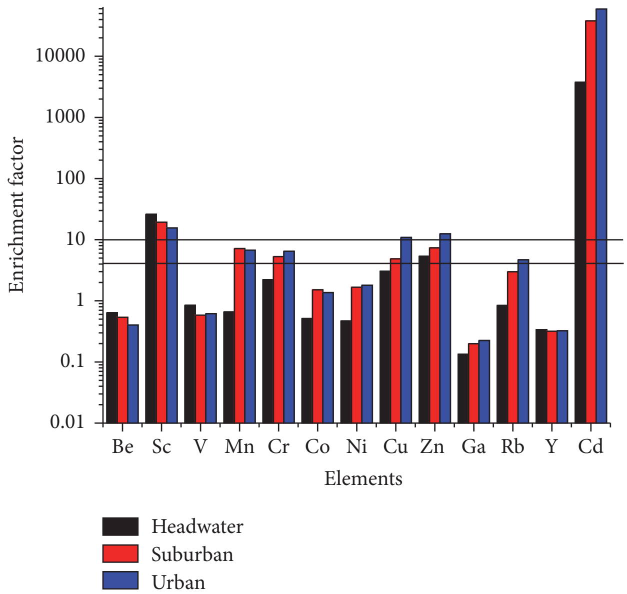

FIGURE 4: Average enrichment factor of trace elements in the water of Bagmati River basin presented as three sections: headwaters and suburban and urban areas within the Kathmandu Valley.

TABLE 4: Principal Component Analysis (PCA) of elements in the Bagmati River basin within Kathmandu Valley.

Elements	Component		
	1	2	3
Nb	**.880**	.389	.050
Y	**.880**	.309	.211
V	**.868**	.115	.209
Be	**.865**	.010	.276
Ga	**.743**	.573	.303
Ti	**.716**	.501	.429
Mn	.297	**.850**	.250
Co	.532	**.783**	.198
Ni	.309	**.770**	.540
Cr	.222	**.763**	.566
Mo	.047	**.723**	.485
Cd	.132	.208	**.817**
Cu	.251	.459	**.771**
Zn	.342	.494	**.738**
Rb	.221	.629	.725
Li	.523	.350	.674
Sc	.550	.181	.638
% of variance	69.31%	12.83%	8.79%
Eigen value	11.79	2.18	0.99

fossil fuels and solid waste dumping [32, 59, 60, 68, 69]. The elements in PC3 (Cd, Cu, and Zn) can be attributed to anthropogenic origin. The sources of Cd are generally from coal combustion for heating purpose and also from vehicular emission. Other possible sources of Zn, Cd, and Co may be electronic waste and batteries that are disposed into the river system. A very good correlation between Zn and Cu (r^2 = 0.96) as well as Cu and Cd (r^2 = 0.85) further indicates their similarity of sources.

3.5. Water Quality and Ecological Risk Assessment. The water of Bagmati River is considered holy where many people bathe, drink, or wash their body, besides using the area for cremation, especially near some temples on the banks of the river. The HQs of trace metals for local residents and devotees visiting the Pashupatinath, Guhyeshwori, and many other temples located on the banks of the Bagmati River within the Kathmandu Valley are summarized in Table 5. Eleven metals were considered for HQ analysis because of their available Rfd *ingestion* and *dermal* values. HQs > 1 suggest that the water could possibly have deleterious effect on the residents' health [70]. Therefore, $HQ_{ingestion}$ of heavy metal in the study area was studied and found in the order of Sb > Mn > Cr > V > Co > Cd > Cu > Zn > Ni > Li > Mo. In this study, the $HQ_{ingestion}$ and HQ_{dermal} values were found to be less than unity, which indicates that the water may have little or no health effect; however for some samples of Sb and Mg, the values were close to unity. Among all the elements studied, the highest $HQ_{ingestion}$ was found for Sb followed by Mn, which was similar to that of Yellow river delta [46] and drinking water in Karachi [70] but was however higher than the study conducted in a playground of Madrid [71], some rivers of China [72, 73], and streams in northern Pakistan [45]. $HQ_{ingestion}$ for Cr was also higher compared to other studies form China, Pakistan, and other parts of the world. Similarly $HQ_{ingestion}$ for Cd was higher than the studies conducted in the Yangtze River in Nanjing [44], Madrid [71], Dan River [72], and Upper Han [73] but was however lower than Yellow river delta [46] and Besham area in northern Pakistan but comparable to Jilal-dubair and Alpuri of Pakistan [45]. Even though the overall $HQ_{ingestion}$ and HQ_{dermal} values are less than 1, special attention should be paid to elements like Sb, Mn, and Cr, and strict measures should be taken to maintain a healthy aquatic ecosystem for this holy river in the heart of Kathmandu.

4. Conclusion

This study provides the detailed information on water quality of the Bagmati River and its tributaries within the Kathmandu Valley. Since the origin of all the tributaries of Bagmati River is within the Kathmandu Valley, the river water quality is mostly determined by human activities within the valley. Most of the elements and ions showed higher concentration in the urban section of the river compared to the headwaters and exhibited a dependency with the population density adjacent to the river. Meanwhile, natural governing factor like weathering of soil parent materials seems to play insignificant role. The concentration of nitrate and sulfate in most of the samples in the lower reaches of the river was found to be very low due to depletion of dissolved oxygen. The concentration of Mn, Cd, Cr, Co, and Zn was particularly higher in urban and semiurban section of the river. Cd, Co, and Zn were also highly enriched indicating anthropogenic origin. The source of V and many other elements can be attributed to the construction of roads beside the river mainly due to

Table 5: Reference dose and hazard quotient for each element.

Elements	$RfD_{ingestion}$	RfD_{dermal}		$HQ_{ingestion}$	HQ_{dermal}
			Max	$4.11E-03$	$6.90E-06$
Li	20	10	Min	$3.84E-04$	$6.44E-07$
			Mean	$1.87E-03$	$3.13E-06$
			Max	$1.02E-01$	$8.61E-03$
V	1	0.01	Min	$7.07E-03$	$5.94E-04$
			Mean	$3.92E-02$	$3.29E-03$
			Max	$3.52E-01$	$7.39E-03$
Mn	20	0.8	Min	$7.16E-04$	$1.50E-05$
			Mean	$1.45E-01$	$3.04E-03$
			Max	$2.72E-01$	$9.14E-02$
Cr	3	0.015	Min	$5.75E-03$	$1.93E-03$
			Mean	$1.04E-01$	$8.89E-03$
			Max	$7.89E-02$	$2.65E-02$
Co	0.3	0.0003	Min	$3.93E-03$	$1.32E-03$
			Mean	$3.89E-02$	$3.51E-02$
			Max	$5.66E-03$	$3.52E-06$
Ni	20	5.4	Min	$3.29E-05$	$2.05E-08$
			Mean	$2.00E-03$	$1.24E-06$
			Max	$2.51E-02$	$7.02E-05$
Cu	40	12	Min	$1.22E-04$	$3.41E-07$
			Mean	$4.70E-03$	$1.32E-05$
			Max	$8.83E-03$	$2.23E-05$
Zn	300	60	Min	$3.78E-04$	$9.53E-07$
			Mean	$2.10E-03$	$5.30E-06$
			Max	$6.41E-03$	$1.42E-05$
Mo	5	1.9	Min	$2.03E-04$	$4.48E-07$
			Mean	$1.82E-03$	$4.02E-06$
			Max	$1.33E-01$	$1.11E-02$
Cd	0.5	0.005	Min	$1.10E-04$	$9.21E-06$
			Mean	$1.29E-02$	$1.08E-03$
			Max	$8.29E-01$	$3.48E-02$
Sb	0.4	0.008	Min	$4.47E-02$	$1.88E-03$
			Mean	$2.24E-01$	$9.42E-03$

the use of tar, cement, and other raw materials. Primary health risk assessment for trace metals indicated that the surface water in Bagmati River has low risk; however, some metals like Sb and Mg were close to unity indicating possible threat. Furthermore, this study could be used as reference for further research as this paper provides the first health risk assessment of trace metals for urban river in Nepal. At a glance, the water quality of Bagmati River is governed by anthropogenic sources such as sewage effluents, industrial waste, and dumping of solid waste besides the river. Overall, the Bagmati River is polluted and is comparable with some of the most polluted rivers around the world and needs restoration.

Competing Interests

The authors declare no conflict of interests regarding the publication of this paper.

Acknowledgments

This study was supported by the Strategic Priority Research Program (B) of the Chinese Academy of Sciences (XDB03030504), the National Natural Science Foundation of China (41225002), and the Academy of Finland (Decision no. 268170). The authors would like to thank Muhammad Adnan for helping them in Figure 1.

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