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COMPARATIVE ASSESSMENT OF WATER QUALITY IN THE BAGMATI RIVER BASIN, NEPAL

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ABSTRACT

Kathmandu, the capital city of Nepal is one of the most populated destinations of the country. The water pollution remains a challenging issue for the sustainable development in the valley despite several pollution control devices, awareness-raising and policy measures. During monsoon period 2018, surface water samples were collected from 10 sites of the Bagmati River and its tributaries within the valley to evaluate the water quality. The different physico-chemical parameters were determined to assess pollution along a 26.5 km stretch between Sundarijal Dam to Balkhu Bridge of the Bagmati River and its selected tributaries. The Electrical Conductivity (EC) ranged from 33-816μS/cm while turbidity ranged from 0.3- 981 NTU and Total Dissolved Solids (TDS) ranged from 16 to 612 mg/l. The ionic concentrations were higher in the lower sections where the population density is high compared to the head waters. The high value of TDS and low value of Dissolved Oxygen (DO) in the lower belts of rivers were due to large inputs of waste water, uncoordinated rapid urban expansion, inadequate waste water treatment facilities and organic loads caused by anthropogenic activities. A comparative study for the water quality variables in the urban areas showed that the main river and its tributaries were equally polluted. From water analysis, downstream sites showed contamination and comparatively polluted among the tributaries and Bagmati River. There is a need to take action plan against polluted site for sustainability of aquatic health of the riverine environment and to address the river for its longer life both by public and government sectors.

Key words: Surface water, physico-chemical parameters, quality monitoring, pollution, anthropogenic activities, Kathmandu.

INTRODUCTION

Water quality can be regarded as a variable network such as pH, oxygen concentration, temperature, etc. and any changes in these physical and chemical variables can affect aquatic biota in various ways. The Bagmati River is the heart of the valley and one of the most important rivers of urban areas in Nepal. The river has immense importance in terms of drinking, irrigation, small scale hydroelectricity, industrial, recreational, cultural and religious uses and it is not merely a river but a symbol of civilization. The flow of waste water into the Bagmati River and its tributaries are mainly fed through domestic waste, storm-water run-off and

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industrial waste routes. In the valley, the river is utilized as a sewer for domestic and industrial waste. The pollution of water in Kathmandu is a serious concern for its sustainable development (Shrestha *et al.*, 2015; Regmi *et al.,* 2014).The major tributaries of the river system, Bagmati have been destroyed by pollution; the water is black and poisonous, crawling with flies and contaminated with sewage (Kumar, 1994). In absence of proper plans the river's environment is under intense degradation for last couple of decades. The degradation thus depicts the degradation of the civilization within the river valley. The other major aspect is the religious and social importance of the river. 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 (Rimal *et al.*, 2017), 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. 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. (Rimal *et al.*, 2018).

The valley comprises three districts namey 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 population Census 2011. 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 (ENPHO, 1997; DHM, 2008; Bhatt and Mc Dowell, 2007; Kannel *et al.*, 2007a; Bhatt and Gardner, 2009; Bhatt *et al.*, 2014). In this paper we focus on the contribution of chemical load from the tributaries of Bagmati into its main stream. However, there is a lack of information on the chemistry of the tributaries of Bagmati River, their possible sources within the valley. This study, for the first time, provides the detailed information regarding the hydrochemical status of the Bagmati River and its tributaries under the context of rapid urbanization, and socioeconomic development in the valley.

MATERIALS AND METHODS

Study area

This study was carried out in the Bagmati River Basin, Kathmandu valley Nepal. It is a medium sized river basin with a catchment area of 3700 km^2 at the Nepal-India border. It originates from the Shivapuri hills in the Mahabharata range of mountains and flows down south into the Terai plains before crossing the Indo- Nepal border. The Bagmati Basin lies between the latitudes 26°23'18" N and 27°49'11" N and longitudes 85°1'25" E and 85°57'10" E. The sampling sites of Bagmati River and its tributaries were selected randomly by collecting a total of 10 water samples (one from each site) (Figure 1). Moreover, the sampling basis of the study sites was on the basis of difference in substratum, topography, abiotic and biotic factors and level of water pollution. The samples were collected during monsoon season in September 2018 and the characterization of these sampling points is given in Table 1.

Sampling

The samples were taken in sterilized bottles of a liter capacity. 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. After the collection, the water samples were acidified immediately with adding 2 ml concentrated nitric acid (HNO_3) as described by APHA (1998). The sampling bottles were labeled and delivered on the same day to laboratory. The sampled bottles were packed inside the double polyethylene zip-lock bags and kept in refrigerator at 4°C until the laboratory analysis (Paudyal *et al*., 2016).

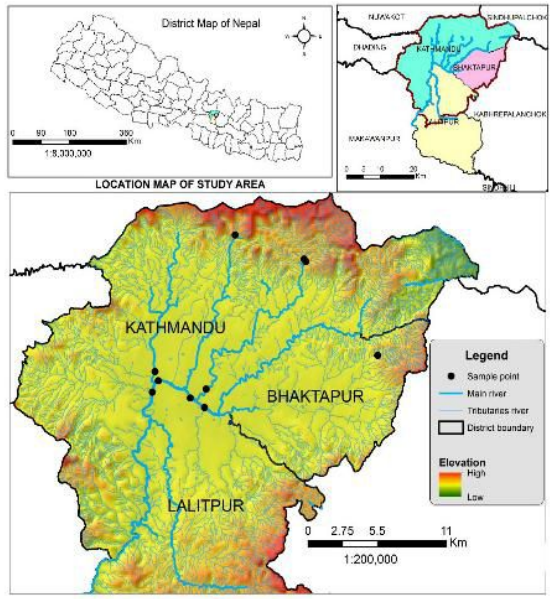

Figure 1. Location map of study area

Table 1. Description of study sites in Bagmati and its tributaries, Kathmandu, Nepal

ID	Sample code	Location	Latitude	Longitude
S1	Mahadev Khola intake	Bhaktapur	27°42'17.50"N	85°28'56.13"E
S2	Sundarijal Khola (Okhreni side)	Kathmandu	27°46'23.74"N	85°25'33.49"E
S3	Sundarijal Khola (before Sundarimai temple)	Kathmandu	27°46'17.20"N	85°25'37.77"E
S4	MuhanPokhari Budhanilkhantha,	Kathmandu	27°47'29.89"N	85°22'15.39"E
S5	Hanumante Khola(near Balkumari Bridge)	Kathmandu	27°40'23.97"N	85°20'29.73"E
S6	Bagmati River (near Shubhidanagar, Tinkune)	Kathmandu	27°41'9.79"N	85°20'36.34"E
S7	Bagmati River (near Shankhamul Bridge)	Kathmandu(after mixing)	27°40'49.24"N	85°19'49.42"E
S8	Bagmati River (Black Suspension Bridge ,Teku)	Kathmandu	27°41'34.80"N	85°18'18.48"E
S9	Bishnumati River (near Huymat Badhashala)	Kathmandu	27°41'58.04"N	85°18'9.71"E
S10	Bagmati River (before mixing at Sanepa-Balkhu Bridge)	Kathmandu	27°41'7.01"N	85°17'59.71"E

Note: 'S' represents sampling site.

Laboratory analysis

In order to assess the water quality, present work has intensively examined the major physico-chemical parameters at the site and laboratory. Before sampling for chemical test, proper cares was taken to make the container neat and clean to avoid the effects of impurities. The physiochemical parameters of the collected water samples were analyzed as per the standard methods (APHA, 1998). The water temperature, pH, EC and TDS were detected using a multi-parameter water quality monitoring instrument (HANNA) whereas turbidity was monitored by Turbidity meter, dissolved oxygen (DO) was determined by modified Winklers method instrument on the site. Likewise, chloride was determined by using argentometric method and hardness was measured by the complexometric titration (EDTA) method. Similarly iron and arsenic were detected in accredited laboratory of National Food and Feed Reference, Nepal, by AAS method.

RESULTS AND DISCUSSION

The status of hydro-chemical parameters in the head waters and urban stretch of river for all samples are presented in the Table 2. The chemical load in the river water and its tributaries increases with increasing population in the core urban areas due to the excessive effluents from the major settlements (Table 2).

Table 2. Physicochemical characteristics of Bagmati River and its tributaries in Kathmandu.

Parameters	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean
Temperature	18.3	18	18.5	19.3	16	18.3	17.8	18.5	19.6	19.7	18.40
EC	58	38	33	48	475	428	387	551	816	645	347.90
TDS	29	19	16	22	347	356	275	397	612	458	253.10
pH	7.2	7.21	7.21	6.98	6.5	7.3	7.54	7.14	8.94	8.45	7.44
DO		5.93			2.17	3.14	3.14	2.95	2.75	2.41	3.21
Turbidity	8.2	0.3	1.8	3.4	981	214	256.8		285.6	448	244.34
Iron	0.27	<0.2	<0.2	0.34	-	-	-	-	-	-	0.30
Hardness	39	42	24	48	142	87	83	102	161	134	86.20
Arsenic	<5	<5	<5	<5	-	-	-	-	-	-	
Chloride	85.2	71	198.8	213	497	653.2	568	596.4	937.2	610.6	443.04

All units in mg L^{-1} (except EC: $\mu S\ cm^{-1}$, Temperature °C, Turbidity: NTU, Arsenic: $\mu g/L$ and pH)

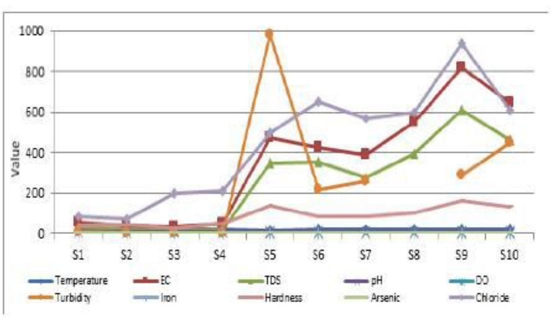

Figure 2. Spatial variations of hydro-chemical parameters in the Bagmati River and its tributaries, Kathmandu.

Naturally water bodies show changes in temperature daily and seasonally due to different activities that can contribute to changes in surface water temperature. Time of day, weather, terrain, and incoming tributaries, all influence the water temperature naturally but pollution and the subsequent chemical reactions can also affect its status. The temperature is one of the important parameters of the water and is important for its effects on the chemical and biological reactions in the water (Trivedy and Goel, 1986). As the temperature regulates physicochemical and biological activities (Kumar *et al.,* 1996), it has vital role in determining the chemical, physical and biological status of the riverine health. Also, the warmer water generally increases the rate of growth of plants and algae and their interactions with many aquatic animals. A higher temperature has depleted solubility of dissolved oxygen in water, and reduced its concentrations. The warmer water obviously accelerates the decay of organic matter contents in the river (Asthana and Asthana, 2003). The temperature of water sample taken from Bagmati River and its tributaries were ranged from 16°C - 19.7°C.

pH is the measure of acidity or alkalinity (APHA,1998). It has a major role in determining the speciation of metals in aqueous system and the biotic life both in lentic and lotic environments. Higher pH leads to precipitate the ionic species of heavy metals to the sediment (Pradhanang, 2010). The pH values are usually changed by the presence of organic and inorganic solutes together with reaction of carbon dioxide (Wetzel, 1975). The pH of the Bagmati River water was found to be in the range of 6.5 at Hanumante Khola (S5) to 8.94 at Bishnumati River (S9).The sample collected from the S5 i.e., Hanumante Khola is the most polluted section of the Bagmati River basin. However the range of pH values along the Bagmati River system is within a typical river water value (4.5-8.5), as suggested by (Mc Cutcheon *et al.*,1992). However the pH value of water collected from Bishnumati River exceeds this typical river water pH range.This indicates that the pH of the Bagmati River water is not critical and the water is not objectionable for variety of purposes including irrigation.

Electrical conductivity (EC) qualitatively reflects the status of inorganic pollution and is a measure of total dissolved solids and ionized species in the waters (Trivedy and Goel, 1986). The ionic strengths were higher in the lower sections where the population density is high compared to the head waters this could be due to the less dilution and high pollution load in the downstream regions (Pant *et al.,* 2017). When evaporation takes place from the surface of water then the concentration of dissolved solid in the remaining water increases and leads to the increase in conductivity. The conductivity of the Bagmati River water was found to be in the range of 33 µS/cm at Sundarijal Khola (S3) to 816 µS/cm at Bishnumati River (S9). The lowest conductivity was found at Sundarijal Khola after dam before Sundarimai temple which is one of the main head waters of Bagmati River with high flow rate. On the contrary, high conductivity was found in the urban section of Bagmati River as well as its tributaries (S10), (S9), (S8), (S7), (S6) and (S5).The conductivity of water was found to increase from headwaters to the downstream due to the increase intensities of anthropogenic activities downstream.

The TDS of the Bagmati River water were found to be in the range of 16 mg/L at Sundarijal Khola (S3) to 612 mg/L at Bishnumati River (S9). The lowest TDS was found at Sundarijal Khola after dam before Sundarimai temple which is one of the main head waters of Bagmati River with high flow rate. On the contrary, high total dissolved solid was found in the urban section of Bagmati River as well as its tributaries i.e., at the sites of (S10), (S9), (S8), (S7), (S6) and (S5). The TDS of water was found to increase from headwaters to the downstream due to the increase intensities of anthropogenic activities in the core urban areas. The high value of TDS in the lower belts of rivers is due to large inputs of waste water, rapid urban expansion, inadequate waste water treatment facilities and organic loads caused by anthropogenic activities like industrial activities, municipal waste water and road construction besides the rivers.

Generally, DO value should be greater than 4 mg/L and drinking purpose 6 mg/L for sustaining the healthy aquatic ecosystem and metabolic activities of microorganism (Onozeyi, 2013). The higher value of DO contents was found in headwaters of the Bagmati River and it was decreased to the downstream river indicating water was critical with extremely very low values within the Kathmandu Valley river stretch. As the river passes through the city core area, DO contents become minimum and fresh water aquatic lives may not be possible in such low quality river water. The high concentrations of organic pollution due to anthropogenic inputs like industrial activities, municipal waste water and road construction besides the rivers is responsible to lower the DO in the River water of urban area.

The turbidity of the Bagmati River water was found to be in the range of 0.3 NTU at Sundarijal Khola above dam of Okhreni side (S2) to 981 NTU at Hanumante Khola near Balkumari Bridge (S5).The high turbidity must be due to high sediments loading in the downstream sites.

The hardness of water depends on the dissolved minerals present in it which determines water quality for all purposes. Calcium and magnesium are among the most common elements found in natural waters and their salts are an important contributor to the hardness of water.The total hardness in water is due to the sum of concentrations of alkaline earth metal ions such as Ca^{2+}, Mg^{2+} (Fulvio and Olori, 1965). The values for calcium were associated with sewage and weathering, rich caustic rocks or sedimentation materials (Akan *et al.,* 2008). The present study showed that the total hardness ranged from 24 mg/L at Sundarijal Khola below dam before Sundarimai temple (S3) to 161mg/L Bishnumati River near Huymat Badhashala (S9). The total hardness of water was found to increased from headwaters to the downstream due to the increased intensities of anthropogenic activities downstream. The ionic concentrations of Ca^{2+} and Mg^{2+} were higher in the lower sections where the population density is high compared to the head waters.

The content of chloride in water found most important indicators of pollution. The higher amount of chloride reacts with sodium making the water salty and also increases TDS values of water (Taylor, 1949). The high amount of Cl^- ions is mainly from anthropogenic sources (Roy *et al*., 1999; Meybeck and Helmer, 1989). Moreover, the high value of Cl^- concentration is an indicator of unforested land and is considered as good indicator of human disturbance (Herlihy *et al*., 1998). The chloride is sourced from domestic effluents like fecal deposition and household sewage, roads, and industries in the river system. The chloride contents in water may be due to the minerals like mica, apatite and from the liquid inclusions through the igneous rocks, including some anthropogenic signature (Das and Malik, 1998). The Cl^- ions concentrations of the Bagmati River water was found to be in the range of 71 mg/L at Sundarijal Khola above dam of Okhreni side (S2) to 937.2 mg/L at Bishnumati River (S9). It has been revealed that the concentrations of Cl^- are higher in urban stretch than in head waters due to intense anthropogenic sources in the core city area.

The arsenic and iron concentrations were considered because of their toxicity and threat to the human life and environment (Purves, 1985). They are mainly sourced from industrial effluents, leaded petrol, and leaching of metal ions from the soil into rivers by various processes including acid rain. The level of arsenic concentration was found in lower than the generic standard (0.2 mg/L) in all the samples. The lower concentration might be due to the dilution of the effluents in all the samples. The result revealed that the concentration of arsenic in water sample of head waters lies below 5μg/L indicating the head water of Bagmati River is less polluted. The iron content was measured only at head water section of Bagmati River and its concentration ranged from < 0.2 to 0.34 mg/L.The result revealed that the iron content was also beyond the desired limit (<0.3 mg/L) with Muhan Pokhari (Budhanil khantha) being highest among these four sites.

Contribution of chemical load from tributaries to main stream

Samples from four 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 Hanumante Khola and Bishnumati flow through highly urbanized and densely populated areas of Kathmandu valley, the elemental concentrations were relatively higher. Similarly, major ions Cl^-, and Ca^{2+} and Mg^{2+} hardness were highest in the Bishnumati River near Hyumat Badhashala (S9). The elemental and ionic concentrations were relatively lower in the headwater of Bagmati than downstream of river. 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. 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 Hanumante, Bishnumati, and also inputs from domestic and industrial effluents. The concentration of chloride was highest in water sample collected at Bishnumati River near Hyumat Badhashala. This may be due to the presence of dumping site in the area. In general, the concentrations of elements showed an increasing trend along the river channel to the downstream. The population density was generally high in lower section of the basin, indicating population density as one of the major factors for elemental concentrations.

Comparison of water quality between Bagmati River and other major rivers in the Himalaya

The comparative assessment of the physicochemical parameters of Bagmati River of present and past study with the Seti River and Gandaki River is shown in the Table 3. The water quality assessment parameters such as conductivity, chlorides, turbidity, TDS and hardness found to be nearly comparable in Bagmati River now and measurement done in 2007.

The observed data indicates that the nature of water in all rivers was alkaline in nature. The water quality assessment parameters such as co`nductivity, chlorides, turbidity, and hardness found to be high in Bagmati River water within the Kathmandu Valley than to the Seti river water outside the valley indicating more pollution in Bagmati River than Seti River. This fact is further supported by the lesser value of DO in Bagmati than Seti River. It was found that the EC values of the most rivers are more or less comparable; however, the values are relatively higher in the Gandaki and Bagmati River which may be probably due to excess salinity and mineral contents due to anthropogenic inputs

Table 3. Comparison of water quality paramters between Bagmati River and other major rivers in the Himalaya.

Rivers	Temp.	EC	pH	DO	Turbidity	Hardness	Chloride	TDS	Reference
Bagmati	18.40	348	7.44	3.20	244.34	86.20	443.04	188	Present study
Bagmati	12.49	422	7.98	4.12	-	-	-	228	Kannel *et al.*, 2007 a, b
Seti	18.00	166.00	8.00	8.00	81.40	65.00	24.30	90	Pokharel *et al.*, 2018
Gandaki		530	8.27			53.57		269	Pant *et al.*, 2017
Global mean			8			6.40	7.80	120	Gaillardet *et al.*, 1999
WHO limit			6-8.5			150	250	1000	WHO, 2011

Note: All units in mg/L (except EC: µS cm^{-1}, and pH),*some of the TDS calculated from EC.

like more organic pollution and is lowest in Seti River (Figure 3).

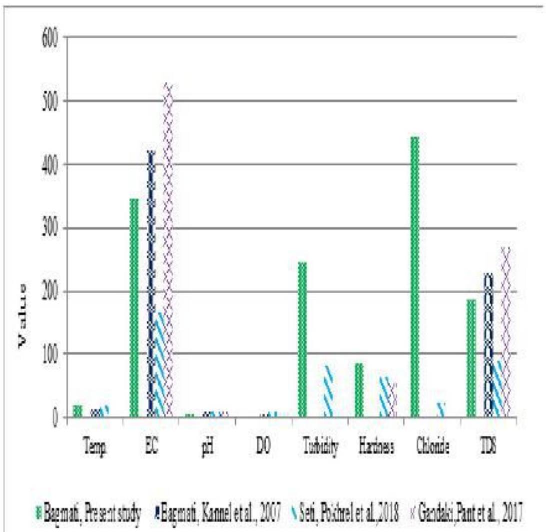

Figure 3. Comparison of water quality parameters among different river systems of Nepal.

The present status for chloride contents of Bagmati River is almost twenty times higher as compared to the Seti River indicating that the household discharges, organic waste from animal origin, and the organic wastes could be elevated in the Bagmati River. It is found that the TDS values of Seti River was relatively lower than other river indicating less extent of natural and anthropogenic inputs in Seti river. The DO value of Bagmati River taken at present and on 2007 for which data are provided indicates that the values are comparable to each other, indicating mild organic pollution. The relatively high values of DO in Seti River are indicative of less polluted nature of water body to some extent. This study provides the detailed information on water quality of the Bagmati River in comparison with other rivers. Also, the water quality in all the rivers is found to be determined by natural and anthropogenic inputs which could be the serious threat and needs restoration of the polluted rivers.

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 Valley, the river water quality is mostly determined by human activities. The Bagmati River in the rural upstream region was relatively clean but heavily polluted in the urban areas due to anthropogenic inputs. Most of the elements and ions showed higher concentrations in the urban section of the river compared to the headwaters and exhibited a dependency with the population density adjacent to the river. In downstream urban areas, the river was heavily polluted with untreated municipal sewage. The result also indicated that water quality is largely unsuitable for any practical purpose in the urban area. Meanwhile, natural governing factor like weathering of soil parent materials seems to play insignificant role. The sewerage system of Kathmandu Valley is of combined type, designed to collect rainwater runoff, domestic sewage, and industrial waste water in the same pipe. At a glance, the water quality of Bagmati River was 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.

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