Research Article

Water quality assessment along the segments of Bagmati River in Kathmandu valley, Nepal

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Abstract

Identification of pollution in the river helps to know the state of the river ecosystem. The study aimed to assess the water quality of the Bagmati River by analyzing the physical and chemical condition and comparing it with national and international standards. The water samples were taken from 10 different sampling sites along the length of the Bagmati River inside Kathmandu Valley, i.e., from Sundarijal to Saibubhanjyang. A total of 30 physical and chemical parameters were examined. The results showed that the pH ranges from 6.0 to 7.5 in different sampling locations. The highest dissolved oxygen (DO) (8.5 mg/L) was found at the upstream while the lowest, i.e., 3.4 mg/L and 3.5 mg/L, was found at the urban core of the valley, i.e., Teku and Thapathali, respectively. The BOD, COD, oil, and grease considerably exceeded the WHO and national generic effluent standard. Most of the heavy metals in the river water were below the range of standard. The concentrations of all pesticides were found below 10 μg/L except heptachlor exoepoxide. The highest concentration of heptachlor exoepoxide (75 μg/L) was found at Balkhu, followed by Thapathali (69 μg/L) and Teku (62 μg/L). The result showed that the middle-urbanized segment, i.e., from Gokarna to Teku, is heavily polluted than the upstream and downstream segments of the river. The results are of great significance for policy formulation and implementation of the ecosystem restoration project of Bagmati River in the Kathmandu valley, Nepal.

Keywords: Bagmati River, Kathmandu valley, Nepal, Water pollution

Introduction

Healthy river ecosystems maintain the structural integrity of their physical, chemical, and biological environment. Meanwhile, they provide ecosystem services through ecological processes and ecosystem function (Shrestha et al., 2019). Nepal is one of the richest countries in the world in the water system (WECS, 2011). Among several river systems in Nepal, the Bagmati River is the principal river in central Nepal, which originates from the Shivapuri range in the north of Kathmandu. The river is fed by springs and monsoon rainfall and drains across the Mahabharat Range to the Gangetic plain (GoN/NTNC, 2009). The Bagmati River basin can be divided into the upper basin, middle basin, and lower basin. The river in the Kathmandu Valley (the upper basin) stretches for 51 km with a catchment area of 678 km² (Shrestha & Tamrakar, 2012). The Bagmati River System not only has immense cultural and economic value for the people of Nepal, but it is also essential for the small-scale hydroelectricity, irrigation, and drinking water source. The river provides most of the city's drinking water from its upstream sources.

About 82% of the water volume is extracted daily from the surface water sources for drinking water supply in the Kathmandu Valley (Dahal et al., 2011). However, the water quality of the river is becoming a challenge because of severe pollution, especially in the downstream regions. Water quality refers to the set of concentrations, speciation, and physical partitions of inorganic and organic substances, including the composition and state of aquatic biota in the water body (APHA, 1998). Thousands of people suffer and die from water and sanitation-related diseases in the world (WHO, 2008). The water is still pristine in the upstream segment, but water qualities deteriorate with the start of the urban area and get heavily polluted across the city core of Kathmandu (ICIMOD, 2007; Pradhan, 1998). The overall water quality is sometimes difficult to evaluate from the limited number of samples and parameters (Chapman, 1992). The primary cause of the river quality deterioration is domestic and industrial effluents, solid waste disposal, washing, bathing, and substrate abstraction (Shrestha et al., 2008).

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Kathmandu Metropolitan City, the only million-plus city in the country, has 9.72% of the national urban population (CBS, 2011). Rapid population growth, expansion of the urban areas, decreased agricultural and forest lands are responsible for the degradation of the Bagmati River (NUDS, 2015). Kathmandu city began to witness a population influx during the 1950s, and the rate increased exponentially after the 1980s (NWCF/NTNC, 2009). Normalized difference vegetation index has also shown risen urbanization in the Kathmandu Valley (Baniya et al., 2018). With the expansion of settlements, the volume of waste entering the river has increased. In 2012, the average municipal solid waste generation was 0.317 kg per capita per day, which is 1,435 tons per day or 524,000 tons per year of municipal solid waste generation in Nepal (ADB, 2013). The current water supply is remarkably lower than the demand in the Kathmandu Valley. In Kathmandu Valley, the water demand is 415.5 million liters per day (MLD) in 2016 and is expected to reach about 482 MLD by 2021. At the same time, KUKL's water supply is 366 MLD in 2016 and expected to increase 481.5 MLD in 2021 (Udmale et al., 2016). People heavily rely on private vendors, deep boring as well as alternative sources (e.g., well water, rainwater harvesting) which supply 50 MLD (MoUD, 2013). The rapid and unplanned expansion of Kathmandu city has left the river biologically dead. The river enters the valley near Sundarijal, after which the water quality starts to deteriorate (ADB, 2013). The river has been used as a dumping site for wastewater (domestic and industrial) and solid waste. Besides waste disposal, the river has been widely used for sand extraction and land encroachment (MoUD, 2015). The squatter settlements at the bank of the river add the organic load and pollutants to the river. During the last three decades, the discharge of Bagmati River has been observed to be decreasing except for pre-monsoon season (Dhital et al., 2013). The impacts of water quality deterioration have negative consequences on the aquatic eco-system, health, cultural, and aesthetic values.

Previous studies showed that water quality has deteriorated in the Bagmati River, mainly in the urbanized areas (Mishra et al., 2017; Paudyal et al., 2016). The concentration of the major ions and trace metals are reported in the urbanized section of the Bagmati River (Bhatt et al., 2013). A very few studies deal with the water chemistry of the Bagmati drainage network within Kathmandu Valley (Bhatt & Gardner, 2009; Dhital et al., 2013; DHM, 1996, 2008; ENPHO, 1997; ITECO, 2003; Kannel et al., 2007; Karna & Harada, 2001; Mishra et al., 2017; Paudyal et al., 2016). However, these studies have used limited parameters and focused only on nutrients, major ions, and trace metals. The results of water quality analysis revealed that the Bagmati River's water within the Kathmandu Valley is not suitable for drinking, recreation, and irrigation purposes (Stanley, 1994), which has been more deteriorated in the present condition. The length of sewerage in Kathmandu Metropolitan City is 1320 km, where the urban population per kilometer sewerage service is 763 (MoLD, 2011). The poor management of drainage networks and direct discharge of sewage into the water sources are the primary cause of Bagmati water pollution. The estimated Biological Oxygen Demand (BOD) in the Kathmandu Valley from industries and people is about 42 tons/day (Paudel, 1998). In most parts of the river, BOD is more than 15 mg/L (Mishra et al., 2017). In the dry season, the Bagmati River drains only 40% of the daily BOD generation, and the remaining is retained in the valley itself which is a major source of land and ground water pollution. The assessment of physical and chemical status of the river provides recent updates and basis for framing the appropriate pollution control measures. This study is intended to assess the water quality of the Bagmati River based on physical and chemical parameters by point sampling from its source to the end below 1.5 km down from Chovar in different length interval. In addition, the physical and chemical environmental parameters of Bagmati River are compared with the national and WHO standard.

Materials and Methods

This study has been conducted using laboratory experiments. The physical, chemical and pesticide characteristics were investigated during the pre-monsoon season in 10 different sites from upstream of the river (source of the river) to the downstream (lower end) of the Kathmandu city. Water samples were collected in sterilized plastic bottles with an airtight cap. During the sampling, air bubbles were avoided entirely from entering the sampling bottles. The samples were safely transported to the laboratory. The pH and Total Suspended Solid (TSS) were measured in the field.

Study area

The study area, Kathmandu Valley, is in the hilly region of Nepal at the geographical location of 27° 32' 13" to 27° 49' 10" N and 85° 11' 31" to 85° 31' 38" E with three administrative districts (Kathmandu, Bhaktapur, and Lalitpur). The Bagmati River originates from the north of Kathmandu, flows across the valley draining from the Lalitpur district on the south (Fig. 1). The water sampling was conducted from Sundarijal to Saibubhanjyang in the pre-monsoon season. The sampling sites were selected based on land use and river morphology of the Bagmati River. The ten sampling points along the river are Sundarijal, Gokarna, Tilganga, Gairigaun, Shankhamul-Dobhan, Thapathali, Pachalighat (Teku), Balkhu, Chobhar, and Saibu-bhanjyang (Fig. 1).

The river stretch of the study area was divided into upstream (Sundarijal and Gokarna), mid-stream (Tilganga, Gairigaun, Shankhamul-Dobhan, Thapathali, Pachalighat, and Balkhu), and downstream (Chobhar and Saibu-bhanjyang) of the Bagmati River within the Kathmandu Valley. Sundarijal and Gokarna are located at forest areas in the headstream of the river where the urban influences are minimal. Tilganga, Gairigaun, Shankhamul-Dobhan, Thapathali, Pachalighat, and Balkhu sampling sites are located at the mid-stretch, i.e., downtown (urban) core of the Kathmandu city. The remaining Chobhar and Saibu-bhanjyang are in the suburban areas with sparse settlements and agricultural lands downstream of the river.
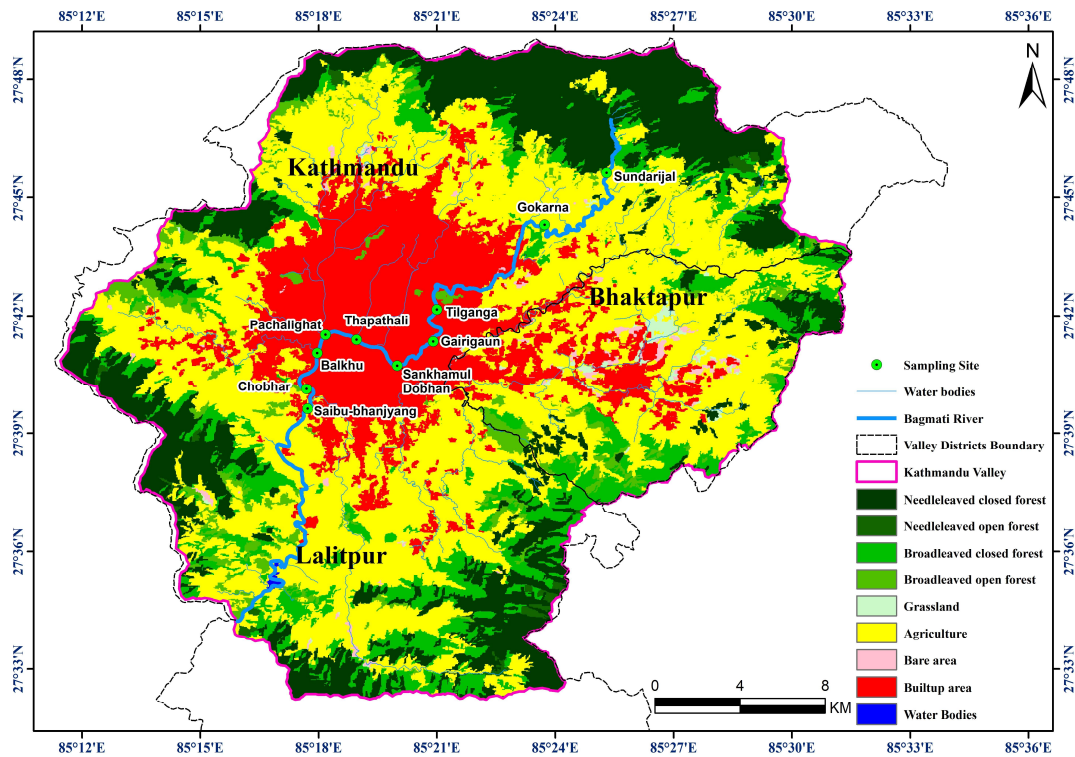
Figure 1 Land use and land cover of the Kathmandu valley (Uddin et al., 2015) and the location of 10 sampling points in the
Bagmati River

Methods and data analysis

Thirty different water quality parameters (Table 1) were
measured by using the standard method (APHA, 1998). The
five days incubation at 20 °C for BOD, Potassium
dichromate oxidation (open reflux, titrimetric) was used for
Chemical Oxygen Demand (COD), heavy metals were
determined by Atomic Absorber Spectrometer (AAS)
method. Pesticides were measured by using Gas
Chromatography and Mass Spectrophotometer following the
standard guideline of the American Public Health
Association (APHA) handbook (APHA, 1998). The
parameters such as pH, DO, and TSS were instantly
measured in the field. Total dissolved solids were determined
as the residue left after evaporation of the unfiltered sample.

For COD and BOD measurements, water samples were
fixed in the field and brought to the laboratory. Similarly, the
Argentometric method for Chloride, Gravimetric method
(with the ignition of residue) for Sulfate, Partition
gravimetric method for oil and grease, Zincon method for
zinc were applied. Total chromium was obtained after
digestion of the sample with H_2SO_4 and HNO_3. To
determine total chromium, the trivalent chromium can be
oxidized to hexavalent by potassium permanganate. Arsine
was identified by passing through a scrubber containing glass
wool soaked with lead acetate and absorbed in silver diethyl-
dithiocarbamate dissolved in pyridine. Arsenic reacts with
the silver salt to form a red complex, which can be
determined colorimetrically. All parameters were measured
using the standard guideline given by APHA (1998).

Table 1 Water quality parameters analyzed in the Bagmati River

Physical Parameters	Chemical Parameters and pesticides		
	Organic constituents	Inorganic constituents	Pesticides
pH, Total Suspended Solids (TSS)	Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD)	Chloride (Cl), Sulphate (SO₄), Fluoride (F), Sulphide (S), Arsenic (As), Cadmium (Cd), Lead (Pb), Mercury (Hg), Chromium (Cr), Oil and grease, Selenium (Se), Zinc (Zn), Silver (Ag) Copper (Cu), Nickel (Ni), Cyanide (CN)	Organochlorine, Alachlor, Aldrin, Dieldrin, Methoxychlor, Endosulfan, Heptachlor, Heptachlor exoepoxide, Organophosphate, Chlorpyrifos, Chlorfenviphos, Carbamate, Aldicarb,

Results and Discussion
Physical and chemical parameters

The results showed that the magnitude of water quality parameters, especially TSS, BOD, and COD, vary in different sites. The dissolved oxygen (DO) concentration was found to be higher in the upstream region, declining to a minimum in urban cores and increasing in downstream sites (Fig. 2). The highest DO was found at Sundarijal (8.5 mg/L), followed by Gokarneshwor (7.2 mg/L) and Tilganga (6.3 mg/L). The DO level started to decline after Tilganga with the lowest value at Teku (Pachalighat) and Thapathali, accounting for 3.4 mg/L and 3.5 mg/L, respectively. However, when the river reaches Chobhar, the DO level started to increase by 5.4 mg/L. The DO level at Saibubhanjyang was 5.5 mg/L. The pH did not vary considerably, ranging between 6.5 and 7.2. The maximum pH was observed at Thapathali (7.5), whereas the minimum pH was observed at Gokarneshwor (6.1).
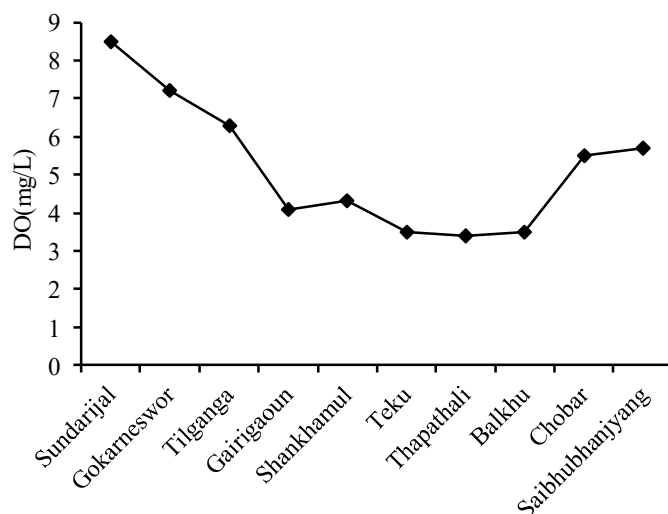

Figure 2 Concentration of dissolved oxygen (DO) at different sampling sites

The physical and chemical parameters are indispensable parameters of water quality assessment to restore the river and ecological balance (Pant et al., 2017; Pradhan, 1998). Quantitative measurements of physico-chemical parameters can describe the quality of the river environment (Mishra et al., 2017; Paudyal et al., 2016). Dissolved oxygen is one of the vital water quality indicators in the river system (Kannel et al., 2007). A suitable pH range (7.0-8.5, WHO standard) is necessary at all times to maintain the health of the aquatic system. The observed pH ranges between 6.0 and 7.5 across the river stretch from Sundarijal to Saibubhanjyang. The water is a little acidic in the upper region, and the pH increases gradually towards the downstream region. Land use in the upper segment is mostly agriculture and forest (Uddin et al., 2015). Therefore, agricultural runoff and humus leaching might reduce the pH level making the water acidic. Towards the city core and downstream sites, pH gradually increases, which could be due to high ammonia concentration downwards. The presence of high ammonia in water increases the pH level. The results are compared with the WHO standard for portable water and the national standard for industrial effluent. Similarly, the pH for the standard of industrial effluent ranges from 5.5 to 9.0 (DOI, 2003), and the drinking water standard is 6.5-8.5 (NDWQS, 2015). The pH in Bagmati River remained within the given pH standard.

The maximum concentration of TSS was obtained as 4605 mg/L at Thapathali, followed by Teku (4066 mg/L). The minimum amount of TSS was found at Sundarijal (2 mg/L) followed by Gokarneshwor (5 mg/L). The BOD level was lowest (82 mg/L) at Sundarijal and gradually increased downstream of the river, reaching the highest BOD level at Gairigaun (1885 mg/L). Similarly, Sundarijal accounted for the lowest concentration of COD (220 mg/L). However, the highest COD (4075 mg/L) was noticed at Gairigaun, followed by Shankhamul (4062 mg/L). The Chobhar consists of the highest sulphide concentration (1.7 mg/L), followed by Saibubhanjyang (1.3 mg/L). Thapathali contained the highest concentration of fluoride and total chlorine with a magnitude of 0.65 mg/L and 0.5 mg/L, respectively. The lowest amount of sulphide was obtained at Gairigaun (0.35 mg/L), whereas the lowest fluoride concentration was at Gokarneshwor (0.05 mg/L), followed by Sundarijal (0.06 mg/L). Balkhu contained the smallest amount of total chlorine with a magnitude of 0.01 mg/L (Fig. 3).

The floodplain of the river has been occupied by shantytown and landless people who often use the river as a free dumping site. Therefore, the concentration of ammonia, TSS, and heavy metals like arsenic, cadmium, mercury, nickel, selenium, and copper was increased. The ionic and

elemental concentrations were found higher in the urbanized and lower region as compared to the headwaters (Paudyal et al., 2016).

The increased TSS concentration after Gokarneshwor is due to increased discharge and volume of waste in the river. The increased inorganic and organic wastes after Gokarneshwor played a crucial role in increasing the TSS. All parameters, including TSS and BOD, declined when water reaches Chobhar and further declines at Saibubhanjyang. The simulation of the previous study also showed that DO and BOD values for 2020 and 2030 would not significantly improve in the Bagmati River (Mishra et al., 2017). The BOD level for the national generic standard for industrial effluent is 50 mg/L, and the WHO standard for portable water is 6 mg/L. These levels exceeded in all sampling sites of Bagmati River. Meanwhile, Gairigaun and Tilganga contained the BOD level 30 times more than the given standard. The less urbanized area such as Sundarijal and Gokarneshwor also exceeded the standard, which clearly showed organic pollution in the river. All sampling sites, except Sundarijal and Gokarneshwor, contained more COD than the WHO standard (10 mg/L) and standard for the national industrial effluents (250 mg/L).

The chloride and sulphate concentration is below the maximum allowable concentration for portable water given by WHO, which should not exceed 600 mg/L and 400 mg/L, respectively. In the same way, the observed concentration of chloride and sulphate seem below the national standard for industrial effluents (1000 mg/L and 500 mg/L, respectively). Except for Sundarijal and Gokarneshwor, the concentration of oil and grease in all sampling sites exceeds both WHO (1 mg/L) as well as the national generic industrial effluent standard (10 mg/L). The main cause of high oil and grease is due to a high number of garage and service centers of vehicles along the river corridor. Beside it, the massive inflow of sewage and industrial wastes is the leading cause of oil and grease in the river. Similarly, the WHO standard for ammonia is 0.5 mg/L, and this value is fulfilled only in Sundarijal and Gokarneshwor. The national effluent standard for ammonia is 50 mg/L, which is also surpassed in all sampling sites except in the upstream region. Sulphide and residual chlorine are not high since the concentration at all sampling sites are below the national standard (2 mg/L and 1 mg/L, respectively). The fluoride concentration at all sampling sites is below the WHO (1.5 mg/L) and national standard (2 mg/L).

Heavy metals
The concentration of heavy metals did not vary considerably at different sampling sites (Table 2). The concentration of silver ranges from 0.01 to 0.02 mg/L, which was quite similar at all the sampling sites. Thapathali encountered highest concentration of arsenic (0.65 mg/L), cadmium (0.005 mg/L), selenium (0.007 mg/L) and copper (0.075 mg/L). The mercury concentration was below 0.001 mg/L in all sampling sites except at Thapathali and Balkhu that accounted for 0.001 mg/L. In the same way, cyanide concentration was below 0.05 mg/L in Sundarijal, Gokarneshwor, Tilganga, Teku, and Saibubhanjyang,

whereas the remaining sites contained a concentration of 0.05 mg/L. The highest zinc concentration was found at Gairigaun (0.85 mg/L), followed by Shankhamul (0.82 mg/L) and Tilganga (0.81 mg/L) (Table 2).

The WHO standard of arsenic for portable water is 0.05 mg/L, whereas the concentration for the national effluent standard is 0.2 mg/L. Thapathali exceeds these values for arsenic, which is attributed to waste from hospitals and commercial areas. The variation of arsenic was also attributed to a geospatial variation such as latitude, longitude, and depth of tube well or groundwater concentration (Yadav et al., 2014). The human groundwater footprints are more stressful (BGR/UNESCO, 2008; Gleeson et al., 2012), and groundwater are depleting in the Kathmandu valley. The arsenic contamination in food and water has severe effects on human health (Ravenscroft et al., 2009). Other heavy metals, including copper, zinc, lead, cyanide, nickel, selenium, and mercury concentrations also seem below the WHO and national standards.

Pesticides concentration
Pesticide concentration was found below the measurable range. All sampling sites contained pesticide concentration below 10 µg/L, which is connected to less agricultural cultivation and pesticide practices in the Kathmandu valley. The observed data on pesticides was found within a similar range except for Heptachlor exoepoxide. All other compounds from the Organochlorine group were measured below 10 µg/L (Table 3). The highest concentration of Heptachlor exoepoxide was 75 µg/L at Balkhu, followed by Thapathali (69 µg/L) and Teku (62 µg/L). Pesticides from organophosphate, carbamate, and pyrethroids were also measured below the range of 10 µg/L at all sampling sites.

According to the WHO and national effluent standards, the concentration of the pesticides should be zero. However, the concentration of Heptachlor epoxide, an Organochlorine compound, was found to be very high that ranges from 31 to 75µg/L. Other pesticides are also present in the range of below 10 µg/L, indicating pesticide pollution in the river. Organochlorines are a synthetic organic product, also known as chlorinated hydrocarbons, which have long term residual effects on the environment and toxic to human health (Yadav & Devi, 2016).

River pollution and implications for river restoration
The middle-urbanized segments, i.e., from Gokarna to Teku, have shown heavily polluted. However, the upper segment from Sundarijal to Gokarna is unpolluted (Fig. 4). The concentration of observed pollutants further revealed that the lower segment, i.e., from Teku to Balkhu, gets moderately polluted, and Balkhu to Saibu-Bhanjyang had slightly polluted. Below the Saibu-Bhanjyang, the river gets restored. After the confluences of small tributaries at Shankhamul (Manohara and Hanumante Khola) and Teku (Tukucha, Dhobi Khola, and Bishnumati Khola) have also not filtered Bagmati River because these all tributaries were heavily loaded from urban discharge. The river quality has a little bit of improvement after Balkhu to Saibu-bhanjyang. In between this segment, the Balkhu Khola and Nakkhu Khola are mixed into the Bagmati River.

Thapathali seems to be the most polluted area since most of the parameters are observed as the highest value. The Bagmati River at Thapathali receives not only household sewage but also waste from hospitals. Two large hospitals (Norvic international and maternity hospitals) are situated in the Thapathali area. Besides, Dhobi Khola, a tributary passing from the city center, confluence the Bagmati River just above the Thapathali site, adding a high amount of waste sludge. Based on these pollutants load in Bagmati River, it can be said that urbanized segments of Bagmati River have shown heavily polluted. After the Saibubhanjyang, the river had got natural restoration.
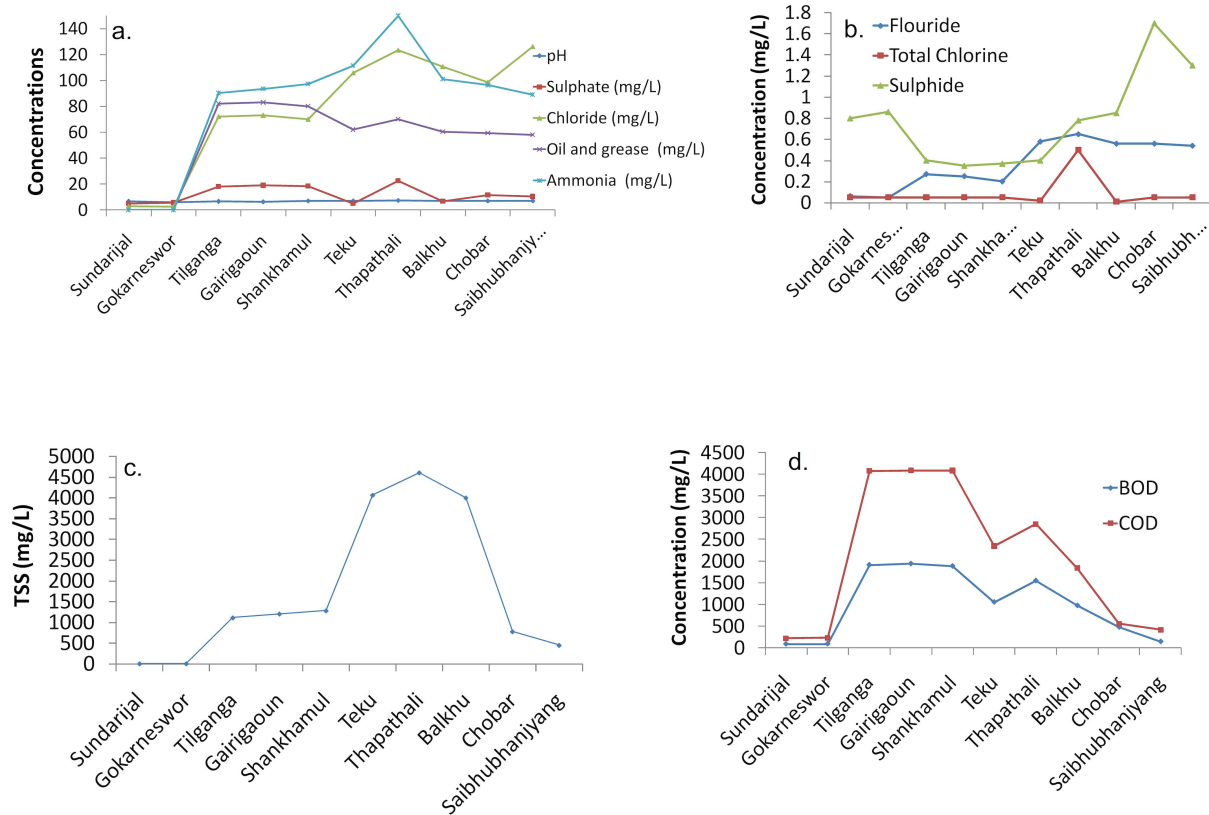

Figure 3 Physical and chemical concentration; a. pH, sulphate, chloride, oil and grease, ammonia; b. fluoride, total chlorine, sulphide; c. total suspended solids and d. BOD and COD (mg/L) at ten sampling sites of the Bagmati River

Table 2 Concentration of heavy metals (mg/L) at different study sites

Study sites	As	Cd	Pb	Hg	Cn	Ni	Se	Cu	Zn	Ag
Sundarijal	<0.005	<0.002	<0.05	<0.001	<0.05	0.01	<0.005	<0.01	0.07	0.01
Gokarneshwor	<0.005	<0.002	<0.05	<0.001	<0.05	0.01	<0.005	<0.01	0.062	0.01
Tilganga	<0.005	<0.002	<0.05	<0.001	<0.05	0.01	<0.005	0.16	0.81	0.01
Gairigaun	<0.005	0.002	0.05	<0.001	0.05	0.01	0.005	0.18	0.85	0.02
Shankhamul	<0.005	0.002	0.05	<0.001	0.05	0.01	0.005	0.15	0.82	0.02
Thapathali	0.65	0.005	0.05	0.001	0.05	0.023	0.0065	0.075	0.47	0.01
Teku	0.03	0.004	<0.05	<0.001	<0.05	0.01	0.006	0.06	0.37	0.01
Balkhu	0.01	0.003	0.05	0.001	0.05	0.01	0.005	0.035	0.36	0.01
Chobhar	<0.005	<0.002	0.05	<0.001	0.05	0.01	<0.005	0.049	0.4	0.01
Saibubhanjyang	<0.005	<0.002	<0.05	<0.001	<0.05	<0.01	<0.005	0.04	0.36	<0.01

Currently, the cleaning campaign of the Bagmati River is a concern for all stakeholders and has gathered nationwide attention. The cleaning campaigns by several stakeholders have reached more than 100 weeks. However, it is challenging to improve river quality until the inflow of pollutants is curbed. The urban pollutants are enormous and need to be treated before disposing into the river. So far, several organizations are working to improve the river status.

However, the river condition is not improved. The river restoration plan had envisioned in five years (2009–2014) Bagmati action plans (GoN/NTNC, 2009), which are almost failed; neither river ecosystem has been restored, nor discharge has been increased. Effective ecological restoration measures are required to implement for restoring life on the Bagmati River (Pan et al., 2016).

Table 3 Concentration of pesticides (mg/L) at various sites

Pesticides/study sites	Sundarijal	Gokarneshwor	Tilganga	Gairigaun	Shankhamul	Thapathali	Teku	Balkhu	Chobhar	Saibu-bhanjyang
Organochlorine	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Alachlor	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Aldrin	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Dieldrin	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Methoxychlor	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Endosulfan	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Heptachlor	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Heptachlor exoepoxide	40	40	45	50	58	69	62	75	36	31
Organophosphate	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Chlorpyrifos	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Chlorfenviphos	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Carbamate	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Aldicarb	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Cabofuran	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Pyrithoids	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Deltamethrin	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Cypermethrin	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

River restoration is one of the prominent areas of applied water resources science (Wohl et al., 2015), and it is possible to make river water pristine and biologically alive. One of the examples of the Qinhuai River of Nanjing, China, can be taken as a successful example of river restoration (NORRP, 2008). This study provides a fundamental assessment of the pollution load in the Bagmati River, which is primarily essential for ecological restoration along with the river segments in the Kathmandu Valley.

Conclusion
In this study, we have investigated a total of thirty physical and chemical parameters and compared with national and WHO quality standard. The water in the upstream region, covering Sundarijal to Gokarneshwor sites are comparatively cleaner since most of the parameters are within the WHO and national effluent standard. Thapathali is the most polluted area, which exceeds the carcinogenic compound

such as arsenic. Most of the parameters exceed both the WHO and national generic effluent standards. The pollution level started to decrease when the river reached to Chobhar site. However, some parameters such as BOD, COD, oil, and grease have exceeded both WHO and national standards. No considerable variation has been found in the concentration of heavy metals, pesticides, and pH in the upstream and downstream regions. However, the difference in TSS, BOD, and COD was observed, which was attributed to increased flow rate and temperature. It has indicated that the urbanized segment of the Bagmati River had been heavily polluted. It reflects an urgent need for ecological restoration using a large variety of ecological, physical, spatial management measures and practices. In Bagmati River, sludge treatment is essential before disposing into the river. At the same time, all tributaries of the river should be treated equally.
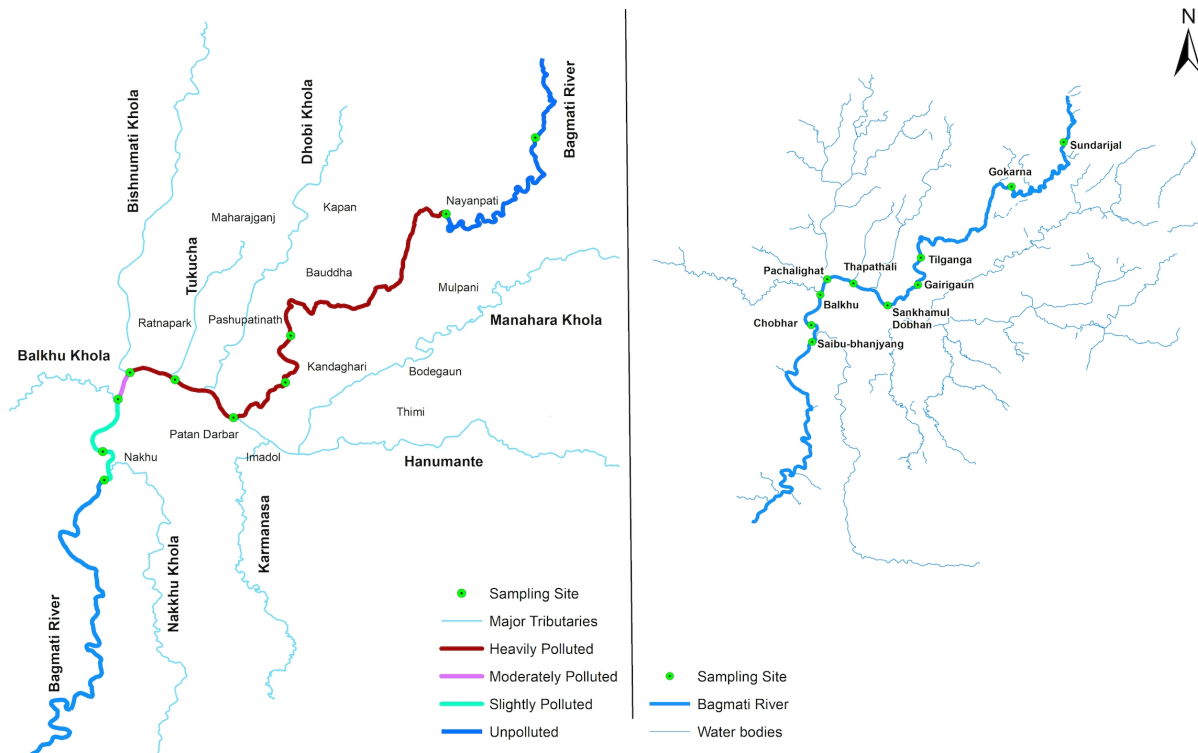
Figure 4 Major tributaries and degree of pollution level in Bagmati River from Sundarijal to Saibu Bhanjyang segments in the Kathmandu valley; the right map shows the drainage and sampling sites of the study area

Acknowledgements

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