Asian Journal of Water, Environment and Pollution, Vol. 20, No. 3 (2023), pp. 29-37.
DOI 10.3233/AJW230035

Delineating Contaminant Hotspots Through Hydrochemical Assessment of a Severely Degraded Watershed in Nepal

Mohammad Iqbal,* Tara Nidhi Bhattarai[1], Chad Heinzel, Sushil Tuladhar[2], Sunita Magar[1] and Nirmal Raila[1]

Department of Earth and Environmental Sciences, University of Northern Iowa, Cedar Falls, Iowa, USA
[1]Department of Geology, Tri-Chandra Campus, Tribhuvan University, Kathmandu, Nepal
[2]Environmental Sciences Division, Weaver Consultants Group, Naperville, Illinois, USA
✉ m.iqbal@uni.edu

Received August 14, 2021; revised and accepted December 12, 2022

Abstract: This project deals with the environmental assessment of the Bagmati River in Kathmandu Valley, Nepal. Rapid population growth and urban development in recent decades have turned this river into a highly polluted water body. To delineate the contaminant hotspots, water and sediment samples were collected from eleven (11) sites along the river. Water samples were analysed for temperature, pH, total dissolved solids (TDS), conductivity, dissolved oxygen (DO), total suspended solids (TSS), turbidity, *E. coli*, biochemical oxygen demand (BOD), nitrate, total phosphorus (TP), chloride, and heavy metals in sediments. The data showed considerable degradation of the aquatic system. The TDS increased from 52 mg/L in Sundarijal (near source) to 595 mg/L near Teku (city center). Simultaneously, TSS increased from 43 mg/L to 1233 mg/L, with a contamination hotspot near the Thapathali area. DO quickly dropped below 2 mg/L at all sites near downtown. *E. coli* increased from 4000 MPN/100 mL in Sundarijal to 46,000 MPN/100 mL in Teku. The high levels of *E. coli* and the low DO were attributed to the direct disposal of sewage, house-hold trash, industrial effluents, and wastes from hospitals and slaughter houses. In recent years, sediment accumulation of heavy metals has also gone up, namely Cr (35%), Cu (59%), Fe (7%), Pb (7%), and Zn (25%). Phosphorus ranges from 0.2 mg/L at the source to 6.2 mg/L near the city. Phosphorus comes from the area's wastewater treatment plant, industrial discharges, and sewage. From people's survey results, 23% said they dispose off part or all of their trash into the river or directly on the street. The urban impact is also evident in the dramatic rise of dissolved Cl in water from the suburbs (26.2 mg/L) to the central city area (73 mg/L). Based on the results, areas near Teku, Thapathali, and Kalimati should be prioritised for immediate remedial measures. Urgent recommendations include dredging of stream sediments, contaminant source cutoff, stringent industrial regulations, and buffer strips and filter beds along the stream banks.

Key words: Bagmati River, hydrochemical assessment, Nepal, urban pollution, water quality.

Introduction

This paper presents results from an international research collaboration between the University of Northern Iowa (UNI), USA and Tribhuvan University (TU), Nepal. The project deals with the environmental assessment of a highly polluted river, called Bagmati River, in Kathmandu Valley, Nepal. The capital city of Kathmandu is located on the banks of the Bagmati River with close to 1.7 million people. There has been

*Corresponding Author

rapid urban development in the area in recent decades, turning the river into a highly polluted water body. The project activities included site characterisation for urban pollution, mapping of high-risk areas, and survey of impacts on people's health.

Several regional studies have shown concerning data, making Bagmati among the most polluted rivers in the world (Bhatt and McDowell, 2007, Khadka et al., 2015). The Kathmandu Valley contains several economically and culturally important cities in Nepal, such as Kathmandu, Bhaktapur and Patan. In an area of about 600 sq. km, these cities house almost 30% of the country's urban population, including direct disposal of untreated municipal and industrial wastes to the river (ICIMOD, 2007). UNESCO has described Kathmandu as a "living heritage site" where people from different faith coexist and perform religious activities. Many of their festivals are related to rivers and other elements of nature. Therefore, improving the health of the Bagmati River is vital to the population living in the Kathmandu Valley.

Study Area

The Bagmati River flows through the Kathmandu Valley (Figure 1). The river has 3,500 km^2 drainage areas. The main tributaries are Bishnumati, Manohara, Hanumante, Godawari, Tukucha, Balkhu, Kodhu, and Nakhu (Bhatt and McDowell, 2007). The river discharge increases from 0.142 m^3/s near the headwater areas to 1.51 m^3/s toward the lower end of the Valley. There are close to 2000 types of industrial activities in the area along with dumpsites and outfalls from garment and carpet factories (Bhatt and Gardner, 2008).

Hypothesis and Objectives

Even though there are agricultural activities in the watershed, this project hypothesised that the urban point sources have been responsible for the ecological destruction of the river in recent decades. Population density and unregulated discharge of industrial effluents into the river have considerably increased in recent years. Besides, there are endless streams of municipal

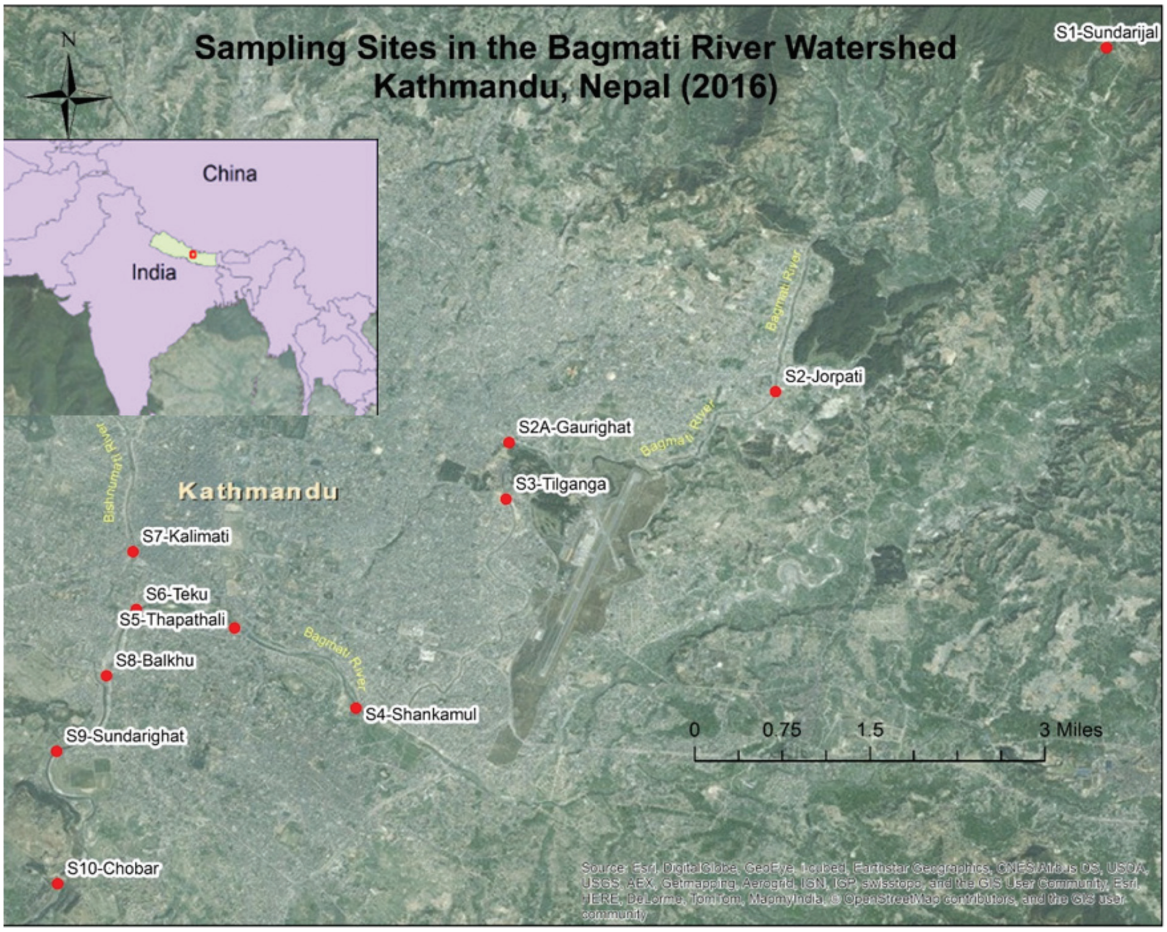

Figure 1: Sampling sites in the Bagmati River Watershed in Kathmandu, Nepal.

as well as human/animal wastes running into the river. To test the hypothesis, multiple water quality indicators were studied in this project. A long-term goal is to understand the impact of environmental degradation on people's health.

Broader Impacts of the Project

The broader impacts of the project can be viewed in three contexts: (1) *Ecosystem management issues*: The data obtained through this project will aid in developing long-term best management practice (BMP) guidelines. Due to the shortage of funding and resources the Nepal state agencies have faced challenges in making full assessments of the watershed and developing restoration plans. The current project is expected to serve as a good example of a worst-case pollution scenario addressed to develop appropriate best management practices; (2) *Environmental health issues*: Every year, a high volume of solid waste is accumulated in the river during the dry season. The dissolved oxygen in the stream water is decreasing over time, whereas the biochemical oxygen demand is increasing. The use of agricultural products, discharge from toilets, and wastes from slaughterhouses are among the problems. This study identified the hotspots of pollution and made recommendations to improve the quality of stream water and people's health; and (3) *Environmental awareness of people*: People's participation in voluntary cleanup programs is one of the best methods in solving urban water pollution problems. An important step toward this initiative is to make people aware of those problems and their consequences. This project aims to bring new knowledge to the area population. During site visits, the investigation team provided community members with necessary health tips. They discussed many factors associated with the toxic effects of water pollution. Community meetings were arranged to help people understand water's controlling influence on the environment. The general population has been given direct access to project data. Those living in the area can assess their proximity to any degraded segments of the river and take necessary steps. For state and private organisations, data from this project can be very useful to develop watershed assessment models. Regulatory agencies can use the data to design effective monitoring schemes.

Materials and Methods

Three (3) rounds of field works were conducted in the study area in 2015 (site selection, baseline data), 2016 (water quality, sediment analysis), and 2017 (health and people's survey). Eleven (11) sites along the Bagmati River were sampled twice a week during the summer of 2015 and once a week during 2016. The sampling sites are identified as Sundarijal (site 1), Jorpati (site 2), Gaurighat (2A), Tilganga (site 3), Shankamul (site 4), Thapathali (site 5), Teku (site 6), Kalimati (site 7), Balkhu (site 8), Sundarighat (site 9), and Chobar (site 10). Site 1 marks the source area of the river, and site 10 is at the point where the river exits the urban portion of the Kathmandu Valley. The total stretch of the river from site 1 to site 10 is approximately 35 km. Water samples were analysed for temperature, pH, total dissolved solids (TDS), conductivity, dissolved oxygen (DO), total suspended solids (TSS), turbidity, *E. coli*, biochemical oxygen demand (BOD), nitrate, total phosphorus (TP), and chloride. Some of the parameters were analysed on-site and several were sent to a professional lab (CEMAT Lab) in Kathmandu. Sediment samples were transported to the University of Northern Iowa (UNI), USA for analysis of heavy metals. Daily rainfall data were collected from the Nepal Department of Hydrology and Meteorology in Kathmandu. In 2017, a set of the survey questionnaire was used to study people's health and understand how they perceived the overall value of the river in their lives.

Sample Collections and Analysis

A set of portable water quality sensors was used to conduct on-site analysis of pH, temperature, conductivity, TDS, DO and turbidity. The instruments were properly calibrated prior to field measurements. TSS was measured in the filtration manifold setup using glass fiber filters of pore size 0.7 µm. After filtration, the TSS was calculated by subtracting the mass of the original filter paper from the mass of the oven-dried filter paper with the solids. The BOD was calculated by subtracting the 5-day DO from the initial DO. The concentrations of dissolved chloride, nitrate, and sulphate were determined by ion chromatography under suppressed conductivity. Ion elution was accomplished by using a CO_3-HCO_3 solution. The flow rate was set at 1.84 mL/min with a column pressure of 2900 PSI. Known standards (5, 25 and 50 mg/L) of the target ions were used for machine calibration. The unknown samples were poured into 5 mL plastic vials fitted with 20-micron filter caps and then loaded into an AS40 automated sampler for injection into the system. The analytical margin of error was ± 0.5 mg/L.

The concentrations of TP were determined by the persulphate digestion and the ascorbic acid assay method. The heavy metals analysed in soil samples were arsenic (As), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), nickel (Ni), lead (Pb), and zinc (Zn). The analysis was done at UNI using a PANalytical MiniPal 4 X-Ray Fluorescence (XRF) Spectrometer. Samples were dried in a Thermo Scientific forced air oven for sixteen hours. Course fragments, X>2mm, were removed by sieving and pulverized in a porcelain container for 10 minutes in a SPEX 8000 Mixer/Mill.

Perception Survey

A survey was conducted in the area on health issues as well as people's perceptions of the area's environmental condition in general. For many families along its bank, Bagmati is the only source of water for bathing, laundry, and other household purposes. Many homes have their own ways of treating the stream water before use. During project activities, children were seen swimming in the dirty water. Many women jeopardize their health while collecting stream water for washing clothes and cleaning utensils. Surveys were carried out by way of visiting the neighbourhoods and interviewing people on their health, aesthetics, and dependence on the river for their daily water requirements. Interview questions focused on (a) the quantity of water used per day in the household, (b) their distance from the river, (c) their level of dependence on stream water, (d) probable access to alternate water sources, and (e) evidence of water-borne disease in the household. A total of 132 homes were surveyed by the project team.

Data Management Plan

A rigorous quality assurance and quality control procedure was in place to maintain data quality and storage. Each project participant received thorough training in sampling protocol, storage, and analysis according to standard data quality policies and procedures in respective areas. Their performance in the field was constantly monitored during the project. There were evaluations of data to determine if they were of the right type, quality, and quantity to support their intended use. Besides, data were qualitatively checked against external factors, such as dilution by episodic rains or seasonal fluctuations in dissolved nutrients. All field and lab data were compared with their expected levels based on seasonal trends. Also, data were checked against expected stream behaviour, including the stream's response to sensors. When needed, a graphical data verification approach (XY plots, etc.) was taken to detect any errors in data. Instrumental calibration was done by following standard scientific methods recommended by the manufacturers. For each set of samples, machine calibration was verified by running known chemical standards. Trained technicians were available to assure instrumental operation, maintenance and troubleshooting. The participating faculty were responsible for the day-to-day management of machine operation, work schedule, and data quality. For public access and sharing, all data are freely available through the existing hydrology website on the university server (www.uni.edu/hydrology).

Results and Discussion

Hydrochemical Assessment of Stream Water

The average TDS value in the area increased from 52 mg/L in Sundarijal (site 1, near source) to 595 mg/L further downstream near Teku (site 6, mid-town Kathmandu) (Figure 2). Water in site 1 had high clarity lacking any visible debris. Similar conditions were found at the next two sites downstream with average TDS of 103 mg/L (Jorpoti) and 130 mg/L (Gaurighat). After Gaurighat, the TDS values went up rather dramatically. From sites 1 through 6, the TDS gradient was 28 mg/L increase per km, indicating severe degradation of stream water in the area. The highest average value (633 mg/L) was observed at site 7 (Kalimati), where the river drains the core urban areas of the city. Other urban sites (sites 5, 8 and 9) also showed an average TDS greater than 500 mg/L. From site 7 through 10 (Chobar), the average TDS declined at a consistent rate of 50 mg/L/km. Temporally, the average TDS dropped from 657 mg/L in early May to 147 mg/L in late July (Figure 3). The dilution is attributed to the cumulative effects of the monsoon rains. The rate of rain dilution is 46 mg/L per week. There were consistent patterns of high and low peaks, indicating that non-rainfall periods were influenced by the high influx of pollutants from the surrounding areas.

Pokhrel (2018) investigated the impact of land use on stream flow and sediment yield by using the SWAT model. From 2000 to 2010, they found a 6% increase in built-up areas and a general decrease in surface water bodies and other natural areas. As a result, the contributions of surface runoff to stream flow and sediment yields increased by 27% and 5%, respectively. On the other hand, lateral flow and groundwater contribution to stream flow decreased by 25% and 21%, respectively (Pokhrel, 2018). The current study not only found increased sediment yield around non-natural lands, but it also found a correlation of TDS values with the % built-up areas and population density (Figure 4). The land cover and the digital

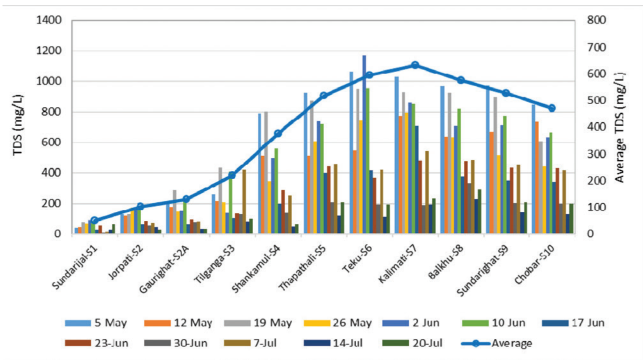

Figure 2: Spatial distributions of total dissolved solids in the study area.

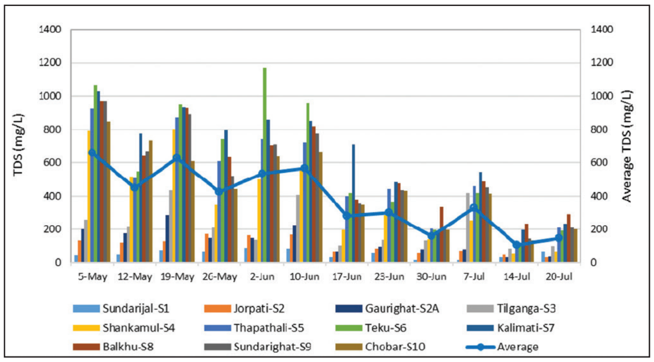

Figure 3: Temporal distributions of total dissolved solids in the study area.

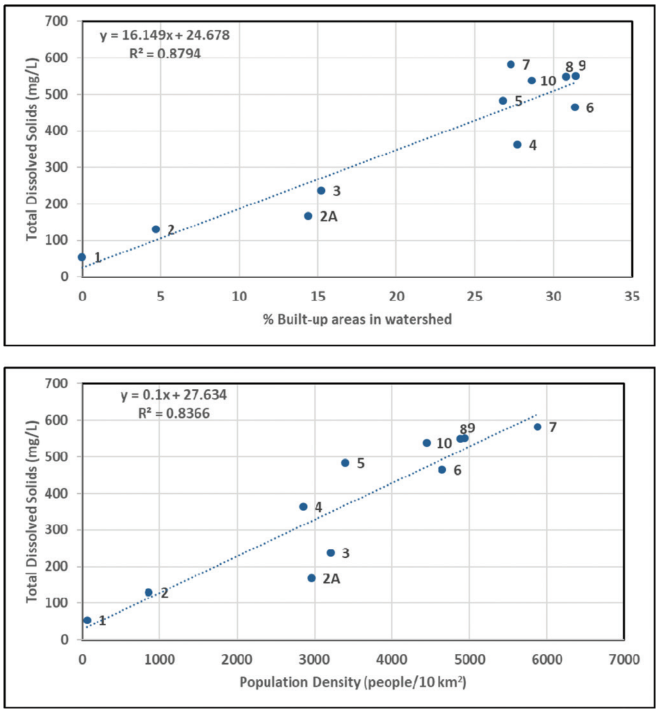

Figure 4: Correlation of TDS with % built-up areas and population density in the watershed (Poudel, 2020).

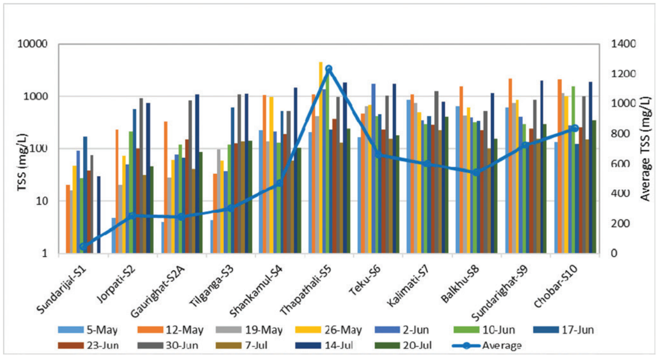

Figure 5: Spatial distributions of total suspended solids in the study area.

Figure 6: Left: Large pieces of garbage and debris floating in Bagmati River near the Kathmandu City area; Right: Liquid waste discharged into the river through large pipes.

elevation model (DEM) data were downloaded from the ICIMOD (an intergovernmental knowledge hub) and the Humanitarian Data Exchange websites (HDX, 2019; Uddin, 2013). The population density raster was downloaded from the WorldPop website (WorldPop, 2017). The R^2 values for the correlation are 0.88 and 0.84, respectively (Poudel, 2020). As the Bagmati River enters the urban areas, the water quality rapidly deteriorates due to human activities and urban land use. The negative impact of the built-up areas on the watershed is reflected by the cluster of urban sites (sites 4-10) in Figure 4.

TSS increased from 43 mg/L at site 1 to 1233 mg/L at site 5, indicating a contamination hotspot around the Thapathali area (Figure 5). There were large pieces of garbage and debris floating in the river at most sites (Figure 6). Also, there was trash coming from small industries operating along the river banks. Downstream of Thapathali, the TSS dropped to 538 mg/L near Bahlku (site 8), then went up for the next few km of the stream flow. The last sampling point in the study area (Chobar, site 10) recorded a high TSS of 835 mg/L. Except for a couple of low peaks during late June and early July, the monsoon rain does not seem to remove suspended solids from the river. Most sites had strong odours in the water from decomposing trash and the liquid waste coming from city streets (Figure 6). The average turbidity in the river increased from 15 NTU at site 1 to 299 NTU at site 5 (Figure 7). The turbidity remains high all the way to the end of the study area in Chobar (322 NTU).

Even though DO in the upper reaches (Sundarijal and Jorpati) were mostly recorded between 5 and 7 mg/L, the values quickly dropped below 2 mg/L at all sites in the city areas (Figure 8). The average DO values ranged from 0.99 mg/L to 1.5 mg/L near sites 5, 6, 7 and 8. A water body so depleted in dissolved oxygen cannot support a healthy aquatic environment. Monsoon rains increase the average DO by close to 5 mg/L in late June and July. Mishra et al. (2017) used Water Environment And Pollution (WEAP) model to compare DO at five different locations in this area. In 2014, they found an average DO of 1.31 mg/L at Teku. The current study found comparable DO (av. 1.5 mg/L) at this site in 2016. However, the current study also reveals that DO values widely vary from pre-monsoon (0.75 mg/L) to monsoon (1.9 mg/L) seasons due to an increase in stream discharge. *E.coli* increased from around 4000 MPN/100 mL in Sundarijal (site 1) to 46,000 MPN/100 mL in Teku (site 6). The high concentrations of *E. coli* and very low DO in the urbanized section of the river resulted from the direct disposal of sewage. The piles of municipal waste around the city and the drain pipes connected to the river are noteworthy. Phosphorus and dissolved nitrate range from 0.2 mg/L and 2.1 mg/L at site 1 (source) to 6.2 mg/L and 0.6 mg/L near site 6 (city), respectively (Figure 9, Table 1). The high phosphorus and low nitrate near the city areas indicate that phosphorus likely comes from the area's wastewater treatment plant and industrial discharges of food processing, cleaning agents, paper industry, and human and animal wastes. The urban impact is also evident in the dramatic rise of dissolved Cl in water from Tilganga (site 3, 26.2 mg/L) to central city areas

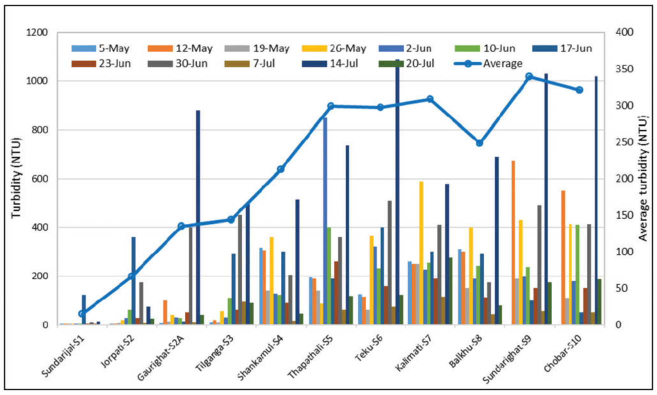

Figure 7: Spatial distributions of turbidity in the study area.

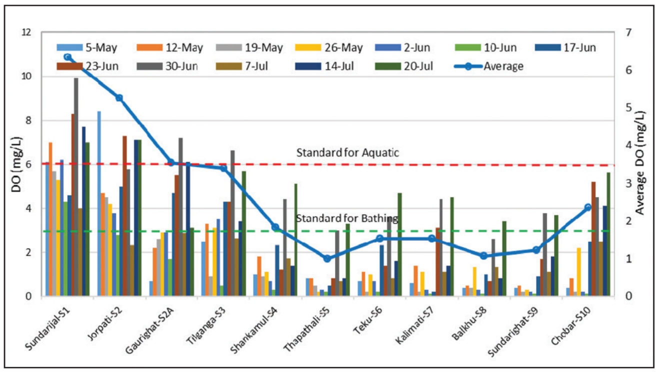

Figure 8: Spatial distributions of dissolved oxygen in the study area.

Table 1: Average concentrations of dissolved nitrate and chloride observed in the river from early May through late July

Sampling location	*Nitrate (mg/L)*	*Chloride (mg/L)*
Sundarijal S1	2.1	2.6
Jorpati S2	2.6	11.5
Gaurighat S2A	3.2	44.9
Tilganga S3	0.5	26.2
Shankamul S4	1.2	38.3
Thapathali S5	0.7	64.3
Teku S6	0.6	72.4
Kalimati S7	0.6	73.0
Balkhu S8	1.4	67.8
Sundarighat S9	1.9	62.2
Chobar S10	1.1	54.2

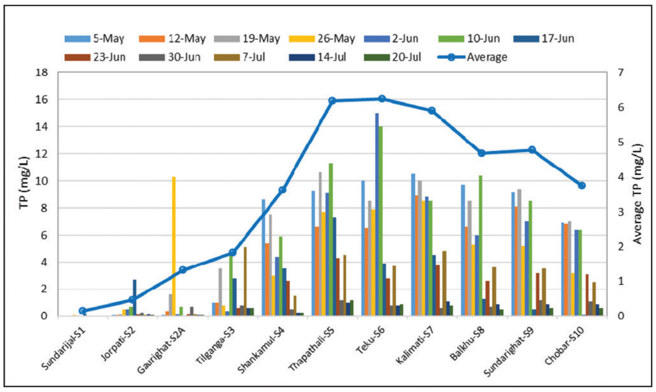

Figure 9: Spatial distributions of total phosphorus in the study area.

near Teku (site 6, 72.4 mg/L) and Kalimati (site 7, 73 mg/l) (Table 1). This rise in Cl is attributed to sewage and industrial effluents. The average Cl sharply drops to 54.2 mg/L near Chobar (site 10). Toward the rural, upper reaches of the stream, the average nitrate is quite low (<10 mg/L), ruling out agricultural leachate as the source of contamination (Table 1).

Heavy Metals in Stream Sediments

Many investigators studied dissolved metals in Bagmati and adjacent Himalayan rivers (Bhatt et al., 2014; Paudyal et al., 2016; Tripathee et al., 2016). Paudyal et al. (2016) measured the hazard quotient of dissolved metals by using a risk assessment model. They reported that the existing levels of Mn, Cr, Co, Cu, and Zn can have serious health effects among the area residents. The current study finds a high accumulation of metals in the stream sediments, such as As (5.6 mg/kg), Co (6.5 mg/kg), Cr (67.2 mg/kg), Cu (37.6 mg/kg), Fe (3000.2 mg/kg), Ni (21.9 mg/kg), Pb (40.4 mg/kg), and Zn (97.6 mg/kg). Comparing these data with a 2011 study in this watershed, concentrations of several metals have increased significantly, such as Cr (35%), Cu (59%), Fe (7%), Pb (7%), and Zn (25%) (Khadka et al., 2015). These data suggest that a complete risk analysis must consider both dissolved and sediment-adsorbed metals in polluted rivers. Heavy metals in rivers and lakes are largely retained by bottom sediments, suspended particles, and organic matter. Depending on the redox potential of the stream water, these metals can be released from mineral complexes to the water column. Even though the current levels of heavy metals in Bagmati sediments are low compared to the large rivers in Asia, the industrial sources of metals must be cut off to protect the stream from further degradation. High metal concentrations are mostly found in city areas characterized by heavy industrial activities, including textile weaving, and metal handicrafts (Khadka et al., 2015). Large industries, such as shoe manufacturing, garments, and cement plants have rapidly grown in the area in recent decades (ICIMOD et al., 2007). Also, the area has industries that manufacture car batteries, herbicides, and insecticides.

Impact of Stream Discharge on the Water Quality

The average stream discharge near Teku (site 6) went up from 3.19 m^3/s on June 2 to 8.28 m^3/s on June 30 (Table 2). The highest flow was recorded as 16.99 m^3/s during mid-July. The observed discharge was mostly episodic in nature with periods of high flows during monsoon rains. Dhital et al. (2021) published a useful review

Table 2: Temporal changes in stream discharge and dissolved oxygen observed near the central city area (Teku, site 6)

Sampling dates	*Discharge (m^3/s)*	*Dissolved oxygen (mg/L)*
May 5	3.68	0.7
May 12	2.64	1.1
May 19	1.45	0.2
May 26	3.30	1.0
June 2	3.19	0.7
June 10	3.19	0.2
June 17	6.80	2.3
June 23	4.91	1.4
June 30	8.28	3.6
July 7	6.88	0.8
July 14	16.99	1.6
July 20	5.78	4.7

of the model used to study flow variabilities in the Bagmati River. They used Hydro-Informatic Modeling System (HIMS) to demonstrate that for monthly runoff simulation, there was a very good correlation between observed and simulated hydrographs. On the other hand, the correlation was very poor for daily runoff simulation. They also indicated that discharge was trending low during monsoon, but increasing in pre-monsoon season. Many investigators cautioned that runoff simulation in watersheds like Bagmati can be quite challenging. Further improvement in input parameters would be necessary for a better interpretation of runoff mechanisms (Babel et al., 2014; Hwang). Unusual variations in hydrologic characteristics have been reported in these watersheds in recent years. The current study shows that discharge during monsoon seasons is still very high compared to the pre-monsoon periods, reiterating the need for site-specific input data for smaller modeled areas. This study also shows that the chemical characteristics of the Bagmati River are considerably impacted by high monsoon discharge. The highest flow coincided with the highest TSS value (1728 mg/L) recorded on July 14, which is attributed to the debris carried to the river by monsoon rains (Figure 10). Some of the DO values were 400% to 600% higher than those recorded in pre-monsoon months, presumably due to the free oxygen dissolved in rainwater. Rainfall seemed to have particularly affected the urban parts of the river (such as site 6). A notable effect of the rain was observed on the average TDS. During June and early July, the weekly TDS levels were recorded as 1170 mg/L, 958 mg/L, 418 mg/L, 367 mg/L, and 195 mg/L (Figure 10). The monsoon rains seemed effective in diluting some of the contaminants.

Community Health Survey

People's general perception of Bagmati's health revealed concern. A total of 86% surveyed said that they have a bathing facility in their house. About 13% of the populationsaid that they did not have any bathing facilities, indicating their dependence on the adjacent river. In regards to waste disposal, 74.4% said they use the public sewage network, and over 13% said that they dispose of it in the river or directly on the street. About 10% said they use a combination of public sewage, the adjacent stream channel and the nearby city streets for disposal. About 15% of those surveyed admitted that they depend upon the river for bathing, washing clothes and utensils, and performing ceremonies.

Conclusions

The hydrologic environment in the Bagmati Watershed has severely deteriorated in recent years. TDS, TSS, DO, *E. coli*, and turbidity showed significant spatial variations between the rural and the urban sites. The TDS concentration gradient from sites 1 through 6 was calculated as a 28 mg/L increase per km. The TSS increased from 43 mg/L at site 1 to 1233 mg/L at site 5 (near Thapathali) with a simultaneous increase in turbidity from 15 to 299 NTU. These results raise great concern for the area population.

With DO values below 2 mg/L, the urban segment of the river did not support a sustainable aquatic environment. Also, the *E. coli* levels were ten folds higher in the city center compared to the upper reaches of the river. There were piles of municipal solid waste all over the city. At many points along the stream banks, drain pipes are connected to the river dumping liquid waste from a variety of sources. The urban impact is also evident in the high phosphorus levels (average 6 mg/L) in the water. The phosphorus comes

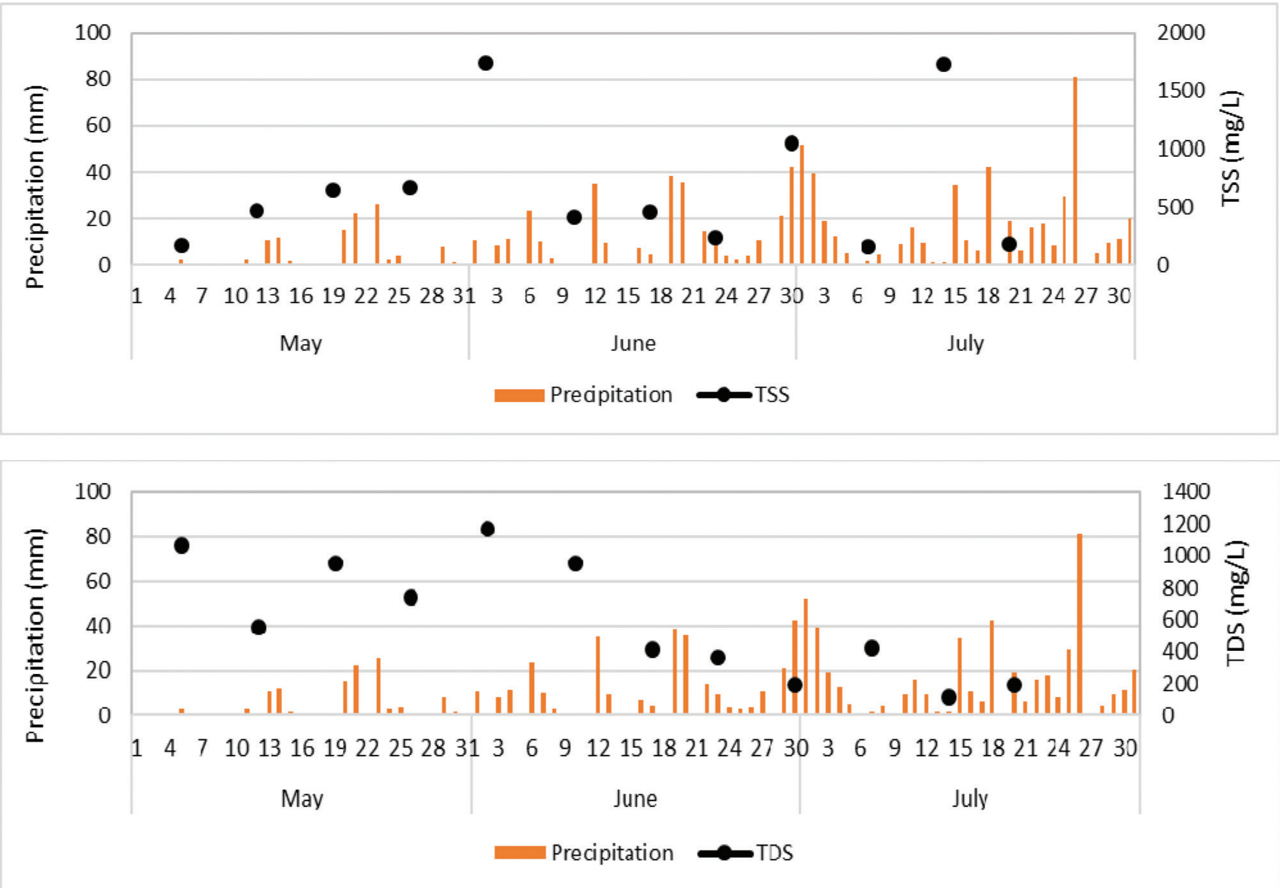

Figure 10: Effects of rainfall on total suspended solids (top) and total dissolved solids (bottom) near the central city area (Teku, site 6).

from industrial discharges, including wastewater, food processing, paper industry, and animal waste. The high dissolved Cl was another evidence of urban pollution. In addition, there were elevated levels of heavy metals in the stream sediments. In some instances, the monsoon rains reduced the dissolved chemicals by dilution. From early to late June (high monsoon), the average flow at Teku increased from 3.19 m^3/s to 8.28 m^3/s. The highest discharge was 16.99 m^3/s during mid-July.

Based on the water quality results, areas near the city center (sites 5, 6, 7 and 8) should be prioritised for immediate remedial measures. A set of recommendations was handed over to the Deputy Mayor of Kathmandu City in October 2018. Urgent recommendations include dredging of stream sediments, contaminant source cutoff, stringent industrial regulations, and buffer strips and filter beds along the stream banks. It was emphasized that the dredged sediments must not be piled up on the stream banks. This will prevent their reentry to the river during rain events. Also, the disposal of liquid sewage and house-hold garbage must be remodeled in areas close to the river, including the installation of sanitary landfills. In recent initiatives, the city government has built recreational parks with vegetation along the banks, which proved highly beneficial to the community. The existing barriers to prevent open trash from entering the river should be further extended. Also, cleanup initiatives by citizen volunteers help maintain a healthy aquatic environment in the valley.

Acknowledgements

We acknowledge the funding from the National Science Foundation, USA to conduct this international collaboration project in Nepal. We thank Junu Shrestha, Pratik Poudel, Sushma Magar, Padma Nepal, Riddhi Karki and Steve Smith for helping with the field work, lab analysis, and maintenance of equipment.

References

Babel, M.S., Bhusal, S. P., Wahid, S.M. and A. Agarwal (2014). Climate change and water resources in the Bagmati River Basin, Nepal. *Theoretical and Applied Climatology*, **115:** 639-654.

Bhatt, M.P., McDowell, W.H., Gardner, K.H. and J. Hartmann (2014). Chemistry of the heavily urbanized Bagmati River system in Kathmandu Valley, Nepal: Export of organic matter, nutrients, major ions, silica, and metals. *Environmental Earth Science*s, **71(2):** 911-922.

Bhatt, M. and K. Gardner (2008). Variation in DOC and trace metal concentration along the heavily urbanized basin in Kathmandu Valley, Nepal. *Environmental Geology*, **58:** 867-876. DOI 10.1007/s00254-008-1562-z.

Bhatt, M. and W. McDowell (2007). Evolution of chemistry along the Bagmati drainage network in Kathmandu valley. *Water Air Soil Pollution*, **185:** 165-176.

Dhital, Y.P., Dawadi, B., Kattel, D.B. and K.C. Devkota (2021). Rainfall-runoff simulation of Bagmati River Basin, Nepal. *Jalawaayu*, **1(1):** 61-71.

HDX (2019). Nepal Digital Elevation Model (DEM) [TIFF]. 90m. Nepal Digital Elevation Model (DEM) – Humanitarian Data Exchange. Retrieved February, 2019, from https://data.humdata.org/dataset/nepal-digital-model-elevation-dem.

Hwang, Y., Clark, M.P. and B. Rajagopalan (2011). Use of daily precipitation uncertainties in streamflow simulation and forecast. *Stochastic Environmental Research and Risk Assessment*, **25:** 957-972.

ICIMOD (2007). Kathmandu valley environment outlook. ICIMOD, MOEST, and UNEP.

Khadka, Y.J., Iqbal, M.Z. and K.J. De Nault (2015). Urban pollution of Bagmati River corridor within the densely populated Kathmandu Valley in Nepal. *Asian Journal of Water, Environment and Pollution*, **12(4):** 43-59.

Mishra, B.K., Regmi, R.K., Masago, Y., Fukushi, K., Kumar P. and C. Saraswat (2017). Assessment of Bagmati river pollution in Kathmandu Valley: Scenario-based modeling and analysis for sustainable urban development. *Sustainability of Water Quality and Ecology*, **9-10:** 67-77.

Paudyal, R., Kang, S., Sharma, C.M., Tripathee, L. and M. Sillanpää (2016). Variations of the Physicochemical parameters and metal levels and their risk assessment in urbanized Bagmati River, Kathmandu, Nepal. *Journal of Chemistry*, **2016:** 6025905.

Pokhrel, B.K. (2018). Impact of land use change on flow and sediment yields in the Khokana Outlet of the Bagmati River, Kathmandu. *Nepal Hydrolo*gy, **5(22):** 1-13

Poudel, P. (2020). The correlation of total dissolved solids (TDS) in the Bagmati river in Kathmandu, Nepal with land cover and population density in its sub-watersheds. Undergraduate Project Report, University of Northern Iowa, USA.

Tripathee, L., Kang, S., Sharma, C.M., Rupakheti, D., Paudyal, R., Huang, J. and M. Sillanpää (2016). Preliminary health risk assessment of potentially toxic metals in surface water of the Himalayan Rivers, Nepal. *Bulletin of Environmental Contamination and Toxicology*, **97(6):** 855-862.

Uddin, K. (2013). Land cover of Nepal 2010 [TIFF]. 30m. ICIMOD Regional Database System. Retrieved February, 2019, from https://rds.icimod.org/Home/DataDetail?metadataId=9224.

WorldPop (2017). Nepal 100m Population, Version 2. University of Southampton. Retrieved February, 2019, from DOI: 10.5258/SOTON/WP00531.

Asian Journal of Water, Environment and Pollution

Volume 19 Number 6 **November, 2022**

Contents

Editorial i

❑ *Snapshot* ii

Effect of Hydraulic Conductivity on Three Dimensional Contaminant Transport in Riverbank Filtration System
Shaymaa Mustafa and Mohamad Darwish 1

Optimal Reactive Power Dispatch by Success History Based Adaptive Differential Evolution Salp Swarm Algorithm
Naveen Kumar and Ramesh Kumar 11

Development, Current Status and Challenges of Multiple Use Water Systems in Nepal: A Review
Nani Raut, Smriti Gurung, Abda Khalid, Bed Mani Dahal, Kumud Raj Kafle and Anjal Prakash 19

Monitoring of Pesticide Residues in Lebanese Vegetables and Agricultural Soils and Their Impact on Soil Microbiological Properties
Mohamad H. Omeiri, Rony S. Khnayzer and Hoda H. Yusef 27

Adaptation Practices by the Farmers for Reduction of Salinisation Problem in the Paddy Fields of South-Eastern Coast of Bangladesh
Prabal Barua, Syed Hafizur Rahman and Saeid Eslamian 37

Optimization of Two-Stage Operational Amplifier Using Firefly Algorithm Considering Environmental Constraints
Kumari Archana, Ram Kumar, Sourav Nath and Prabhat Kumar Srivastava 45

Storm Surge Hazard Assessment Along the East Coast of India using Geospatial Techniques
Harshith Clifford Prince, R. Nirmala, R.S. Mahendra and P.L.N. Murty 51

Assessment of Primary Parameters in Sawa Lake and Their Impact on Productivity
AlaaJabar Mahmoud, Ali Abdulhamza Al-Fanharawi and IbtehalAqeel Al-Taee 59

Assessment of Temporal Variation in Hydrogeochemical Facies of River Water in the Central Himalayan Region
Kajal Sinha, Chandrashekhar Azad Vishwakarma, Jaya Dwivedi and Prashant Singh 67

Optimisation of Defluoridation of Water by Zirconia Nanoparticles Using RSM
Poornima G. Hiremath, Prashanth G.K., Abdul Bais Kadli, Sheril Varghese and Vishnu V. Bhaskar 75

Effect of Sodium Fluoride on Glycemic Index and Liver Functions in Rats
Sadiq Jaffer Ramadhan, Muna Hassan Youssef and Khalisa Khadim Khudair 85

A Bibliographic Analysis of Adaptive Techniques for the Development of Environment-Friendly Renewable Energy Systems
Shashi Gandhar, Jyoti Ohri and Mukhtiar Singh 93

Study the Effect of Some Citrus Peel Extracts Against Plant Pathogenic Fungi
Ahmed Mshari, Alaa M. Alrudainy and Najwa M.J.A. Abu-Mejdad 103

Removal of Fluoride from Synthetic Wastewater Using Carbonised Saw Dust and Suspended and Immobilised Culture of *Pseudomonas oleovorans* Strain NITD 20 – A Comparative Study
Bhaskar Bishayee, Abhilasha Rai, Biswajit Ruj and Susmita Dutta 111

Placement of Renewable Distributed Energy Resources in the Radial Distribution Network to Overcome the Losses and Air Pollution
Amandeep Gill, Himani Bali and Abhilasha Choudhary 119

Environment News Futures 127