Original Research Article

Water Quality of Bagmati River in Kathmandu Valley, Nepal

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Abstract

Background: *Water quality degradation is one of the major challenges especially in under developed and developing countries and Nepal is no exception from it. Adequate water quality and quantity is one of the greatest factors affecting human and ecosystem health, and is essential for socio-economic growth and the improvement in the quality of life. This study aims to assess the water quality of Bagmati River in Kathmandu, the capital city of federal Nepal.*

Methods: *Water quality of the Bagmati River in Kathmandu Valley was analyzed to assess the river water pollution. A total ten sites from Sundarijal to Sundarighat along the Bagmati river corroder was selected for sample collection. The samples were analyzed for physical (pH, Temperature, Conductivity), and chemical (dissolved oxygen, oxygen saturation percentage, biological oxygen demand, chloride, nitrate-N, phosphate-P and ammonia-N) parameters in pre-monsoon and post-monsoon seasons using standard methods.*

Results*: The result reveals that water quality of the Bagmati River has degraded due to physical, chemical and biological contaminants. Discharge of untreated sewers, industrial effluents, unmanaged location of solid waste transfer station, dumping and burning of plastic waste and garbage near to the river bank. In both the season pollution was found to be increasing from upstream to downstream as indicated by Bach water quality index. The paired sample t-test of physicochemical parameters in two different seasons showed that all tested parameter were significantly different except dissolved oxygen and phosphate concentration. parameters pH, range between 7.55 to 6.33, temperature 30 °C to 26.23 °C, electrical conductivity 43.73 µS/cm to 810.5 µS/cm, dissolved oxygen 0 mg/L to 9.52 mg/L, oxygen saturation percentage 0 to 119.75 %, biological oxygen demand 2 mg/L to 400 mg/L, chloride 4.97mg/L to 132.54mg/L, nitrate-N 9 mg/L to 110 mg/L, phosphate-P 0.26 mg/L to 2.95 mg/L and ammonia-N range between 0.41 mg/L to 42 mg/L.*

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Conclusion: *Untreated sewerage, industrial effluents, dumping and burning of waste, unmanaged location of solid waste transfer stations, poor management of cremation ash has resulted in the excessive water pollution in Bagmati river. Treatment of waste water before discharge to the river and proper management of cremation ash and garbage, and prevention of illegal dumping of solid waste and burning of garbage and plastic materials along the river can alleviate the water pollution in Bagmati river.*

Keywords: *Water quality, Bach index, pre-monsoon, post monsoon, Bagmati River*

Introduction

Adequate water quality and quantity is one of the greatest factors affecting human and ecosystem health and is essential for socio-economic growth and the improvement in the quality of life. However, drinking and river water quality in many countries, especially in developing countries is not desirable (Li & Wu, 2019).

Bagmati river water pollution results from rapid urban population growth, lack of awareness, discharge of industrial and domestic effluents, inadequate wastewater treatment facility (Mishra et al., 2017). The rapid urbanization in Kathmandu has made it one of the fastest growing metropolitan cities in South Asia. This rapid and unplanned urbanization degrades the overall urban environment and quality of life. It is said that almost all industries in Nepal are free rider to common water resource, called Bagmati River by discharging freely, directly and illegally without any treatment (Bista, 2019). Dumping of solid waste and sewerage connection increase as the river goes down towards city core. The water quality in Bagmati River is degraded intensely progressively towards the downstream from Sundarijal to Chovar area in the Kathmandu valley (Mahat et al., 2020).

The physicochemical parameters of Bagmati River water have been studied by many researches (Sharma (1977), Shrestha (1980), Khadka (1983), Upadhaya and Rao (1982), Pradhananga, (1990), Vaidya et al. (1987), Bajracharya et al (1988), Bottino (1988), Bista (2019), Mishra et al. (2017), Mahat et al. (2020). Almost all research reported the increment of pollution while river enters to city core downstream. The discharge of untreated sewerage and industrial effluents into the river and its accumulation might be one of major causes of water quality degradation and consequently odor problems in Bagmati River.

This study is an attempt to observe physicochemical parameter during dry seasons especially on pre and post monsoon from Sundarijal upstream to the downstream of the river at Sundarighat. These results were used to examine the significance relation between seasons in respective sites. The result may be helpful to identify the impact area around the river. For the restoration of pristine river ecosystem, planner and policy makers could use such information. Thus the study has its great importance.

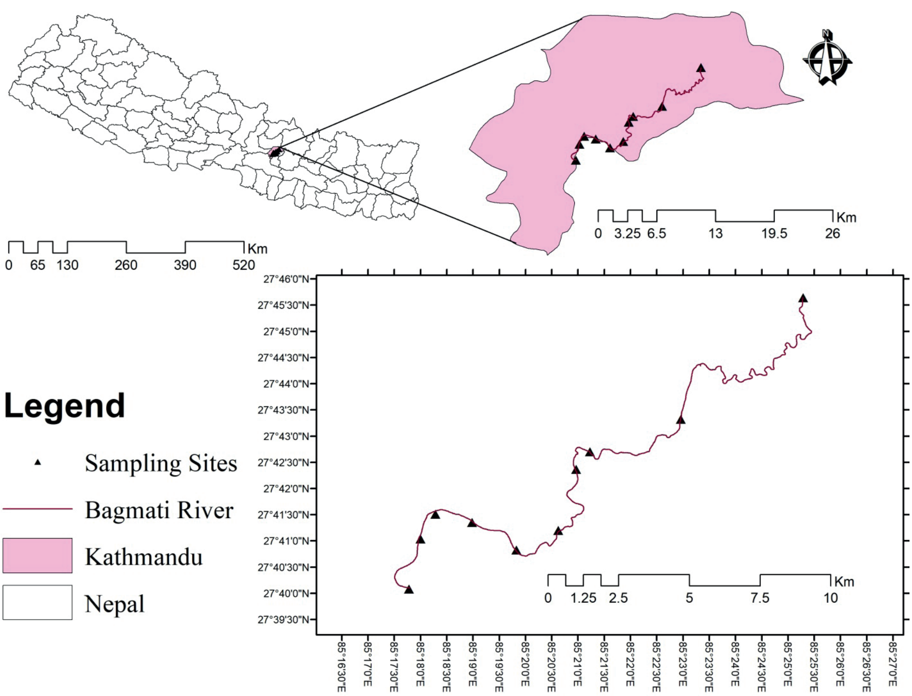
Materials and Method

Materials and methods was presented in following sub headings.

Study area

The Bagmati is the holy river which flows through the city centre of Kathmandu Valley. The valley, located in the midland of the Nepal Himalayas, lies in between 27°32' and 27°49' North and 85°12' and 85°32' East and is almost round in shape with a diameter of approximately 30 km E–W and 25 km N–S (Dill et al., 2001). Bagmati River has its origin in Bagdwar from the southern slope of Shivapuri hill, north of Kathmandu basin at an altitude of about 2650 m and flows south-west cutting Mahabharat range (Sharma, 1977). The Kathmandu Valley has a temperate monsoonal climate with an average annual rainfall of 1,407 mm. Summer temperatures range from 19-27°C and in winter temperatures are between 2-20°C (NTNC, 2008).

Figure 1 *Study area in upper Bagmati basin in Nepal.*



Sample collection

A total of ten sampling sites along the Bagmati River from Sundarijal (upstream) to Sundarighat in the valley were selected based on the rural to semi urban area from where river enters and exits to city centre. Sampling were carried out in pre-monsoon (May, June) and post-monsoon (November, December) in 2013. Polyethylene bottles (~250 mL) were used for sampling. Parameters such as temperature, pH and conductivity were measured in situ. Water samples were collected and preserved for the analysis of BOD_5, NO_3-N, PO_4-P and NH_3-N. All samples were transported to CDES laboratory and refrigerated at ~4^o C till analysis. The water samples for BOD_5 were incubated on the same day at 20^o C whereas other parameters were analyzed within 48 hours (APHA, 2012).

Methods of analysis

Potassium chromate, Silver nitrate, Hydrochloric acid, Mangneous sulphate, Potassium iodide, Sulphuric acid, Sodium thiosulphate, Starch solution, phosphate buffer, Magnesium sulphate, Calcium chloride, Ferric chloride, Phenol disulphonic acid, Liquor ammonia, Ammonium molybdate, Stannous chloride, Sodium nitroprusside, were the AR grade chemicals purchased from local suppliers in Kathmandu. The instruments such as Mercury filled Celsius Thermometer, Digital pH meter, Digital conductivity meter (Model HI 8633), Spectrophotometer were used. Dissolved oxygen, Biochemical Oxygen Demand was analyzed using Wrinkler's method, Phosphate was determined as inorganic phosphate by Spectrophotometric method, Chloride and Nitrate parameter was analyzed volumetrically (APHA, 2012; Trivedi & Goel, 1986).

Water quality classification using Bach Index

Bach water quality index (Bach, 1980) was used to determined quality classes. In this index eight parameters viz. temperature (°C), oxygen saturation (%), BOD_5 (mg/L), pH, NO_3-N (mg/L), PO_4-P (mg/L), NH_4-N (mg/L) and Electrical Conductivity (µS/cm) was used and the transformed value raised to power of the weight of the particular parameter was calculated and thus obtained eight values for eight parameters which are multiplied to get chemical index of that site (Pradhan, 1998). The following equation was used to calculate chemical index as;

$$CI = \prod_{i=1}^{n} q_i^{w_i}$$

Here, CI stand for chemical index, qi is transfer value of each parameter; Wi is relative weight of particular parameter, and qi^{wi} represent the value of each parameter obtained after analysis.

Table 1 *Classification of water quality index*

Index (CI)	Water Quality Class	Water Condition
>83	I	No or very low pollution
73-82	I-II	Low pollution
56-72	II	Moderate pollution
44-55	II-III	Critical pollution
27-43	III	Sever pollution
17-26	III-IV	Very sever pollution
<17	IV	Excessive pollution

The data was analyzed using statistical tools such as, MS Excel 2010 version and IBM statistics SPSS 20. Paired t-test was used to determine variation of water quality in pre-monsoon and post-monsoon season, respectively.

Results And Discussion

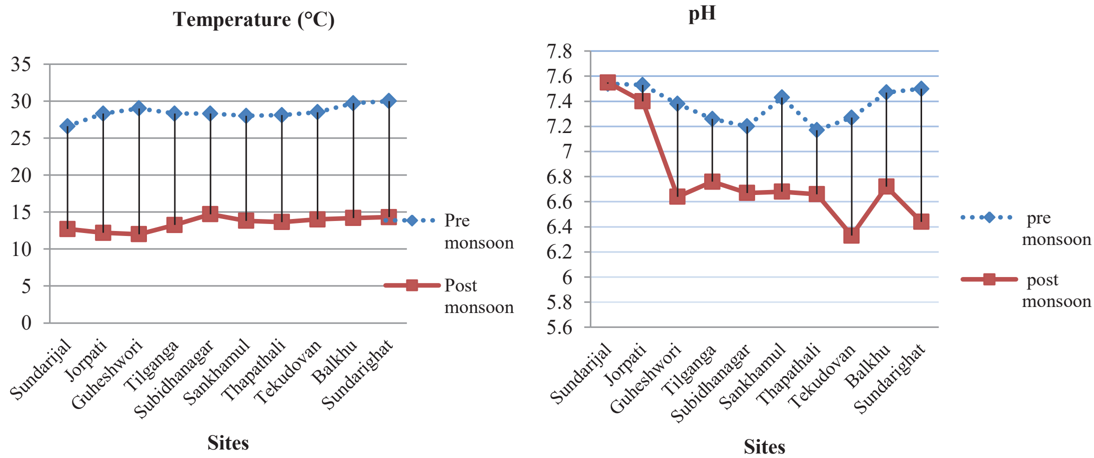
The results in physicochemical analysis and Bach water quality index are as given below.

Physicochemical Analysis

Result showed that temperature was ranged between 30°C to 26.2°C and 14.32 °C to 12 °C in pre-monsoon and post-monsoon respectively (Figure 2 a). There was no drastic change in temperature with respect to sites but high fluctuation of water temperature from pre-monsoon to post-monsoon season was observed. This might be due influence of seasonal weather. High temperature enhances the growth of microorganism and leads to higher microbial activity. Higher temperature also enhances the chemical reaction and higher biological oxygen demand in water thereby lowering the dissolved oxygen (Trivedy & Goel, 1986). The water quality of the Bagmati River was reported relatively better during monsoon season due to higher river flow in comparison to the pre monsoon and post monsoon season (Mishra, et al., 2017).

Similarly high temperature in downstream might be due to mixing of industrial effluents and sewerage. The paired sample t-test on the temperature between two seasons showed that there was significant difference between water temperatures of river at 5 % level of significance.

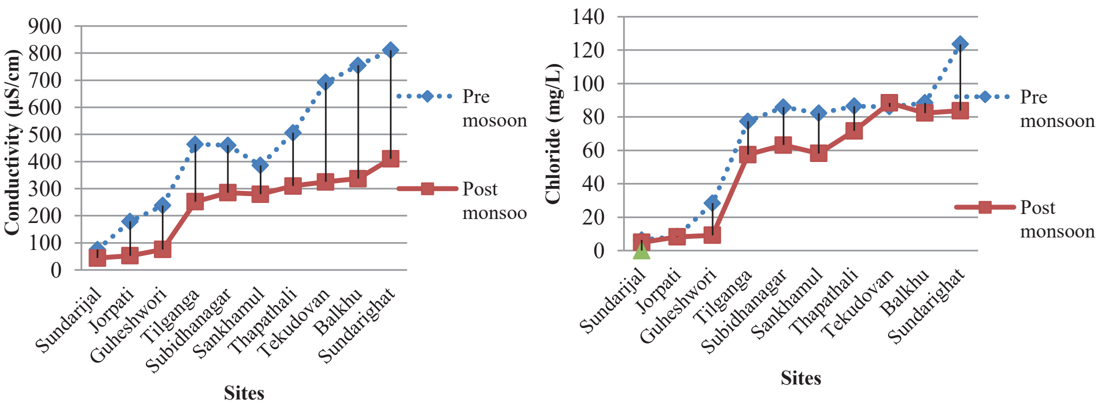
Figure 2 *Variation in Temperature (a) and pH (b)*



The river water pH was found between 7.56 to 7.17 in pre monsoon and 7.55 to 6.33 in post monsoon season (figure 2 b) which was ranged between 6.5 and 8.5 thus indicating normal condition in terms of pH. Result showed that the water pH of Bagmati River was slightly neutral to alkaline in pre-monsoon and slightly acidic in post-monsoon season. This might be due to low water flow in the river during pre-monsoon season resulting into poor water. The result was reported pH range from 7.7 to 8.2 in a report by Mahat and co-workers (Mahat et al., 2020).

Result revealed that from Jorpati to downstream of Bagmati River pH was in decreasing trend in both the season (Figure 2 b). The reduction in pH might be due to industrial effluent discharged from carpet and dyes. The increased of pH from Teku dovan to Sundarighat course might be due to high discharge of sewage into the river. The paired sample t-test of pH between two seasons showed that there was significant difference between pH in pre-monsoon and post-monsoon seasons at 5 % level of significance.

Figure 3 *Variations in Conductivity (a) and Chloride (b)*



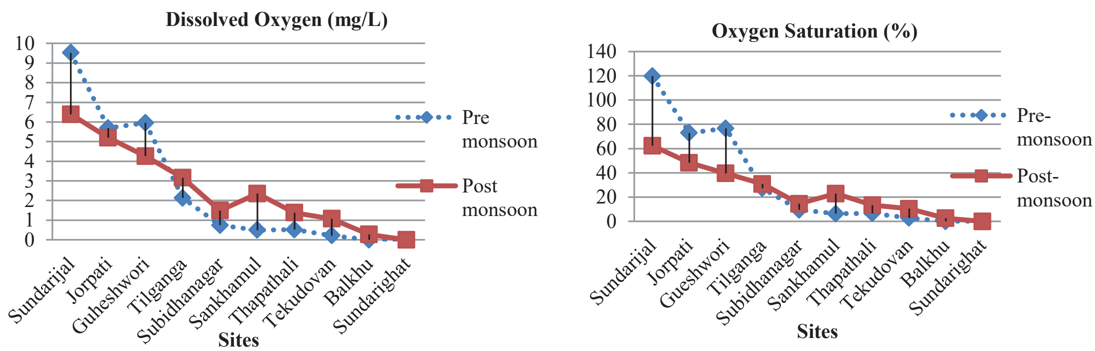
Electrical conductivity (EC) was maximum (810.5µS/cm) at Sundarighat in pre-monsoon season. The minimum value of EC (43.75 µS/cm) was measured at Sundarijal in post-monsoon season. Conductivity increases with increase of the degree of pollution. The increasing trend of EC was found in both the season. Conductivity of water greater than 20 mS/cm is not suitable for irrigation (Trivedy and Goel 1986). Conductivity of river water found between 165 µS/cm to 990µS/cm in a study conducted by Gautam and co-workers (Gautam et al., 2013). Similar result is published in a report by Basnet (2013) where, the EC ranged between 2-758 µS/cm.

Chloride content was higher in post-monsoon as compared to pre-monsoon. The chloride concentration increased from Sundarijal and reached maximum (132.54 mg/L) at Sundarighat downstream of the river. The chloride concentration sharply increased at Tilganga site where the value was measured 77.39 mg/L in pre-monsoon and 57.51 mg/L in post-monsoon. Chloride increased rapidly at Tilganga (77.39 mg/L). This might be due to untreated sewerage and the ash remains which are discharged in the river in between Tilganga and Aryaghat site. This result is in the accordance with the report published by Gautam and co-workers between 14.3 to 145 mg/L (Gautam et al., 2013). The result of paired sampled t-test was found that there was significant difference between chloride in pre-monsoon and post-monsoon seasons at 5 % level of significance. This might be due to low flow in pre-monsoon as compared to post-monsoon. The rapid increase in chloride in downstream both seasons might be due to the mixing of untreated sewers and industrial effluents, which was received as it flows downward city area.

The dissolved oxygen (DO) concentration in pre-monsoon was measured 9.7 mg/L at Sundarijal and 0 mg/L at Balkhu site. It was found that the dissolved oxygen level at Jorpati was 5.69 mg/L, which was slightly increased to 5.95 mg/L at Guheshwori. The dissolved oxygen level then decreased at Tilganga site and gradually reached to zero in downstream at Balkhu and Sundarighat site. Similarly, in post-monsoon, dissolved oxygen concentration was 6.39 mg/L in Sundarijal and zero in Sundarighat site. These findings show the decreasing trend of DO along downstream of the river.

Mahat et al., (2020) reported the DO between 11 – 2.43 mg/L during the monsoon season which is greater than the present result obtained. The maxmium value of DO was reported in monsoon which might be due to high discharge of river. In this season less amount of rainfall was observed. But the paired sampled t-test of DO concentration in the season revealed that there was no significant difference in pre-monsoon and post-monsoon at 5 % level of significance. The zero value of DO indicated that Bagmati River was highly polluted.

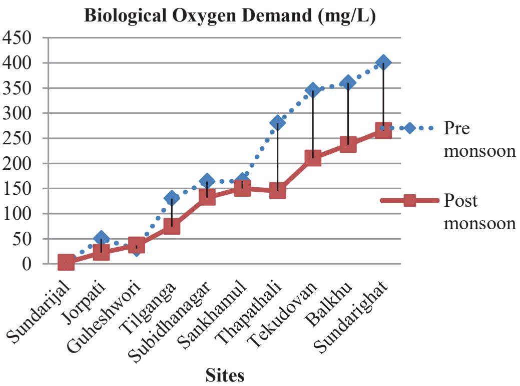
Figure 4 *Variation in dissolved oxygen (DO) (a) Oxygen Saturation (b)*

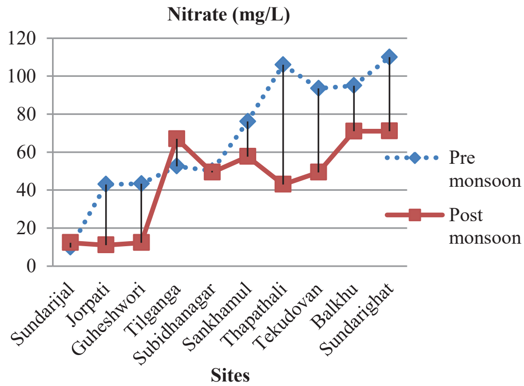


At the same time the oxygen saturation percentage was found to be 129 % and 62 % at Sundarijal in pre-monsoon and post-monsoon respectively. The oxygen saturation gradually decreased when the river passed through the city. But, at Guheshwori in pre-monsoon, the oxygen saturation level again increased to 76 %. Nevertheless, the value in both the season at Sundarighat was zero (Figure 4 b).

Biological oxygen demand (BOD_5) is an important parameter to assess water quality of the surface water. The BOD_5 value is used to measure quantity of degradable waste. The Biological Oxygen Demand (BOD) was measured between 2mg/L - 400 mg/L in pre-monsoon season and 2.4 mg/L - 265 mg/L in post-monsoon at Sundarijal and Sundarighat site, respectively.

Figure 5 *Variation in Biochemical oxygen Demand (BDO) (a) Nitrate (b)*





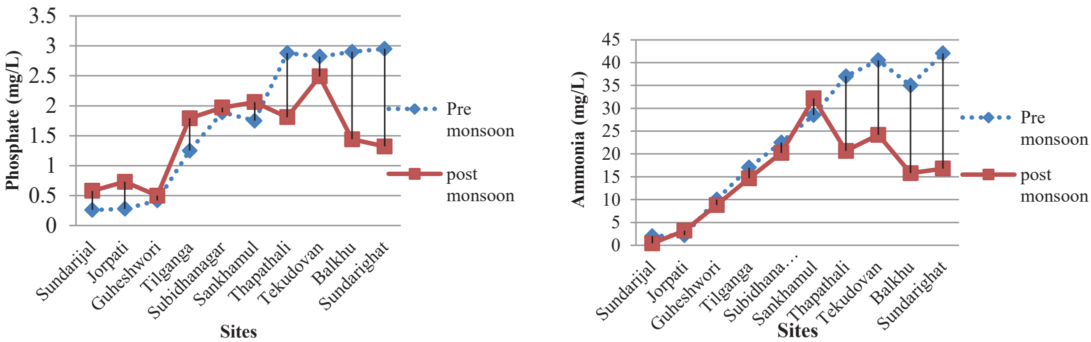
The BOD_5 concentration was increased at Jorpati (50 mg/L) and again decreased (30 mg/L) at Guheshwori site. The result shows an increasing trend of $BOD_5$from Sundarijal to downstream at Sundarighat. The similar trend was obtained in post-monsoon season. This result was similar to the result observed by Gautam and co-workers, (Gautam et al., 2013). In the report the BOD_5 value ranged between 11 mg/L - 293 mg/L. While, a study by Mahat reported between 2.5 mg/L – 112.4 mg/L (Mahat, et al., 2020).

Domestic sewage contains maximum amount of nitrogenous compounds which are transformed in to ammonia producing unpleasant odor (APHA, 2012). The nitrate nitrogen was measured 9.81 mg/L at Sundarijal site and increased to 43 mg/L when the river reached at Jorpati in pre-monsoon season. In post-monsoon, the value was measured between 11 mg/L and 71 mg/L in Sundarijal and Sundarighat sites, respectively. The nitrate concentration was sharply increased at Tilganga and Sankhamul sites where the values were 52.5 mg/L, 76.11 mg/L respectively. At Thapathali site nitrate was measured 106 mg/L in pre-monsoon. Nitrate concentration was rapidly increased at Tilganga for both seasons. Result showed that the increasing trend in nitrate concentration from upstream to downstream in both seasons (Figure 5 a). Similarly, Mahat et al., 2020 reported that nitrate content of the Bagmati River was found between 0.84 – 1.1 mg/L which was not similar with the present result.

Phosphorus occurs in water mostly in the form of phosphate. Phosphate present in soluble or particulate forms. In most natural surface waters, phosphorus ranges from 0.005-0.20 mg/L as PO_4-P (ENPHO, 1997). The phosphate concentration at Sundarijal and Sundarighat sites in pre-monsoon was 0.26 mg/L and2.95 mg/L, respectively

(Figure 6 a). When the river passed ahead from Guheshwori to downstream, the phosphate concentration rapidly increased and measured 2.88 mg/L at Thapathali site. This was the maximum value of phosphate analyzed in pre-monsoon season. The phosphate concentration after Thapathali remained constant till Sundarighat site. In post-monsoon, the value increased from Gueshwori to Sankhamul site. The phosphate concentration at Thapathali decreased to 1.18 mg/L. Thereafter, again at Teku site the value sharply increased and measured the phosphate concentration to 2.49 mg/L. From Thapathali to Sundarighat it was rapidly decreased.

Figure 6 *Variation in Phosphate (a) Ammonia (b)*



Ammonical nitrogen concentration was estimated 2 mg/L - 42 mg/L between Sundarijal and Sundarighar in pre-monsoon. In post-monsoon season, it ranged from 0.41 mg/L - 32.18 mg/L. The analyzed result shows increasing concentration of ammonia from Sundarijalto downstream of the river. In both the seasons, the ammonia concentration sharply increased at Sankhamul site. Thereafter, the value decreased in post-monsoon. In pre-monsoon, ammonia concentrations continue increased till to Tekudovan and decreased to 35 mg/L at Balkhu site. From Balkhu to Sundarighat, the value again increased and reached the concentration to 42 mg/L.

A research reported by Bhandari et al., (2017) the water quality of Bagmati River during pre-monsoon, monsoon and postmonsoon season, the most of the measured parameters EC, TSS, Cl, Ammonia, Phosphorous, BOD and COD was found to be increased as the river flows downward was observed that indicates severe contamination of the river.

Paired sample t-test was used to test whether the physic-chemical parameters in different seasons significantly differ or not. The results were presented in Table 2. The analyzed result shows that dissolved oxygen concentration and phosphate concentration was no significantly different at 95 % level of significance level.

Table 2 *Paired sample t-test for physicochemical parameters in two seasons*

Parameters	t-value	D f	P-value	Significance
Temperature (°C)	26.93	9	0.000	Significant difference
pH	5.578	9	0.000	Significant difference
Conductivity (µ S/cm)	5.265	9	0.001	Significant difference
Chloride (mg/L)	3.491	9	0.007	Significant difference
Dissolve oxygen (mg/L)	-.065	9	0.950	No significant difference
BOD_5 (mg/L)	3.424	9	0.008	Significant difference
Nitrate -N (mg/L)	3.154	9	0.012	Significant difference
Phosphate -P (mg/L)	1.053	9	0.320	No Significant difference
Ammonia (mg/L)	2.483	9	0.035	Significant difference

Water Quality Class by Using Bach Index

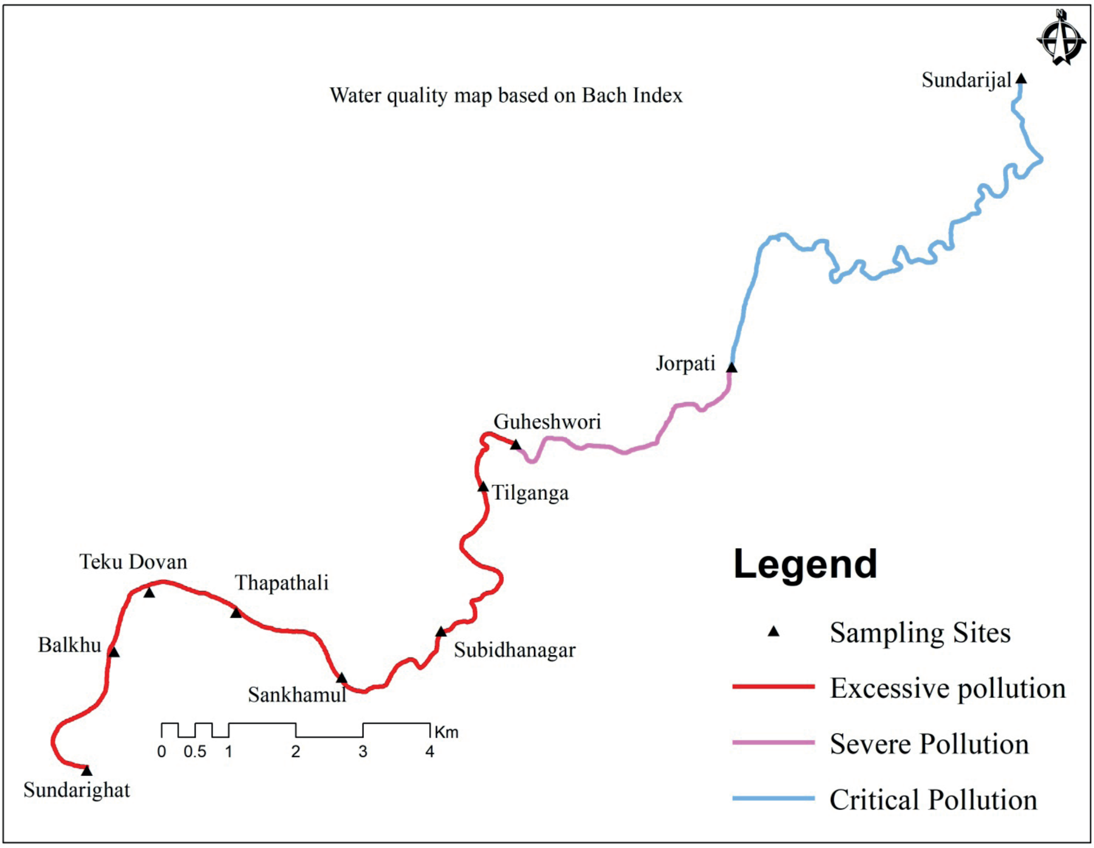
The result of Bach water quality index was presented in Table 3. On the basis of water quality index the river segments were classified and indexed in the map (Figure 2).

Table 3 *Water quality classification using Bach Index*

Segments	Pre-monsoon			Post -monsoon		
	$\prod_{i=1}^{n} q_i^{w_i}$	Class	Water condition	$\prod_{i=1}^{n} q_i^{w_i}$	Class	Water condition
Sundarijal	43.91	II-III	Critical Pollution	47.19	II	Critical Pollution
Jorpati	21.14	III-IV	Very Sever Pollution	18.00	III-IV	Very sever Pollution
Guheshwori	14.04	IV	Excessive Pollution	14.22	IV	Excessive Pollution
Tilganga	8.20	IV	Excessive Pollution	11.38	IV	Excessive Pollution
Subidhanagar	6.35	IV	Excessive Pollution	9.33	IV	Excessive Pollution
Sankhamul	6.18	IV	Excessive Pollution	10.40	IV	Excessive Pollution
Thapathali	6.15	IV	Excessive Pollution	9.18	IV	Excessive Pollution
TekuDovan	5.13	IV	Excessive Pollution	8.54	IV	Excessive Pollution
Balkhu	5.03	IV	Excessive Pollution	7.80	IV	Excessive Pollution
Sundarighat	4.88	IV	Excessive Pollution	7.76	IV	Excessive Pollution

The river segment at Sundarijalin pre-monsoon belongs to class II-III indicating the critical pollution. The reason behind this might be low flow due to the diversion of water for drinking, irrigation and hydropower generation etc. The sampling site was below Sundarijal power plant near settlements thus some human interference may pollute the water. Jorpati in both the season was belongs to class III-IV, very sever pollution with chemical index (CI) 21.14 and 18 in pre-monsoon and post-monsoon, respectively. This might be due to mixing of untreated sewer, industrial effluents and agricultural runoff from nearby agricultural and livestock farms. From Guheshwori and downstream Sundarighat the river water belongs to class IV depicted as excessive pollution. Tilganga and downstream sites belongs to class IV, indicating excessive pollution as indicated by Bach index. The water quality index map was presented in Figure 2.

Figure 2 *Water quality classification map of Bagmati River*



Conclusions

Water quality assessment of Bagmati River clearly shows the river was being deteriorated from upstream Sundarijal to downstream Sundarighat. Pollution level was found higher in Bagmati River during pre-monsoon season as indicated by Bach water quality index. The Physico-chemical parameter except DO and Phosphate concentration in river water was significantly different in two seasons at 5% level of significance. The similar trend of degradation of water quality was found in both the season. Bach water quality index suggested that the river segment at Sundarijal in both seasons belongs to class II-III indicating critical water pollution at the site. Jorpati (class III-IV) classified as very severe pollution. Guheshwori and downstream Sundarijal (class IV) depicted as excessive pollution. As river flows downstream receives excessive pollutant from sewerage canal, industrial effluents, dumping of garbage and solid waste. Such situations constantly degrade water quality and disturb water ecosystem.

Recommendation

Water quality assessment of Bagmati River depicted that there is excessive pollution while river enters into city core due to untreated sewerage, industrial effluents, dumping and burning of waste, unmanaged location of solid waste transfer stations, poor management of cremation ash etc. Thus it is recommended to treat waste water before discharge to the river. It is also recommended to arrange proper management of cremation ash and garbage. Illegal dumping of solid waste and burning of garbage and plastic materials along the river should be prevented. Different Bagmati River protection campaigns such as save the Bagmati River, clean Bagmati River and public awareness program should be promoted and implement effectively to make the Bagmati River free from pollution.

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