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From Source to Sink: Water Quality and Impact Mapping within the Kathmandu Valley

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Abstract. The Bagmati River, the heart of the capital has been degrading substantially challenging public health, environmental health and entire ecological system. Identification of the pollution in the river helps to find the river ecosystem. This study highlighted temporal variations in water quality of the Bagmati River and its major tributaries within the Kathmandu Valley. Using the secondary data analyzed for key physicochemical and microbiological parameters including BOD, COD, DO, fecal coliform, pH, phosphate, TDS, TSS and turbidity, results indicate severe declination in urban stretches, with DO constantly falling below 2 mg/L and BOD values exceeding In areas with a lot of people, the levels were really high around 300 mg/L. The study also looked at how things changed during different times of the year and it was found that pollution hotspots were concentrated during winter due to low amount of water flowing out. In most places, over 80%, the water wasn't very clean. The river is so polluted that it's not good for fish and other water life. However, upstream headwaters with good water quality could be found. In this regard, the tributaries such as Bishnumati, Dhobi Khola, Hanumante, and Tukucha are major tributaries in conveying pollutants into Bigamti River system. The result showed that there was an inverse correlation between BOD and DO, where the high value of BOD accounted for almost 62% variations of dissolved oxygen. Through principal component analysis, four primary pollution sources were detected: sediment laden runoff, organic and nutrient enrichment from sewage, fecal contamination, and untreated urban wastewater inputs. The study shows the urgent need for proper river basin management, better treatment of wastewater, strict laws for environmental protection, and intervention at community levels. The results of this study might offer an effective, scientific framework for effective restorative efforts to ensure sustainable management of water resources in the valley.

Keywords: GIS mapping, Potential Pollution sources, Spatio-temporal analysis, Water quality assessment.

1. INTRODUCTION

Urban rivers form a critical subsystem of the city environment, providing ecological services that support urban populations. However, rapid urbanization and unmanaged economic growth have made urban river pollution an increasingly critical global issue, degrading water quality and disrupting aquatic ecosystems in cities worldwide [1]. Among more than 6000 rivers flowing across the country, the Bagmati River holds profound cultural, religious and ecological significance in Nepal, especially within the Kathmandu Valley. It is regarded as one of the most sacred rivers in Hinduism which plays a central role in the spiritual life of the local population. The Bagmati River is a rain fed river and most of its water is contributed by runoff. There are 24 main tributaries originating from Mahabharat and Siwalik which feed the Bagmati River [2]. The Bagmati River originates in

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Baghdwar just below the summit of Shivapuri hill and is fed by springs and monsoon rainfall and a number of tributaries as it flows down from the Kathmandu Valley floor and passes through the valley at Chovar. The total area of the Basin within Nepalese territory is about 3638 km^2[3].
The sewerage system of Kathmandu valley is of combined type, designed to collect rainwater runoff, domestic sewage and industrial wastewater in the same pipe [4]. The current practice of discharging untreated sewage into the Bagmati River system is causing widespread pollution that becomes hazardous during drier periods. The proposed waste water treatment plants (WWTP) were found to be largely inadequate in reducing the extent and duration of river water pollution [5].
Kathmandu city began to witness a population influx during the 1950s, and the rate increased exponentially after the 1980s [6]. Over 95% of wastewater in the Kathmandu Valley is discharged untreated into rivers like the Bagmati, with 93% originating from domestic sources and 7% from industrial sources [7]. Studies indicate a high presence of waterborne pathogens in the Bagmati River, attributed to the disposal of trash and other debris by the dense population in the area [8]. River water quality is commonly assessed using physical, chemical, and biological parameters such as dissolved oxygen (DO), biochemical oxygen demand (BOD), nutrients, and fecal coliform bacteria. Among these, DO and BOD are widely recognized as critical indicators of organic pollution and ecological stress [9]. 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 [10].
High BOD and nutrient loads promote eutrophication and alter natural river ecosystems [10]. The minimum DO level required for healthy aquatic life is generally considered to be above 5 mg/L. At this level, most fish and invertebrates can thrive. As DO drops below 5 mg/L, aquatic organisms become stressed. Below 2–3 mg/L, the condition is defined as hypoxia (a "Dead Zone"), which is lethal to most fish, causing them to flee or suffocate [11]. The river's decline quality impacts cultural practices historically linked to its waters, reducing its usability for rituals, washing, and community gatherings, compounding local perceptions of environmental loss [12].
The objective of this research is to assess water quality investigation with GIS-based mapping technique. This research analyzes the spatio-temporal trend and seasonal variations for the better understanding of the water quality status along the travel route. Furthermore, this research focuses on the correlation between the water quality parameters and potential pollution contributors which helps to understand the variations in the parameters and its visual and data-driven approach may support the development of targeted restoration efforts. Additionally, the research seeks to raise public awareness about the deteriorating health of the river and emphasize the need for collective environmental responsibility.

2. METHODOLOGY

2.1. **Study area and sampling sites.** This study focused on the Bagmati River within Kathmandu Valley, covering approximately 25 km from Sundarijal (upstream) to Chovar (downstream). As the study relied on secondary data, the sampling locations were those already established by the High Powered Committee for Integrated Development of Bagmati Civilization (HPCIDBC), rather than being selected by the researchers. These locations spanned areas of varying population density and landscape characteristics, and included the Bagmati River mainstem along with its major tributaries Dhobi Khola, Bishnumati, Nakkhu, Tukucha, and Hanumante (Figure 1).

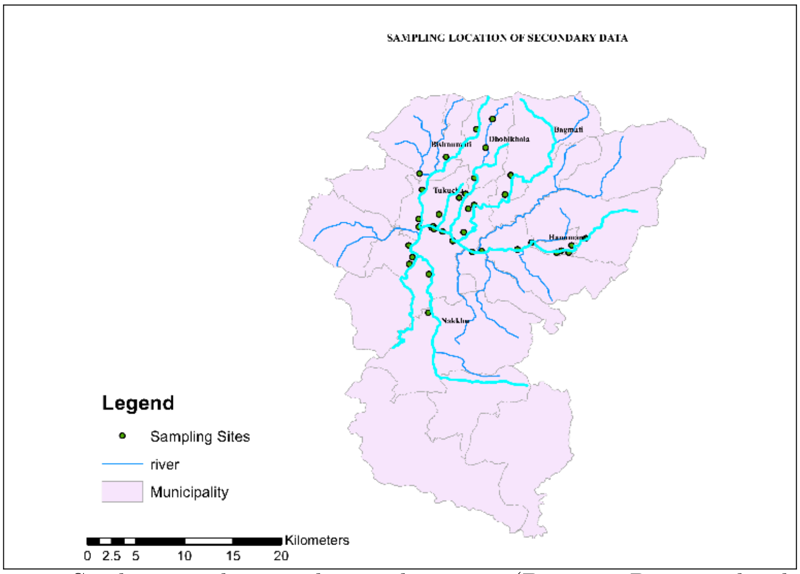

FIGURE 1. Study area along with sampling sites (Bagmati River and tributaries within Kathmandu valley)

2.2. **Data collection.** This project primarily depends upon the secondary data covering four years (2079–2082 B.S.) obtained from the High Powered Committee for Integrated Development of Bagmati Civilization (HPCIDBC). These data provide the physical, chemical and microbiological parameters of Bagmati River Basin within Kathmandu Valley.
The water quality parameters analyzed in this study are listed in Table 1, with threshold values based on national standards.

TABLE 1. Water quality parameters and their ideal value

Parameter	**Threshold Value**	**Ideal Value**	**Unit**
pH reading	6.5–8.5	7	–
Turbidity	< 100		NTU
TSS	< 500		mg/L
TDS	< 10000		mg/L
DO	5–9	6.5–8	mg/L
BOD	< 30		mg/L
COD	< 250		mg/L
Fecal Coliforms	2000		CFU/100 ml
Total Phosphate	0.10		mg/L

2.3. **Water quality assessment.** In this research, WQI was calculated for the river combining all the physicochemical and biological indicators within the scope of study, based on the modified National Sanitation Foundation method (NSF). This approach provides a quantitative assessment of overall water quality by integrating multiple water quality parameters into a single index value, allowing for easy interpretation and comparison across sites. The resulting index value categorized water quality into several classes as in Table 2.
WQI was calculated by using the expression given in equation (1).

$$WQI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \tag{1}$$

where Q_i and W_i represent the Quality rating and unit weight of the i-th parameter, respectively.

The quality rating (Q_i) is calculated using the expression given in Equation (2):

$$Q_i = \frac{V_a - V_i}{S_i - V_i} \times 100 \tag{2}$$

where V_a, V_i, and S_i are the estimated value, ideal value (pure water), and standard permissible value (WHO) of the i-th parameter, respectively. In general, higher values of these parameters contribute to an increase in the Water Quality Index (WQI).Based on the study requirements and selected parameters, standard weights and measurement methods for the National Sanitation Foundation's Water Quality Index provided by [13] were subsequently adjusted, and the modified weighting factors used for the work.

TABLE 2. Water quality index classification

Water Quality Index Range	**Classification**
≤ 25	Very Clean
25–50	Clean
50–70	Moderate
70–85	Polluted
85–100	Heavily Polluted

2.4. **Statistical analysis.** Pearson correlation analysis, linear regression, and Principal Component Analysis (PCA) were performed using Microsoft Excel and SPSS. It helped to simplify the complex raw datasets to determine and develop relationships among parameters providing a scientific basis for effective water resources management and environmental protection. Multivariate statistical techniques, particularly PCA, provide a robust framework for data reduction, pattern recognition, and source apportionment in environmental studies [14].

3. RESULTS AND DISCUSSION

3.1. Spatio-Temporal variation.

BOD. Very low concentration of BOD particularly < 5 mg/L were observed in the upstream site locations of Bagmati and its tributaries, Sundarijal, Gokarna, Budhanilkantha due to minimal human influence. As the river flows through the urban area up to the exit, the concentration exceeded 300 mg/L in most of the area including Teku, Thapathali, Sundarighat, Chovar (Figure 2) exhibiting extreme organic pollution.

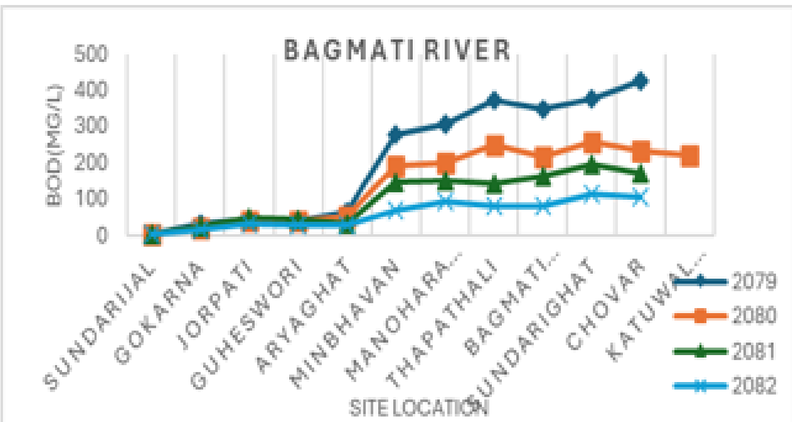

FIGURE 2. BOD variation from upstream to downstream showing sharp increase in urban corridor.

DO. The DO value ranging from 6.5–8.5 mg/L were witnessed at the upstream sites; Sundarijal, Gokarna, Budhanilkantha, Chapali. However, Bishnumati, Tukucha, Dhobikhola showed severe oxygen depletion (< 1 mg/L) throughout their urban reaches (Figure 3 and Figure 4). Partial recovery was seen at Chovar possibly due to dilution and reaeration. The system continues to operate near ecological thresholds, where minor increases in organic load or reduced flow conditions could trigger severe hypoxia.

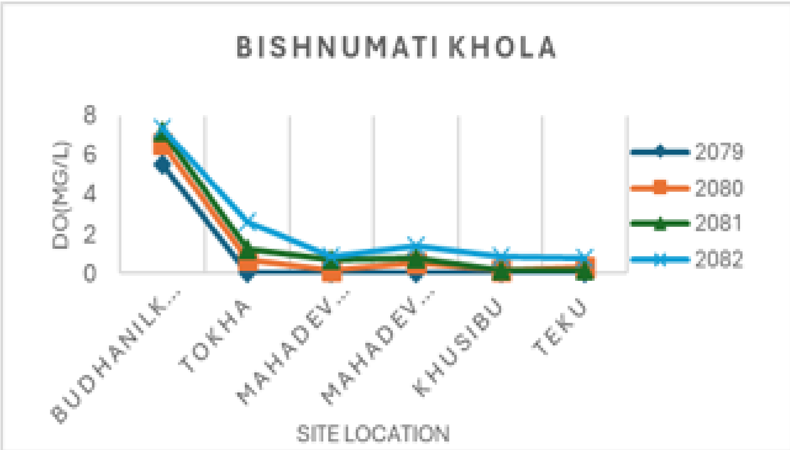

FIGURE 3. DO variation showing hypoxic conditions in urban stretches of Bishnumati

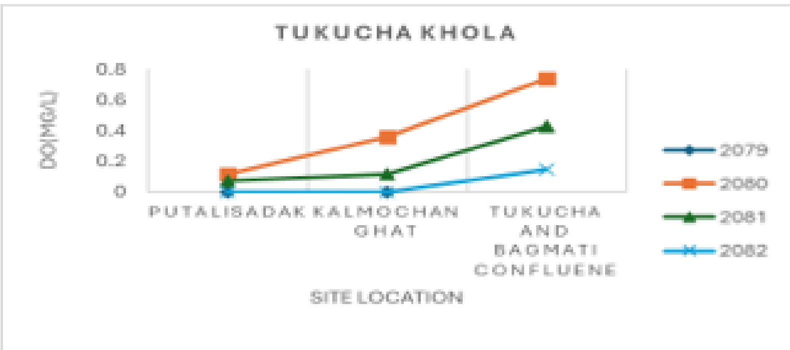

FIGURE 4. DO variation showing hypoxic conditions in Tukucha

pH. The pH pattern across the Bagmati River and its tributaries reflects that the river system remains mostly near neutral to slightly alkaline (6.5–7.5), which is generally favorable for aquatic life. Upstream locations have slightly higher pH values (Figure 5) due to less anthropogenic influence. As the rivers move through densely populated areas, pH values decreased slightly and became more uniform which is mainly due to the mixing of domestic wastewater, organic matter breakdown, and inflow from polluted tributaries rather than strong acidic or industrial discharges. Although pH values remain fairly consistent with only minor fluctuations, it should not be misunderstood as good water quality. The river is still under ecological stress from high organic pollution, and controlling wastewater discharge is essential to protect and improve overall river health.

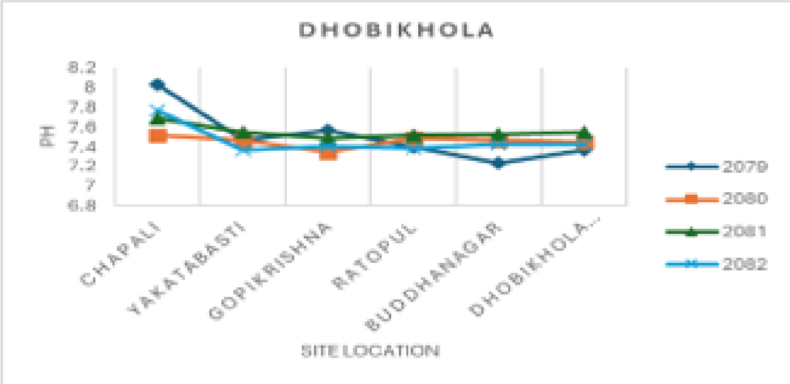

FIGURE 5. pH variation showing almost neutral concentration

TSS. Upstream locations of the Bagmati River, such as Sundarijal and Gokarna maintain relatively low TSS. Bishnumati and Dhobikhola experience exceptionally high TSS, especially in densely built sections (Figure 6), pointing to strong influences from untreated wastewater discharge, road runoff, construction activities, and solid waste disposal. This pattern highlights the Bagmati's limited capacity for natural recovery within the urban corridor, where continuous external inputs dominate over dilution and sediment settling processes. Temporal variation across the years indicates a general reduction in TSS during later monitoring periods, particularly in 2082 B.S., suggesting early impacts of pollution control measures, improved waste management, or reduced sediment mobilization.

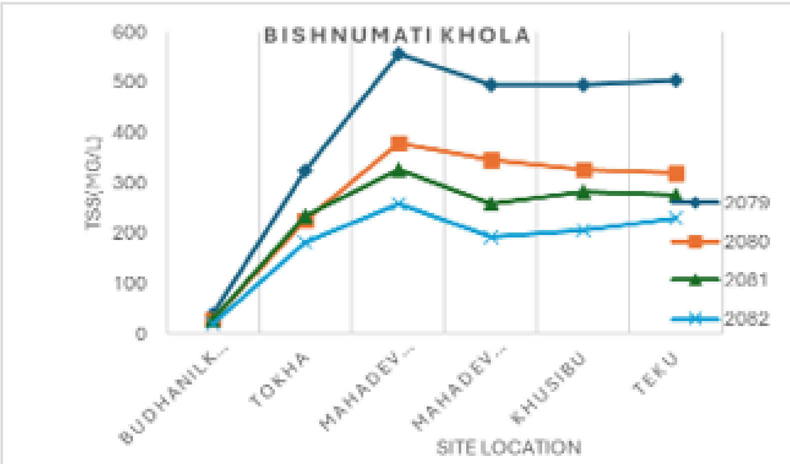

FIGURE 6. TSS variation with peak concentration during 2079 B.S.

Fecal Coliform. Fecal coliform concentrations at headwater locations were quite low, indicating minimal human impact. Dense urban and peri-urban areas such as Minbhavan, Thapathali, Sundarighat, Teku, Mahadev Khola, and Chuping Ghat have highly elevated concentrations, often in the millions per 100 mL (Figure 7), demonstrating serious contamination. Confluences, such as Bagmati–Bishnumati and Mahadev Khola–Bishnumati, frequently exhibit increased microbial loads, a sign of cumulative contamination from several streams. These patterns hint to untreated home wastewater, solid waste leachate, and poorly managed drainage as main sources concentrated in the river's most populous segments. The national standard for bathing is 500 CFU/100 mL, suggesting that urban areas are unsuitable for any human contact.

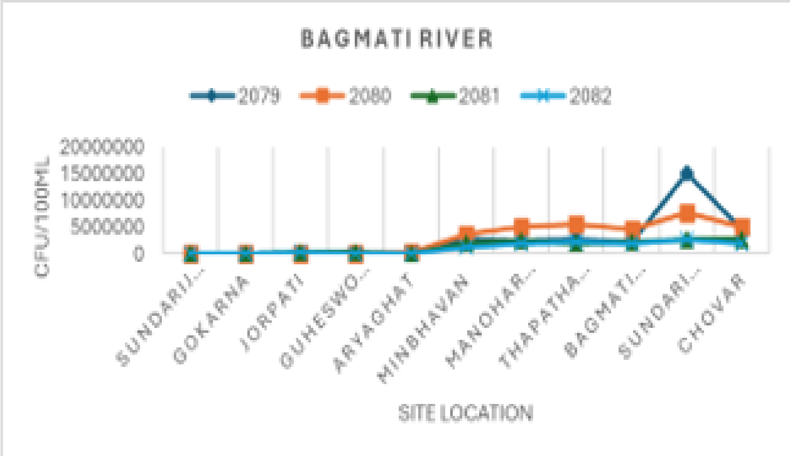

Figure 7. Fecal Coliform variation with severe rise towards downstream

Phosphate. Total phosphate functions as a key nutrient indicator, and elevated levels are typically symptomatic of nutrient enrichment that can trigger eutrophication, excessive algal proliferation, and subsequent depletion of dissolved oxygen. Total phosphate ranged from 0.1 mg/L upstream to > 3 mg/L at urban hotspots; Thapathali, Sundarighat, Chovar In addition, heavily polluted tributaries such as Dhobikhola serve as conduits, transporting nutrient rich waters directly into the main river channel and further amplifying phosphate loads. Among all the tributaries, Nakkhu Khola showed slightly lower concentrations reflecting minimal agricultural runoff and minimal disposal of sullage (Figure 8).

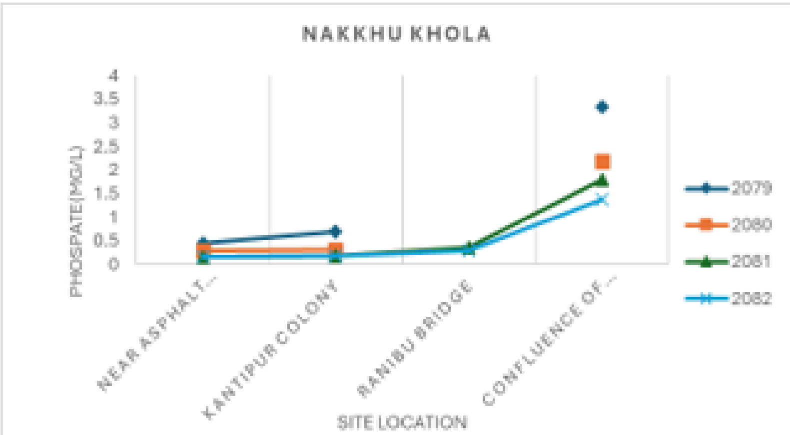

Figure 8. Phosphate variation along Nakkhu stretch

TDS. TDS concentration above 500 mg/L was observed across the urban locations and even in the lower reaches of Bishnumati, Hanumante, Dhobikhola and Tukucha. Tributary rivers contribute significantly to the dissolved load of the Bagmati. Downstream sites like Sundarighat and Chovar also exhibited elevated TDS accumulating dissolved pollutants along the river course with limited natural attenuation.

Turbidity. Upstream sites like Sundarijal and Gokarna maintained relatively low turbidity, consistent with minimal disturbance and natural sediment regulation. Middle stretch of Bagmati, Bishnumati and Tukucha in 2079 B.S. monitoring period showed an immense turbidity of concentration > 600 NTU. This concentration goes on decreasing with the coming years to < 250 NTU showing an immense reduction of the concentration. However, turbidity remains elevated in heavily urbanized tributaries, underscoring the persistence of non-point and point-source pollution.

COD. COD patterns mirrored BOD, with urban sites recording values > 1000 mg/L of first monitoring period of 2079 B.S. in Bagmati, Bishnumati, Hanumante, and Dhobikhola, where large volumes of untreated domestic sewage, industrial effluents, and urban runoff enter the river system. The consistently higher COD values at downstream and confluence points highlight the cumulative impact of these pollution sources. Nakkhu Khola recorded the minimum COD of almost 400 mg/L with gradual decrease around 200 mg/L over the course of 4 years period.

3.2. **Seasonal variation.** Seasonal river flow creates a pattern of dry season pollution and monsoon season cleaning. During winter and pre-monsoon periods low river flow reduces cleaning capacity and increases water sitting time. This leads to high levels of most pollutants, including high BOD (> 300 mg/L), COD, TDS (> 500 mg/L), TSS, phosphate (> 3 mg/L) and fecal coliform bacteria. At the same time, Dissolved Oxygen (DO) drops to hypoxic levels. The monsoon season brings relief with fast flowing water that dilutes pollutants. This results in lower BOD, COD, TDS, phosphate and fecal coliform levels. However, turbidity and TSS increase a lot because of surface runoff and soil erosion. The data shows that water quality improvements during the monsoon season are mainly due to dilution, not pollution control. This is because pollutant levels quickly go up during dry seasons, highlighting the severe impact of untreated wastewater discharge.

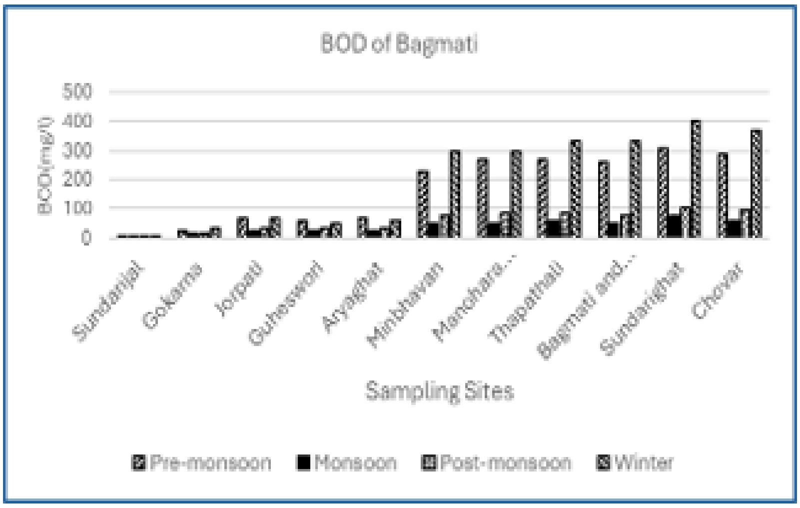

FIGURE 9. Seasonal variation of BOD along stretch of the Bagmati

Temporally, most parameters peaked in 2079 B.S. and showed a slight declining trend toward 2082 B.S.; however, DO remained critically low at urban sites, indicating persistent organic loading. Seasonal analysis revealed higher pollutant concentrations during the dry season due to limited dilution.

3.3. **Regression analysis.** Linear regression between DO and BOD showed a negative slope, with $R^2 = 0.62$, indicating that approximately 62% of the variation in DO concentration is explained by changes in BOD (Figure 10). This inverse relationship reflects the fundamental biochemical processes occurring in polluted river systems. As organic loading increases, microbial respiration intensifies, consuming dissolved oxygen and leading to its depletion.

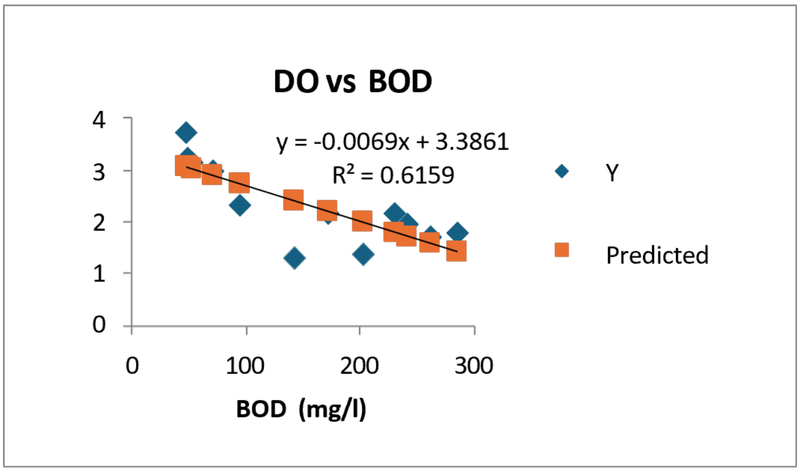

FIGURE 10. Linear regression of DO against BOD ($y = -0.0069x + 3.3861, R^2 = 0.6159$)

3.4. **Principal Component Analysis (PCA).** The principal components accounted for four major pollution sources, whereas all other factors beyond PC4 had very little impact on the variation. Table 3 presents the rotated factor loading matrix.

TABLE 3. Rotated Factor Loading Matrix (PCA)

Parameters	PC1	PC2	PC3	PC4
Fecal coliform	0.420	0.273	0.830	0.217
COD	0.547	0.463	0.380	0.569
Phosphate	0.470	0.545	0.340	0.544
BOD	0.537	0.472	0.400	0.549
DO	-0.366	-0.757	-0.200	-0.390
TDS	0.510	0.551	0.250	0.314
TSS	0.927	0.090	0.250	0.210
Turbidity	0.930	0.111	0.260	0.213
pH	0.027	-0.971	-0.200	-0.120

The four major pollution sources are identified as:

- **PC1 (TSS, turbidity):** Pollution due to erosion and surface runoff.
- **PC2 (negative DO and pH; positive TDS, COD, BOD, phosphate):** Organic and nutrient pollution from sewage discharge and agricultural effluents.
- **PC3 (fecal coliform):** Fecal contamination from domestic and animal waste, open defecation, and sewer line leakage.
- **PC4 (COD, BOD, phosphate, negative DO):** Wastewater discharge and nutrient pollution from small drainages and urban habitation areas.

3.5. **Water Quality Index (WQI).** The WQI at all stations remain within a relatively narrow range, indicating persistently degraded water quality conditions throughout the study period (Table 5). Such a pattern is typical of urban and peri-urban rivers where pollutant sources such as domestic sewage discharge, stormwater runoff, and limited wastewater treatment efficiency are continuously present. WQI values classified 80% of sampling locations as "polluted" (70–85) to "heavily polluted" (85–100). Only upstream sites (Sundarijal, Gokarna, Budhanilkantha) fell under "clean" (25–50) to "moderate" (50–70) categories. Spatial mapping identified critical hotspots at Bishnumati–Bagmati confluence, Dhobikhola–Bagmati confluence, and Hanumante–Bagmati confluence (Figure 11).

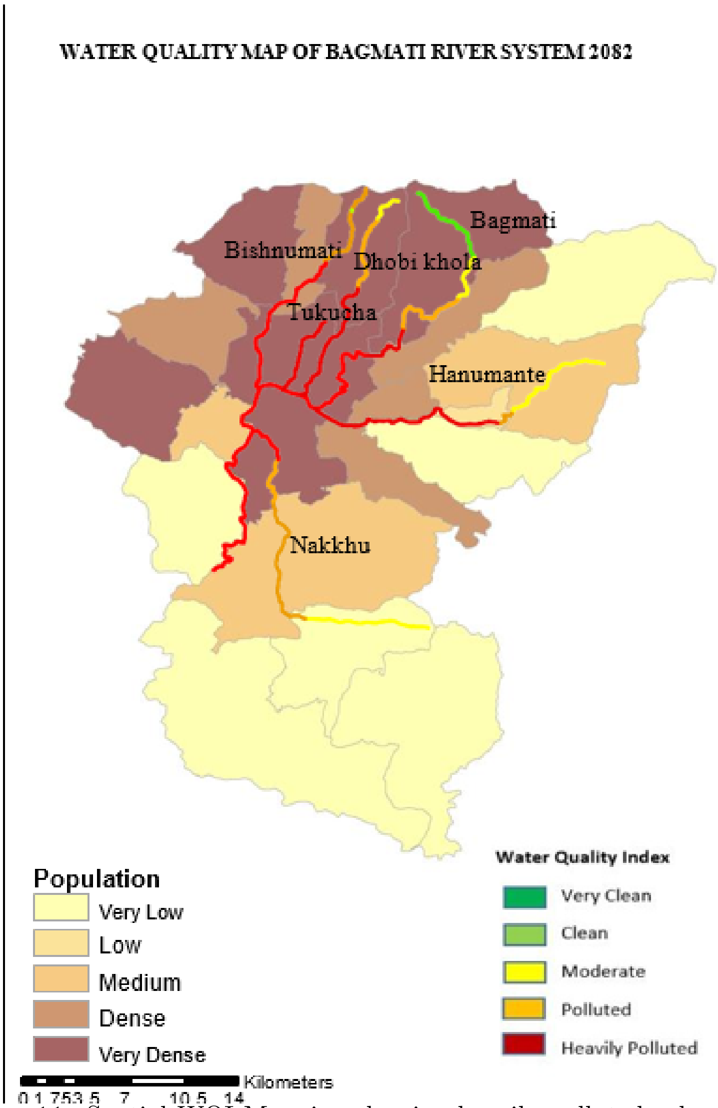

FIGURE 11. Spatial WQI Mapping showing heavily polluted urban corridor and upstream sites

3.6. **Correlation analysis.** Consistent near perfect correlation between Turbidity and TSS showed suspended solids directly contribute to water turbidity. Table 4 showed significant positive correlation of Fecal coliform with BOD (0.823), COD (0.808) and phosphate (0.776) indicating fecal contamination is associated with organic pollution and nutrient enrichment, often from untreated sewage or agricultural runoff, while primary data showed the weak correlation with BOD (0.334) and COD (0.206). This greater variability reflects natural environmental heterogeneity and the limitations of single time grab sampling. DO showed a strong inverse relationship with nutrient and organic pollution indicators (TDS, phosphate, BOD, COD), showing the universal impact of organic loading and ionic concentration on oxygen depletion which is a critical concern for aquatic ecosystem health. The secondary dataset reflected higher internal consistency, potentially indicating more controlled sampling conditions, larger sample size and more homogeneous pollution sources.

TABLE 4. Correlation matrix for secondary data

	pH	**Turb.**	**TSS**	**TDS**	**DO**	**BOD**	**COD**	**Phos.**	**F.Col.**
pH	1								
Turbidity	-0.162	1							
TSS	-0.141	0.996	1						
TDS	-0.625	0.720	0.730	1					
DO	0.803	-0.578	-0.576	-0.919	1				
BOD_5	-0.594	0.787	0.782	0.888	-0.876	1			
COD	-0.582	0.792	0.784	0.876	-0.871	0.997	1		
Phosphate	-0.658	0.729	0.724	0.929	-0.923	0.985	0.982	1	
F. Coliform	-0.445	0.691	0.686	0.692	-0.603	0.823	0.808	0.776	1

TABLE 5. WQI across all the analyzed sites (2079–2082 B.S.)

Site	2079	2080	2081	2082
Bagmati				
Sundarijal	48.74	56.52	52.52	66.63
Gokarna	79.01	82.47	78.22	79.06
Jorpati	89.25	84.94	85.32	87.69
Guheswori	89.90	85.12	85.65	87.13
Aryaghat	87.64	85.62	85.68	86.90
Minbhavan	88.42	86.20	86.39	86.79
Manohara–Bagmati confluence	89.41	86.39	86.70	86.73
Thapathali	88.08	86.92	86.63	86.98
Bagmati–Bishnumati confluence	86.68	86.38	86.52	86.23
Sundarighat	86.75	86.04	87.44	86.28
Chovar	88.71	86.30	87.13	86.58
Dhobikhola				
Chapali	71.83	75.28	75.25	69.99
Yakatabasti	87.16	86.22	86.77	85.41
Gopikrishna	89.12	86.35	87.31	86.66
Ratopul	87.70	87.44	87.74	86.38
Buddhanagar	85.82	86.66	87.62	86.52
Dhobikhola–Bagmati confluence	86.52	86.54	87.60	86.30
Bishnumati				
Budhanilkantha	81.25	62.95	69.35	70.36
Tokha	86.55	86.66	86.67	87.79
Mahadev Khola	86.31	86.80	86.97	87.48
Mahadev Khola–Bishnumati confluence	87.65	86.73	86.85	87.74
Khusibu	88.31	86.45	87.16	87.04
Teku	87.18	86.36	87.35	87.38
Nakkhu				
Near asphalt plant	74.24	75.47	72.67	78.10
Kantipur colony	71.88	77.14	73.62	75.61
Ranibu bridge	–	–	82.39	82.80
Bagmati–Nakkhu confluence	87.19	85.60	87.40	88.31
Tukucha				
Putalisadak	89.52	88.28	88.18	86.94
Kalmochan ghat	89.17	87.65	87.81	87.24
Tukucha–Bagmati confluence	–	87.27	87.55	87.11
Hanumante				
Gonsal	67.16	82.10	66.94	74.14
Bramayani ghat	81.49	82.35	72.86	80.80
Madhu khola	84.89	86.37	86.46	86.10
Birakhola	88.55	85.41	86.29	86.92
Chuping ghat	87.30	85.07	86.69	85.31
Khasangkhusung khola–Hanumante confluence	85.84	86.43	87.80	87.02
Ghattekhola–Hanumante confluence	90.29	86.66	86.73	86.26
Godavari khola–Hanumante confluence	89.65	86.69	86.75	86.84
Manohara–Hanumante confluence	88.44	86.98	87.20	86.95

4. CONCLUSION AND RECOMMENDATIONS

4.1. **Conclusion.** This study confirms severe ecological degradation of the Bagmati River, driven by unchecked urbanization, population growth, and continuous discharge of untreated domestic and institutional wastewater. Water Quality Index results classified over 80% of sampled sites as polluted to heavily polluted, with only the upstream headwaters meeting acceptable standards. Tributaries particularly Bishnumati, Dhobi Khola, and Hanumante were identified as major conduits of pollution into the mainstem, making them priority targets for intervention. Despite modest recent improvements, sewage-driven organic pollution continues to be the dominant factor controlling river health, underscoring the limited effectiveness of current wastewater treatment and restoration efforts. The GIS-based impact mapping developed in this study offers a practical decision-support tool for prioritizing pollution control measures and guiding sustainable, spatially-targeted restoration of the Bagmati River system.

4.2. **Recommendations.** For restoring the quality of the Bagmati River, this study recommends an improvement of the wastewater treatment plants like Guheshwori WWTP along with the compulsory treatment of effluent on site by industries and institutions. Considering the contribution of pollutants made by them, interceptor sewers and treatment processes need to be given priority where Bishnumati, Dhobi Khola, Hanumante, and Tukucha join the Bagmati River. The enforcement of effluent standards together with water quality monitoring will be helpful for early detection of pollution. Cooperation between various agencies is needed for the effective restoration of the river. In future studies, concentration of heavy metals and industrial/hospital effluents can be considered.

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