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Pratik Shrestha[1], Anu Rai[2], Prakash Chandra Wagle[1], and Sheila Ghimire[3]

[1]GoldenGate International College Kathmandu Nepal
[2]Kathmandu University Dhulikhel Karvepalanchok Nepal
[3]Resources Himalaya Foundation Sanepa Lalitpur Nepal

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Research Article

EVALUATION OF DISTURBANCE ZONATION OF BAGMATI RIVER SYSTEM USING BENTHIC MACROINVERTEBRATES IN THE KATHMANDU VALLEY, NEPAL

Pratik Shrestha [1,*], Anu Rai[2,3], Prakash Chandra Wagle[1], Sheila Ghimire[4]
[1]*Department of Environmental Science, GoldenGate International College, Kathmandu. 44600, Nepal*
[2]*Department of Environmental Science and Engineering, Kathmandu University, Dhulikhel, Kavrepalanchok. 45200, Nepal*
[3]*Sustainability and Environmental Studies Endeavor, Kathmandu. 44600, Nepal*
[4]*Resources Himalaya Foundation, Sanepa, Lalitpur. 44700, Nepal*
Correspondence: pratikshrestha2055@gmail.com
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ABSTRACT

The existence of Nepal's holy river, Bagmati, which flows through the core of Kathmandu Valley has been menaced by many anthropogenic threats. It is necessary to identify how vulnerable it has been. This research focuses on the evaluation of disturbance zonation to analyze the Bagmati River System's spatial biological health. Benthic macroinvertebrates (BMIs) were used as biological indicators and were sampled from upstream to downstream using a multi-habitat sampling approach during the post-monsoon period in 2021. The Ganga River System Biotic Score/Average Score per Taxa (GRSBIOS/ASPT) was used to assess river water quality. From the sampling of 21 sites, a total of 5839 individual BMIs from 51 Families and 11 Orders were recorded. Upstream accounted for more than 30% of all the families, making upstream rich in taxonomic preferences, which steadily decreased from midstream to downstream. Facultative taxa were widely distributed in both upstream and midstream, but sensitive taxa were limited to upstream only. There are no signs that facultative and sensitive taxa existed downstream and were fully dominated by pollution-tolerant species. According to classification, the upstream river within Shivapuri Nagarjun National Park of the Bagmati River System was clean and was categorized as Class I, whereas rivers from the boundaries of the protected area to downstream were categorized as Class IV-V with few sites as Class II and Class III, indicating that this stretch of the river was extremely polluted. Water resource managers should utilize the study's findings to assess and restore the water's quality using biological indicators.

Keywords: Bagmati River system, benthic macroinvertebrates, GRSBIOS/ASPT, Kathmandu Valley, river water quality

INTRODUCTION

The freshwater environment is highly sensitive and could immediately react upon a simple influence causing a reduction in water quality and faces a tremendous anthropogenic threat that challenges its existence (Agboola *et al.*, 2019; Dutta *et al.*, 2017). Globally, river pollution has increased tremendously. Keeping track of the status of river water quality is imperative for devising the management action required. However, water quality assessment is a costly endeavor and there are merits and demerits to employing various methods. Aquatic assemblages can be used to find significant gaps in river ecological evaluation and restoration around the world highlighting the most successful instances in Asia, Europe, Oceania, North Central, and South America but drawing a world map of river ecological quality has not been possible thus far (Feio *et al.*, 2021).

Among the various methods available, the use of benthic macroinvertebrates is considered the best biological indicator of freshwater quality as it reveals varying degrees of tolerance to pollution (Rai *et al.*, 2019). The presence and abundance of these macroinvertebrates are altered by the influx of pollutants into the freshwater and hence, can determine the level of disturbances and pollution in a freshwater ecosystem (Hu *et al.*, 2022). The composition and diversity of these benthic macroinvertebrate communities have been strongly used as the foundation for stream evaluation worldwide, leading to several ecological state quantification methods (Kaboré *et al.*, 2022). Benthic macroinvertebrates give a wealth of information on the state of freshwater ecosystems, making them ideal indicator of freshwater quality (Vincent Nakin *et al.*, 2017).

These organisms dwell at the base of substrates like rocks, trash, a chunk of wood, and filamentous algae and rely on them for their survival (Bhandari *et al.*, 2019). The variety and abundance of benthic macroinvertebrates fluctuate as the quality of the river ecosystem deteriorates. Because they are the principal source of food for fish, these benthic macroinvertebrates play a crucial role in nutrient cycling and energy transfer across the lotic ecosystem (Bhandari *et al.*, 2019).

In the 1980s, aquatic insects were used as a bioindicator for the first time in Nepal to assess water quality. Mehta *et al.* (2016) investigated the aquatic biodiversity of the Bagmati River and found that due to the inadequacy of a proper plan, the river's deterioration reached an extreme level, mirroring the decline of civilization in the valley. The Kathmandu Valley has witnessed unpredictable population growth in the last four decades which could be observed through the establishment of new settlement structures near the Bagmati River and its tributaries corridor (Dahal *et al.*, 2011). The results state severe decline in the Bagmati River's ecological state from rural regions to cosmopolitan areas as investigated by Shah & Shah. (2013), which corroborates with the study by Kannel *et al.* (2007) who concluded that the cosmopolitan water quality was substantially worse than rural water indicating a spatio-temporal fluctuation of water quality along the Bagmati River and its tributaries. This is an alarming problem which needs a detailed scientific study. However, only a few studies have looked at the distribution and composition of benthic macroinvertebrates from headwater to downstream of the Bagmati River.

Over time, anthropogenic activities have constantly deteriorated the quality of the river posing threat to its existence and polluting it despite being a holy river and a significant water supply for residential use, irrigation, and commercial purposes. The river's poor water quality has not only impacted human life but has limited the diversity and abundance of aquatic life. Furthermore, the river system's aesthetic value has been diminished as water quality has deteriorated. Different types of approaches have been implemented to conserve the holy Bagmati River, but the river has been extremely polluted. Also, a comprehensive river quality assessment using biological indicator is lacking. Hence, the goal of the study was to determine the spatial biological health of Bagmati River and its tributaries in Kathmandu Valley based on benthic macroinvertebrates, for management and restoration planning as well as further research purposes.

MATERIALS AND METHODS

Study Area

The study area covers a total of 25-kilometer stretch of the Kathmandu Valley's major water system, which includes Bagmati River and its tributaries; the Bishnumati River, and the Dhobi Khola River, all of which originate from the Shivapuri Nagarjun National Park (Figure 1). Kathmandu Valley is located in Nepal's hilly region, between latitudes 27° 32' 13" and 29° 49' 10" N, and longitudes 85° 11' 31" and 85° 31' 38" E, and is divided into three administrative districts: Kathmandu, Bhaktapur, and Lalitpur. The valley sits in the hilly midland and is virtually round in shape, with radii of about 30 km east-west and 25 km north-south and spans a region of about 650 km^2, with averaging an altitude of 1340 m (Kannel *et al.*, 2007).

The Kathmandu Valley has a warm temperate climate, with temperatures ranging from 19°C to 27°C in the summer and 2°C to 20°C in the winter (Regmi *et al.*, 2017). The average annual rainfall is 1900 mm, with the monsoon season (June-September) accounting for around 80% of the total rainfall (Shah & Shah, 2013). The water temperature of the stream varies from 4°C to 24°C with an average of 12°C to 13°C (Rai *et al.*, 2019).

Specifically, at an elevation of 2690 meters, the southern slope of Bagdwar (Shivapuri Nagarjun National Park) is where the Bagmati River commences (Dhital *et al.*, 2021). Likewise, the Bishnumati River and Dhobi Khola also originate from the southern slopes of Shivapuri Hills. Four major tributaries: Manahara, Nakkhu, Balkhu, and Nagmati, drain into the Bagmati River. All these tributaries and the main river are recharged by spring and monsoon rainfall. The water from the tributaries collects in the Bagmati River, which then flows out of the valley through the Chovar Gorge (Shah & Shah, 2013).

Sampling Sites

The spatial biological health of the main river system during the post-monsoon season was investigated by collecting samples from October to December 2021. A total of 21 sites were sampled from the Bagmati River including its two tributaries, the Bishnumati River, and the Dhobi Khola. These sites were distributed among three sub-watersheds of the Bagmati River system. Seven sites are located within the Shivapuri Nagarjun National Park (termed as upstream), six sites are located in the boundaries of the forest area and settlement region (termed as midstream), and the remaining sites are scattered across the city's core (termed as downstream). These locations were chosen based on the types of stressors, land use patterns, river stretch intensity, riverbank accessibility, substrate composition, river flow conditions, tributary confluences, and the presence of anthropogenic activities. Segmentation of upstream, midstream, and downstream are referenced with the urbanization increment, patterns, and trends. The sampling sites along with their location, allocated codes, and substrate types have been tabulated (Table 1).

Collection of benthic macroinvertebrates

The benthic macroinvertebrates samples were collected using the multi-habitat sampling approach (Moog, 2007), during the post-monsoon period when the surface water discharge was comparatively low which increased the accessibility to the study sites. The sampling was carried out in a section of the stream that represented the majority of microhabitat substrates and kinds.

At each location, 20 sub-samples were collected inside a 100 m stretch that includes more than 10% substrate coverage using a kick net with a surface area of 0.25m x 0.25m and a mesh size of 500 μm. A sampling of benthic macroinvertebrates was not considered if there was less than 10% coverage (Shah *et al.*, 2020). Sub-samples from each location were merged into a composite sample, which was then stored in 5% formaldehyde.

The individual sorting of the composite sample was carried out in the laboratory and identified up to the family level using Shah *et al.* (2020). They were enumerated and again preserved in a 5% formaldehyde solution for future reference.

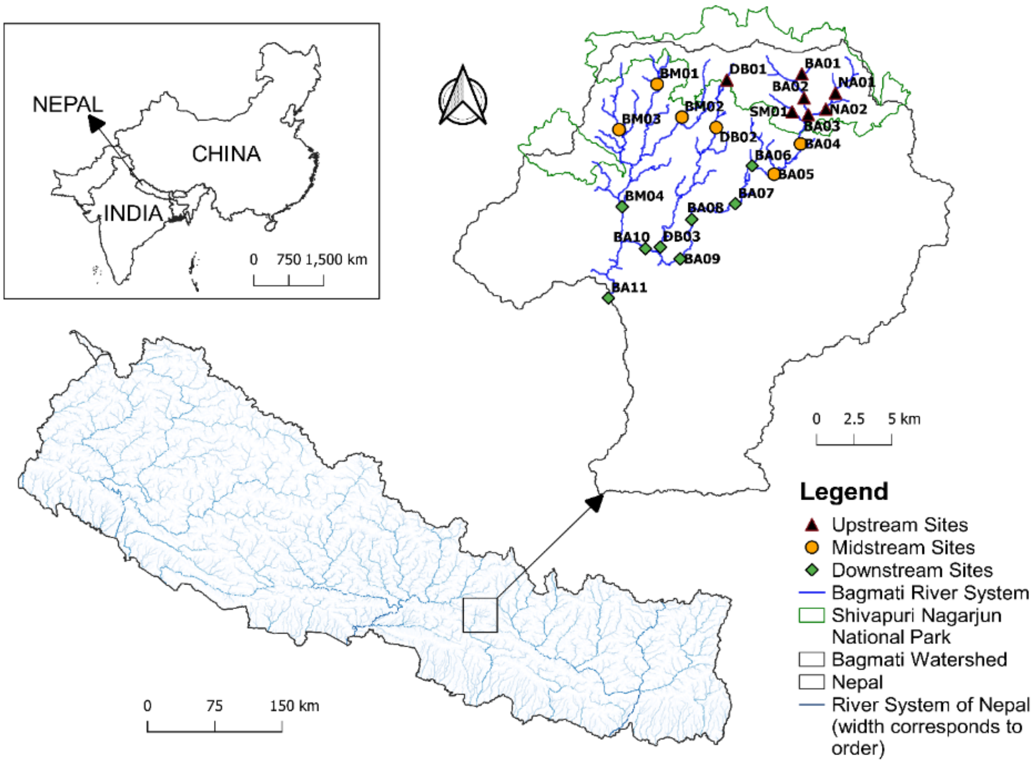

Figure 1. Atlas of Bagmati River System indicating sampling locations in the Bagmati River and its Tributaries: Bishnumati River and Dhobi Khola (River order from HydroSHEDS)

Table 1. Geographic settings of selection sites on the Bagmati River and its tributaries.

Zone	Site Code	Location	Latitude	Longitude	Substrate types
Upstream	BA01	Okhreni	27.79641	85.42201	BD, BU, ST, PB, GR, SA
	BA02	Okhreni	27.78162	85.42368	BD, BU, ST, PB, GR, SA
	BA03	Dam Area	27.77163	85.42669	BD, BU, ST, PB, GR, SA
	NA01	Shivapuri	27.78505	85.44485	BD, BU, ST, PB, GR, SA
	NA02	Shivapuri	27.77502	85.43854	BD, BU, ST, PB, GR, SA, CY
	SM01	Shivapuri	27.7732	85.41581	BD, BU, ST, PB, GR, SA
	DB01	Budhanilkantha	27.79224	85.37148	BD, BU, ST, PB, GR, SA
Midstream	BM01	Tarkeshwor	27.788952	85.324469	BD, PB, GR, SA
	BM02	Tarkeshwor	27.768962	85.341537	BD, PB, GR, SA, CY, SG
	BM03	Dharmasthali	27.7608	85.29925	BD, PB, GR, SA, CY, SG
	BA04	Sundarijal	27.753509	85.421803	BD, PB, SA, CY, SG
	BA05	Nayapati	27.734759	85.404194	BD, PB, SA, CY, SG
	DB02	Chunikhel	27.762866	85.364745	BD, PB, GR, SA, CY
Downstream	DB03	Buddhanagar	27.689152	85.328163	BD, PB, GR, SA, CY, SG
	BM04	Dallu	27.71359	85.30203	PB, GR, SA, CY, SG
	BA06	Gokarneshwor	27.739694	85.389304	BD, PB, GR, SA, CY, SG
	BA07	Naami	27.71633	85.378323	GR, SA, CY, SG
	BA08	Pashupati Area	27.70633	85.34905	GR, SA, CY, SG
	BA09	Shankhamul	27.68212	85.341666	GR, SA, CY, SG
	BA10	Thapathali	27.688066	85.318149	GR, SA, CY, SG
	BA11	Chovar	27.65758	85.29368	GR, SA, CY, SG

(Abbreviations: BD – Bed, BU – Boulders, ST – Stone, PB – Pebble, GR – Gravel, SA – Sand, CY – Clay, and SG – Sludge)

Data Analysis

Biotic scores such as Ganga River System Biotic Score/Average Score per Taxon (GRSBIOS/ASPT), diversity indices, percent composition, and sensitivity were calculated (Table 2). GRSBIOS/ASPT helps to determine the ecological condition of the entire river ecosystem. To calculate GRSBIOS/ASPT index for each sampling site, the sum of the total taxa scores was divided by the number of taxa that were recorded. Three different indices were used to investigate the diversity such as Shannon Wiener Diversity Index, Pielou's Evenness Index, and Simpson's Diversity Index following the standard methods (Table 2).

The percentage computation for taxon composition, EPT taxa (Ephemeroptera, Plecoptera, and Trichoptera) richness, Diptera, Others (Coleoptera, Gastropoda, Hemiptera, Hirudinea, Lepidoptera, Odonata, and Oligochaeta) were performed along with sensitive measures (Sensitive, Facultative, and Tolerant taxa) where each taxon was assigned a sensitivity score. This score is based on GRSBIOS which ranges from 1 to 10, where 1–3 indicates tolerant taxa, 4-6 indicates facultative taxa and 7-10 indicates sensitive taxa. This method has been successfully applied in practice to assess the ecological status of the freshwater systems in Nepal (Shah & Shah, 2012). Further, the bar diagram analysis and the scatter plot analysis were performed in Python (Version 3.9.7) using the Spyder interface. The main libraries used for the analysis were Matplotlib and NumPy.

Table 2. Calculation methods of metrics and diversity indices

Metrics/ Diversity Indices	Calculation
(GRSBIOS/ASPT)	$GRSBIOS/ASPT = \frac{Sum\ of\ total\ species\ score}{Number\ of\ taxa\ recorded}$
Shannon Wiener's Diversity Index (H)	$H = -\sum \frac{ni}{N} \log \frac{ni}{N}$
	Where, ni = number of individual species in each sample
	N= total number of individual species in each sample
	$\log \frac{ni}{N}$ = the natural log of the proportion
Pielou's Evenness Index (e)	$e = \frac{H}{LogS}$
	Where, H = Shannon Wiener Diversity Index
	S = Total Richness
Simpson's Diversity Index (D)	$D = 1 - \frac{\sum n(n-1)}{N(N-1)}$
	Where, n = number of individual species in each sample
	N = Total sum of individual family species in each sample
Percentage Taxon Composition	$\%\ taxon\ composition = \frac{Number\ of\ taxa\ at\ each\ site}{Total\ number\ of\ taxon\ recorded} * 100\%$
Percentage Composition	$\%\ Composition = \frac{Number\ of\ EPT, Diptera, and\ Others\ in\ each\ respective\ site}{Total\ number\ of\ taxon\ recorded\ in\ each\ respective\ site} * 100\%$
Sensitive measures (% Sensitive, % Facultative, and % Tolerant)	$\%\ Sensitive\ measures = \frac{No.of\ sensitive, facultative, and\ tolerant\ taxa\ in\ each\ respective\ site}{Total\ number\ of\ taxon\ recorded\ in\ each\ respective\ site} * 100\%$

Further, cluster analysis based on the abundance and composition of benthic macroinvertebrates, correlation analysis and statistical analysis (Shapiro Wilk Normality Test and Kruskal Wallis Test) were performed in R Studio (version 4.1.2).

The River Water Quality Class Map was created using Quantum Geographic Information System (QGIS 3.18.3). The United States Geological Survey (USGS) online portal provided the Digital Elevation Model (DEM) with a resolution of 30 m and the vector layer of rivers and, boundaries were downloaded from DIVA-GIS and Google Earth Pro for creating River Water Quality Class (RWQC) map. The river order vector layer was downloaded from HydroSHEDS. River water quality mapping of the Bagmati River System was based on GRSBIOS/ASPT and the reference to classify the river water quality was taken from Moog & Sharma (2005), where Class I refers to Not Polluted, Class II Moderately Polluted, Class III Critically Polluted, Class IV Heavily Polluted, and Class V Extremely Polluted.

RESULTS

Macroinvertebrates community structure and disturbance zonation

A total of 5839 individual benthic macroinvertebrates belonging to 51 Families and 11 Orders were recorded from 21 sampling sites. The most abundant Order was Trichoptera with 13 Families, while Orders Gastropoda, Hirudinea, and Lepidoptera were found in lesser numbers (Figure 2). On average the most abundant macroinvertebrate family was Baetidae followed by Elmidae, Hydropsychidae, and Simuliidae whilst the least abundant ones were families – Gomphidae, Micronectidae, and Psychomyiidae.

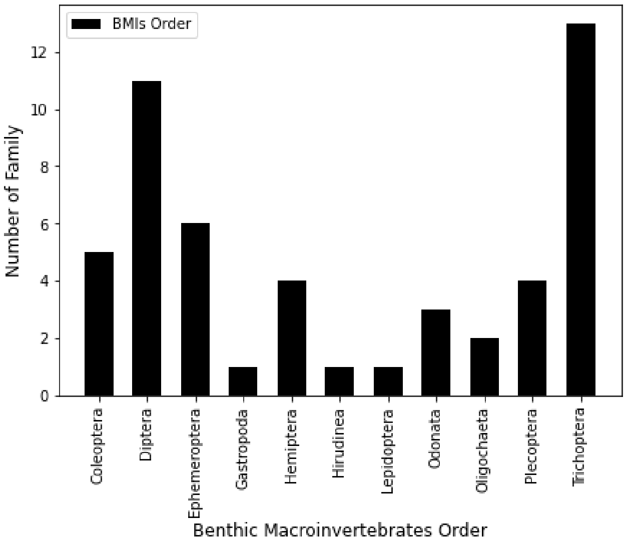

Figure 2. Macroinvertebrate order and families in the study area

The cluster analysis categorized the sites into three distinct groups for the post-monsoon period (Figure 3). This exactly coincides with the site classification as upstream, midstream, and downstream. A separate cluster (in red) was formed with sampling sites (upstream) inside the National Park territory. The cluster analysis shows that the benthic macroinvertebrates composition is totally different in the upstream compared to the midstream and downstream.

Macroinvertebrate metrics

The overall highest richness and highest abundance of benthic macroinvertebrates were found in upstream sites. All zones have considerable species abundance, with median values between 75 to 218 individuals (Figure 4). Although species abundance was considerable, it was not normally distributed ($p < 0.001$). Particularly in comparison to the other zones, upstream has a higher species abundance (median = 218), whilst downstream reported the lowest species abundance (median = 106) despite having a wide range of species recorded (Min = 25 and Max = 502). The species abundance of BA11 formed an outliner with 2573 individuals and was therefore eliminated (Figure 4 – Species abundance). Species abundance does not vary significantly among the zones (Kruskal-Wallis chi-squared = 0.79257, df = 2, p = 0.6728).

Likewise, species richness was also not normally distributed ($p < 0.01$) and upstream among the three zones exhibited divergent findings when accounting for taxon composition, with a range of 29.41% to 41.18% (median = 37.25%). Midstream showed taxon composition with a range of 7.84% to 17.65% (median = 10.78%) and downstream ranged from 5.88% to 17.65% (median = 9.8%). The distribution of species richness between the zones varies significantly (Kruskal-Wallis chi-squared = 13.633, df = 2, $p < 0.001$).

Good species richness and taxon composition were recorded as having substrates (Bed, Boulders, Stone, Pebbles, Gravel, and Sand) whereas few species richness and taxon composition were recorded as having substrates (Clay and Sludge).

The analysis showed that upstream sites posed a good diversity with high index value for all diversity indices (Shannon Wiener Diversity Index: Median = 0.899, Pielou's Evenness Index: Median = 0.70, and Simpson's Diversity Index: Median = 0.82). The diversity declined at midstream with a median = 0.416 for Shannon Wiener Diversity Index, median = 0.61 for Pielou's Evenness Index, and Median = 0.53 for Simpson's Diversity Index. Despite having a wide range (Shannon Wiener 0.028 – 0.776 with Median = 0.398, Pielou's Evenness 0.06 – 0.92 with Median = 0.57, and Simpson's Diversity 0.02 – 0.84 with Median = 0.485) within the context of three different diversity types, the median value of downstream is lower than that of upstream and midstream.

Analysis showed that there was a significant difference in Shannon Wiener Diversity Index among the zones (Kruskal-Wallis chi-squared = 12.6, df = 2, p = 0.001836). In addition, Simpson's Diversity Index also varied significantly among the zones (Kruskal-Wallis chi-squared = 9.6095, df = 2, p = 0.008191). However, Pielou's Evenness Index did not vary significantly (Kruskal-Wallis chi-squared = 1.4305, df = 2, p = 0.4891).

The upstream region had the highest EPT composition accounting for more than 50% along with the highest taxonomic composition with the few presences in the midstream region, and there is no evidence of EPT composition in the downstream region. Sites with a high EPT composition are located inside National Park boundaries. Likewise, Diptera composition was spread throughout the stretch of the Bagmati River System from upstream to downstream. There were also other Orders recorded in this entire stretch which were comparatively lower in upstream where EPT was dominant and increased through midstream to downstream. Maximum taxonomic richness was indicated with a bigger pie chart which gradually decreased upon having minimum taxonomic richness (Figure 5). The majority of sites in midstream and downstream are indicated with a smaller pie chart resulting in minimum taxonomic richness. Results also showed that a high taxonomic composition is influenced by EPT composition.

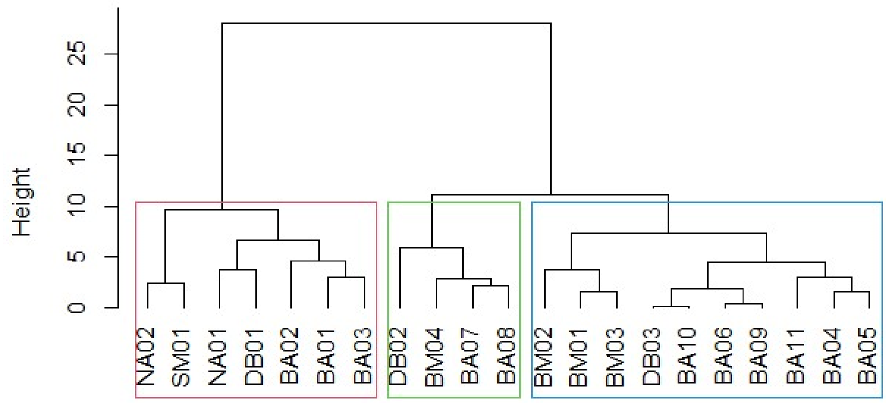

Figure 3. Cluster analysis based on the abundance of benthic macroinvertebrates. The sites in the midstream and downstream are represented by the green and blue clusters, while the entire upstream is represented by the red cluster

Ecological Status

The GRSBIOS/ASPT value for upstream ranged from 6.07 to 7.16 (median = 6.43) which was comparatively higher than in the midstream and downstream (Figure 4). Midstream exhibited 2.2 to 5.25 GRSBIOS/ASPT value with a median value of 3.835 whilst downstream showed 1 to 2.5 with a median value of 1.47. This interpretation shows a declining trend in GRSBIOS/ASPT values as the river flows downstream.

The results showed that facultative taxa were broadly distributed both in upstream and midstream, while sensitive taxa were dispersed in upstream sites with few in the midstream section. However, there was no presence of sensitive and facultative taxa in the downstream section. On the contrary, the number of tolerant taxa was less in the upstream section and drastically increased in the midstream section. In the downstream region, tolerant taxa were dominant with approximately 100% occurrence in a few sampling sites (DB03, BA06, BA09, and BA10) (Figure 6). Statistical analysis showed that there is no significant difference in the distribution of sensitive measures (Kruskal-Wallis chi-squared = 3.7946, df = 2, p = 0.15).

The Bagmati River System's ecological status, based on benthic macroinvertebrates and GRSBIOS/ASPT, ranges from Class I to Class V. The classification was done with reference from Moog & Sharma (2005). Only sites inside the national park were identified to have water quality of Class I, and these sites are the upstream section of the Bagmati River System. Class II and Class III were found in the Bishnumati River, a tributary of the Bagmati River. A few midstream sites with the entire downstream were identified as heavily polluted with the river quality of Class IV and Class V (Figure 7).

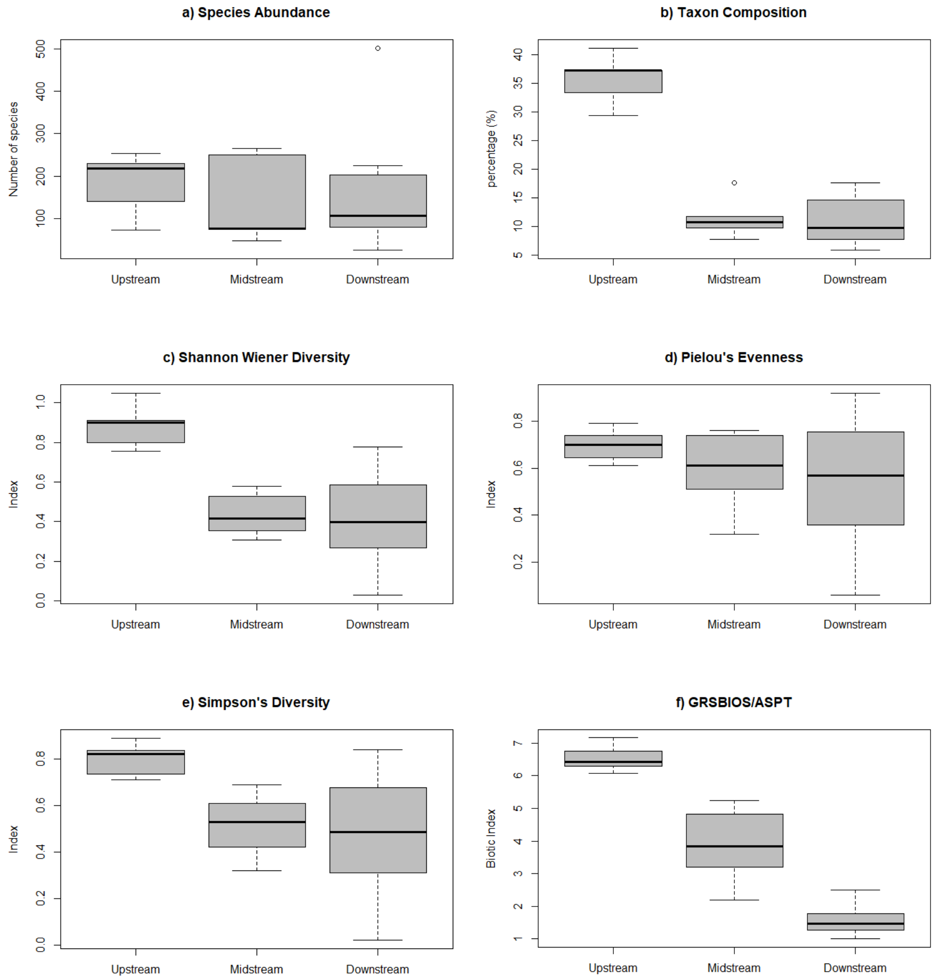

Figure 4. Grouped Box and whisker-plots showing medians and distributions of BMIs metrics – Species Richness (a), Taxon composition (b), Shannon Wiener Diversity Index (c), Pielou's Evenness Index (d), Simpson's Diversity (e) and GRSBIOS/ASPT (f)

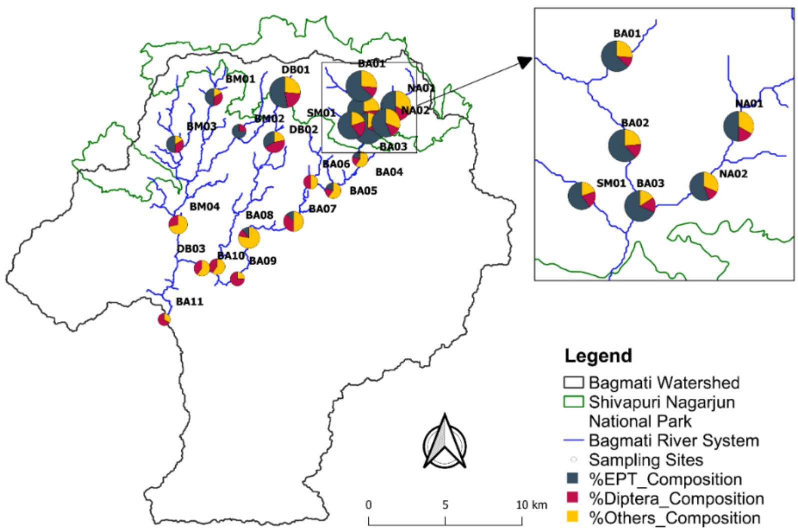

Figure 5. Pie-charts analysis showing the distribution of EPT, Diptera and Other Orders in each sampling site

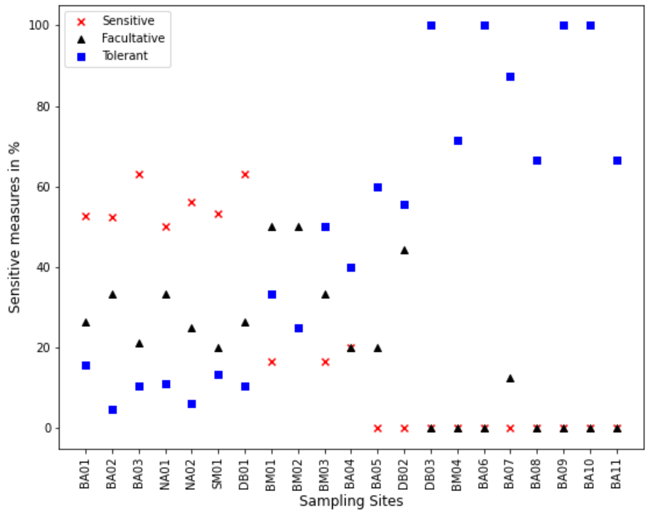

Figure 6. Presence of sensitive, facultative, and tolerant taxa per site. Sensitivity score based on GRSBIOS which ranges from 1 to 10, where 1 – 3 indicates tolerant taxa, 4-6 indicates facultative taxa and 7-10 indicates sensitive taxa. Upstream (BA01 – DB01), Midstream (BM01 – DB02) and Downstream (DB03 – BA11)

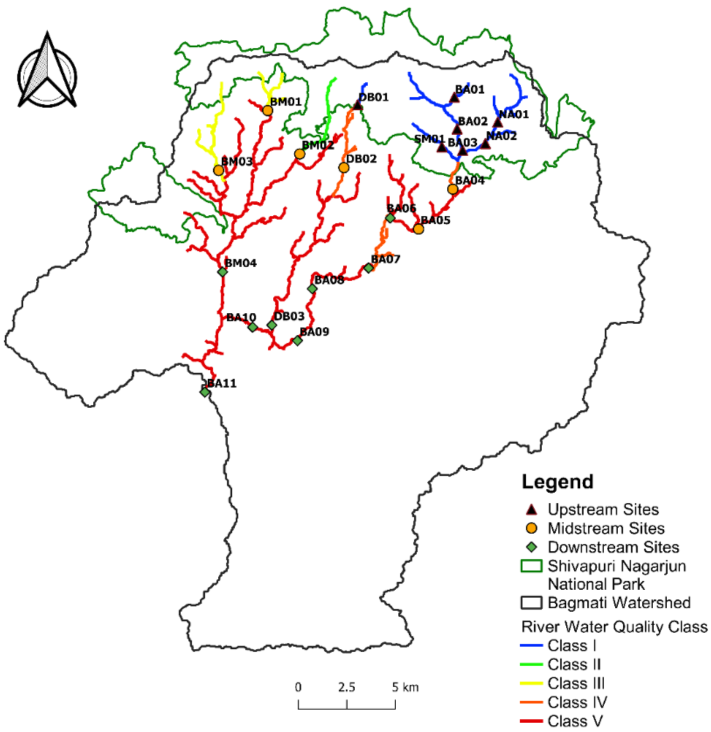

Figure 7. River Water Quality Map of the Bagmati River System

DISCUSSION

The findings demonstrated a rapid deterioration in the Bagmati River System's biological state from upstream to downstream. The order Trichoptera was discovered to have the maximum taxonomic dominance in the Bagmati River System. The family in this order is intolerant of pollution, and also a member of a particularly sensitive group that can only survive in clean freshwater (Shah & Shah, 2013). The upstream of the Bagmati River System had the highest number of taxon compositions in all the sites, demonstrating good water quality. The region is dominated by native deciduous forests and there is hardly any human activity. Since the Shivapuri Nagarjun National Park is a protected area, there is little interference from human activities. So, this could be the reason that the sampling sites in the locations within the park (BA01, BA02, BA03, NA01, NA02, SM01, and DB01) had good water quality. However, when the river leaves the National Park boundaries, the quality of the water starts to deteriorate as a result of intense anthropogenic exposure, activities, and threats.

Further, the cluster analysis showed a distinct difference in the three different zones. The first cluster in red grouped the entire upstream in one cluster having good water quality. The benthic macroinvertebrates' abundance and composition in these sites are totally different compared to midstream and downstream. Sensitive and facultative species mainly dominated the sites while facultative and pollution-tolerant species prevailed midstream and downstream. This could be due to the poor water quality that continuously impacts their occurrence.

Species abundance and species richness were higher upstream that gradually declines in the midstream and downstream. Since benthic macroinvertebrate composition declines as the pollution gradient increases (Rai *et al.*, 2019), this reduction in the taxon composition denotes that the water quality gradually declined in midstream and downstream. The findings are in concurrence with research done in the area by Mehta *et al.* (2016) and Shah & Shah (2013). Since EPT taxa can only survive in a clean freshwater habitat, these organisms are the primary cause of the highest taxon composition upstream. According to our findings, EPT richness represented more than 50% of the total taxon composition in the upstream sites. Sites where EPT taxa predominate have a high taxon composition and GRSBIOS/ASPT Index (Shah *et al.*, 2020). This reflects a healthy ecological condition upstream. These three orders (EPT) of benthic macroinvertebrates are regarded as significant groups in the ecological evaluation of surface water bodies because the gradient of pollution they are exposed to causes a decline in their richness, variety, and abundance (Shah & Shah, 2013).

The taxon composition of benthic macroinvertebrates has been reported to deteriorate when they enter the core area of the Kathmandu Valley, where pollution is extreme due to anthropogenic interferences. The pollution-tolerant species (e.g., *Chironomidae* red worms) completely dominate the downstream of the Bagmati River System, which is similar to the study by Shah *et al.* (2019) where they found that the abundance and composition of pollution-tolerant species grew progressively from upstream to downstream. Ephemeroptera, Trichoptera, Coleoptera, Diptera, and Odonata are habitat generalists, which means they can be found in any substrate. However, Plecoptera and Hemiptera are habitats specific, so substrates are also a major driver of the existence of benthic macroinvertebrates (Bhandari *et al.*, 2019).

Analysis showed that upstream posed a good diversity based on Shannon Wiener Diversity Index, Pielou's Evenness Index, and Simpson's Diversity Index which then declined in midstream and downstream. There was no vast difference in the diversity of midstream and downstream as compared to upstream. Shannon Wiener and Simpson's Diversity both have significant differences in the three different zones, but Pielou's Evenness is exceptional. Pielou's Evenness doesn't have significant differences.

The values of GRSBIOS/ASPT demonstrate a divergent downward trend from upstream to downstream, with high water quality in the upstream but declining through midstream. As the water reached downstream, it was found to be severely contaminated. The GRSBIOS/ASPT value for upstream was recorded 6.07 to 7.16 which indicates a healthy freshwater ecosystem prevailed with sensitive species. In contrast, the predominance of sensitive and facultative species, which are pollution intolerant, prevail at midstream locations, and also has a lower GRSBIOS/ASPT value (2.20 to 5.50) which demonstrates the significant level of contamination in these locations. Further downstream sites are even more serious as these sites are completely occupied by tolerant taxa like Chironomidae, Culicidae, and Tubificidae, which ultimately lowers the GRSBIOS/ASPT Index, indicating exceptionally high pollution levels and bad ecological conditions. The correlation between sensitive and facultative species was very strong ($r = 0.84$) whilst the correlation between sensitive and tolerant species was weak and negative ($r = -0.58$). Similar correlation was found between facultative and tolerant species ($r = -0.57$) which showed that their linkage is weak. This analysis indicated that sensitive and facultative species cannot adapt to such conditions where tolerant species prevail.

Loss of sensitive taxa in the aquatic ecosystem downstream might be a result of eutrophication directly or indirectly caused by human activities such as the use of insecticides and pesticides in fields near rivers (Mahat *et al.*, 2020). This biotic index and sensitive measures clearly demonstrate how badly the Bagmati River System has degraded due to anthropogenic activities. A study by Rico-Sánchez *et al.* (2022) in two rivers running across the Central Plateau of Mexico, found that the combined effect of mining activities, agriculture, and the presence of villages resulted in a high concentration of heavy metals, fertilizers, and salinity, causing a limitation in the presence of sensitive macroinvertebrates, and ultimately affecting macroinvertebrate assemblage in the river.

River water quality mapping showed that upstream sites are categorized as Class I and only a few sites are Class II and Class III while all the remaining sites are Class IV and Class V. Despite the rising urbanization and high population density in Kathmandu Valley, upstream appears to retain their biological integrity (Shah & Shah, 2013). However, the ability of the Bagmati River System to filter itself through the interaction of biotic and abiotic components is essentially nonexistent due to rapid population increase, anthropogenic stress, direct dumping of solid waste, and discharge of industrial effluents downstream (Dahal *et al.*, 2011). The direct effluent discharge of waste and sewage from home and industrial usage is the major cause of the Bagmati River's water quality deterioration.

CONCLUSIONS

The study provides an overview of the current state of the Bagmati River System in the Kathmandu Valley. Despite having a religious significance, the river quality has degraded to such an extreme level that it is unsuitable for any purpose, especially downstream. The upstream of this river system within Shivapuri Nagarjun National Park is suitable for sustaining aquatic and terrestrial life, but as it runs out of the protected area and enters semi-urban and core areas, its quality declines, eventually reaching an extremely contaminated level. As observed in the findings, sensitive species that signal high quality are present only to the upstream, whereas pollution-tolerant species predominate downstream regions. This indicates that downstream has reached a point where quality-determining species can no longer survive. The study also showed that benthic macroinvertebrates can be used as effective biological indicators of river environmental studies. We believe that these results can be utilized as a baseline for future studies related to temporal or spatial patterns of the ecological health of the Bagmati River System in the Kathmandu Valley.

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AUTHOR CONTRIBUTIONS

P.S.: conceptualization, planned the study, conducted the entire field work, analyzed the data and wrote the whole manuscript; A.R.: supported in the design of methodology, reviewed, edited the manuscript, and supervised the analysis; P.C.W. and S.G.: reviewed and edited the manuscript.

CONFLICT OF INTEREST

The author declares no conflict of interest.

DATA AVAILABILITY STATEMENT

The corresponding author will provide the dataset created during the research process and/or analyzed during the current study upon reasonable request.

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