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Benthic Diatom as an Indicator for River Health Assessment in Vindhyan Lotic Ecosystem, Central India

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ABSTRACT

The health of the ecosystem of a central Indian river from the Neolithic era was evaluated. The Belan River, approximately 180 km long and in the pristine north-central region of the Vindhyan ranges, was sampled seasonally at five distinct stations from November 2021 to October 2022. Diatom samples were collected by scraping a 3x3 cm area of substratum (stones) to a depth of 30.48 cm. The most abundant taxa observed at Station S1 were *Aulacoseira granulata, Cymbella affinis*, and *C. tumida* in winter, summer, and monsoon seasons, respectively. At Station S2, *C. affinis* was the predominant taxon only during summer, with none detected in the winter or monsoon seasons. At Station S3, *Navicula radiosa* and *Melosira varians* were the most abundant taxa in winter and summer, respectively, with no presence in the monsoon season. The prevalent taxa varied at Stations S3 and S4 as well. Characteristic variations of taxa were noted across different stations and seasons. Cluster analysis revealed that S1 and S2 were grouped as upper zones, while S4 and S5 were categorised as lower zones, with S3 being distinctly separate. The health assessment indicated that the river was either minimally polluted or not polluted at most stations, suggesting that it remains pristine, mainly due to the sparse human settlement and absence of industrial development along its length.

Key words*:* Belan River, Ecological state, Indicator species, Health Assessment, Vindhyan range

INTRODUCTION

Over the past century, human activities have driven significant environmental changes, notably through deforestation and the transformation of land for agriculture (Jüttner et al. 2003). Urbanisation is a major anthropogenic factor that reduces soil permeability and alters hydrographic systems, leading to increased nutrient concentrations and changes in the morphology of waterways (Walsh et al. 2005). Biological communities within rivers and streams are crucial for assessing water quality (Whitton and Kelly 1995). Among these communities, diatoms - unicellular and microscopic algae with siliceous cell walls - serve as important bio-indicators in water quality evaluations due to their rapid generation times and the sensitivity of certain species to specific ecological conditions found in rivers and streams (Stevenson and Pan 1999). Exceptionally high nutrient uptake rates characterise diatoms compared to other groups (Litchman et al. 2006). They are also known for their ability to thrive across various salinities and temperatures.

Diatoms are crucial in monitoring river waters' environmental conditions and ecological status (Venkatachalapathy et al. 2014). They exhibit sensitivity to various factors, including pH, salinity, and nitrogen uptake (Kelly 1998). In addition, diatoms have demonstrated their efficacy as indicators for a range of ecological and practical issues related to health sciences, forensic sciences, nanotechnology, and global environmental changes (Smol and Stoermer 2010, Pound et al. 2021). For evaluating river health, several diatom indices are utilised to assess eutrophication (van Dam et al. 1994, Kelly and Whitton 1995), organic pollution (Jüttner et al. 2003, Bere and Tundisi 2011, Nautiyal and Mishra 2013).

Diatoms are extensively employed for bio-monitoring rivers and streams, assessing ecological conditions, and monitoring environmental changes during routine water quality surveys across various regions worldwide, including Japan, the United States, Australia, New Zealand, and Brazil (Hill et al. 2000, Potapova and Charles 2003). In India, numerous studies have also been conducted within river systems across different ecological regions, such as the Himalayan region (Nautiyal and Mishra 2013, Nautiyal et al. 2015, Kumar and Nautiyal 2024), the Western Ghats (Karthick and Kociolek 2012, Arulraj et al. 2019), and the Vindhyan region (Singh 2015, Nautiyal et al. 2017, Tiwari et al. 2024). In light of these studies, diatoms serve as crucial biological indicators for assessing the ecological health of rivers and streams. While various ecological areas have been examined, certain sub-regions, such as Belan Valley, remain largely unexplored within the Vindhyan region. The Belan River, a significant watercourse of Belan Valley, flows westward along the Kaimur Hills, a notable upland of the northern Indian Craton just a few km south. It is a tributary of the Tons River, part of the Ganga basin. Consequently, this study is the first to evaluate the ecological condition of the Belan River through the analysis of its diatom community. The objectives of this research are: i) to assess the abundance of diatom taxa about the season, ii) to identify characteristic taxa at each station during different seasons, iii) to evaluate the health of the river, and iv) to determine indicator species at each station throughout the seasons.

MATERIAL AND METHODS

Study area

The Belan River is an important waterway in the Belan Valley, along with several smaller tributaries, including Adwa, Seoti, Lohanda Nala, Tundiari, Gorma, and Naina. This region spans approximately 7,800 km² in the Northern Vindhyas. It encompasses parts of Sonbhadra, Chandauli, Allahabad (now Prayagraj), and Mirzapur Districts in Uttar Pradesh and neighbouring areas in Rewa and Sidhi Districts of Madhya Pradesh. The river originates from the Vindhyan Ranges in Sonbhadra District. It extends about 180 km long, flowing west-northwest before eventually draining into the Tons River near Chakghat (Tiwari 2024).

Ghuwas (S1): Ghuwas was located in the headwater zone of the river (Table 1). This site was relatively pristine, with sparse or no human settlements and a covered dense forest area. The river's right bank was in Uttar Pradesh, and the left was in Madhya Pradesh. The riverbed was characterised by a mixed substratum comprising rock, stone, cobble, and pebble covered with periphyton.

Dholo (S2): The station was located next to S1 in the headwater zone of the river (Table 1). The site located in this stretch was relatively pristine, with a sparse human population and settlements. The riverbed was characterised by a mixed substratum comprising rock, stone, cobble, pebble, and silt.

Devghat (S3): It was located in the middle zone of the river (Table 1), with the riverbed having mainly pebble, gravel and silt substrate. Agriculture was the primary human activity along both river banks at approximately a distance of 500 m. Other activities included cattle bathing and the abstraction of water for local irrigation.

Bhogan (S4): Station S4 was part of the lower section of the river (Table 1). The riverbed is comprised largely of silt and clay substratum and covered with periphyton. Agriculture was the primary human activity along both S3-Devghat S4-Bhogan river banks. Other activities included bathing cattle, water abstraction for local irrigation, and other anthropogenic activities.

Table 1. Geographical coordinates of each sampling station in the river Belan along with land use type and substratum. Acronyms: F=Forest, F+Ag= Forest + Agriculture, Ag = Agriculture, Ag + V= Agriculture +Village, R-G-P-C= Rock-Gravel-Pebble-Cobble, R-B-C-S= Rock-Boulder-Cobble-Sand, S= Sand, C-S= Cobble-Sand

Stations	Ghuwas (S1)	Dholo (S2)	Devghat (S3)	Bhogan (S4)	Purwa (S5)
Latitude (N)	24°41’45"	24°46’21"	24°54’27"	24°56’32"	25°00’38"
Longitude (E)	82°39’42"	82°33’00"	82°02’14"	82°56’40"	81°47’11"
Altitude (m)	249	200	119	118	113
Distance from origin	35 km	60 km	135 km	155 km	180 km
Land use	F	F	F + Ag	Ag	Ag +V
Substrate	R- G-P-C	R-B-C-S	S	C-S	C-S

Purwa (S5): Station S5 was located at the mouth region of the river and approx 4.5 km away from the confluence point with the Tons River near Chakghat (Table 1). The riverbed is comprised largely of silt and clay substratum and covered with periphyton. Agriculture was the primary human activity along both banks of the river. Other activities included cattle bathing, water abstraction for local irrigation, various anthropogenic activities, and alcoholic fermentation on the bank of the river.

Sampling

Diatom samples were collected seasonally (Winter - November to February; Summer - March to June; Monsoon - July to October) from five distinct stations (S1 to S5) along a cobble-stone substratum (3x3 cm area) by using a razor blade during November 2021 to October 2022 (Fig. 1). In the case of a large study area, seasonal sampling was found to be suitable due to cost and travel time (Sheldon 1984). The water temperature (WT) was analysed using a digital probe (PCER Multi thermometer 408), pH by the digital meter (Ocean Star technologies pH meter for water hydroponics digital pH tester pen with 0-14 pH measurement) and electric conductivity by a desktop conductivity meter (Labtronics Delux conductivity meter MODEL LT-26). Dissolved oxygen was determined using Winkler's, and the titration method was used to determine total hardness, free CO_2, alkalinity, nitrate, phosphate and silicate (Anonymous 2017).

The samples were preserved in a 4% formaldehyde solution and cleaned with double-distilled water to eliminate residual formaldehyde. They were then digested with hydrochloric acid and thoroughly washed with double-distilled water to remove all acid traces. The samples were further treated with hydrogen peroxide and distilled water. After processing, the material was mounted in Naphrax to prepare permanent slides for light microscopy. Identification of diatoms was performed at the genus and species levels using standard keys

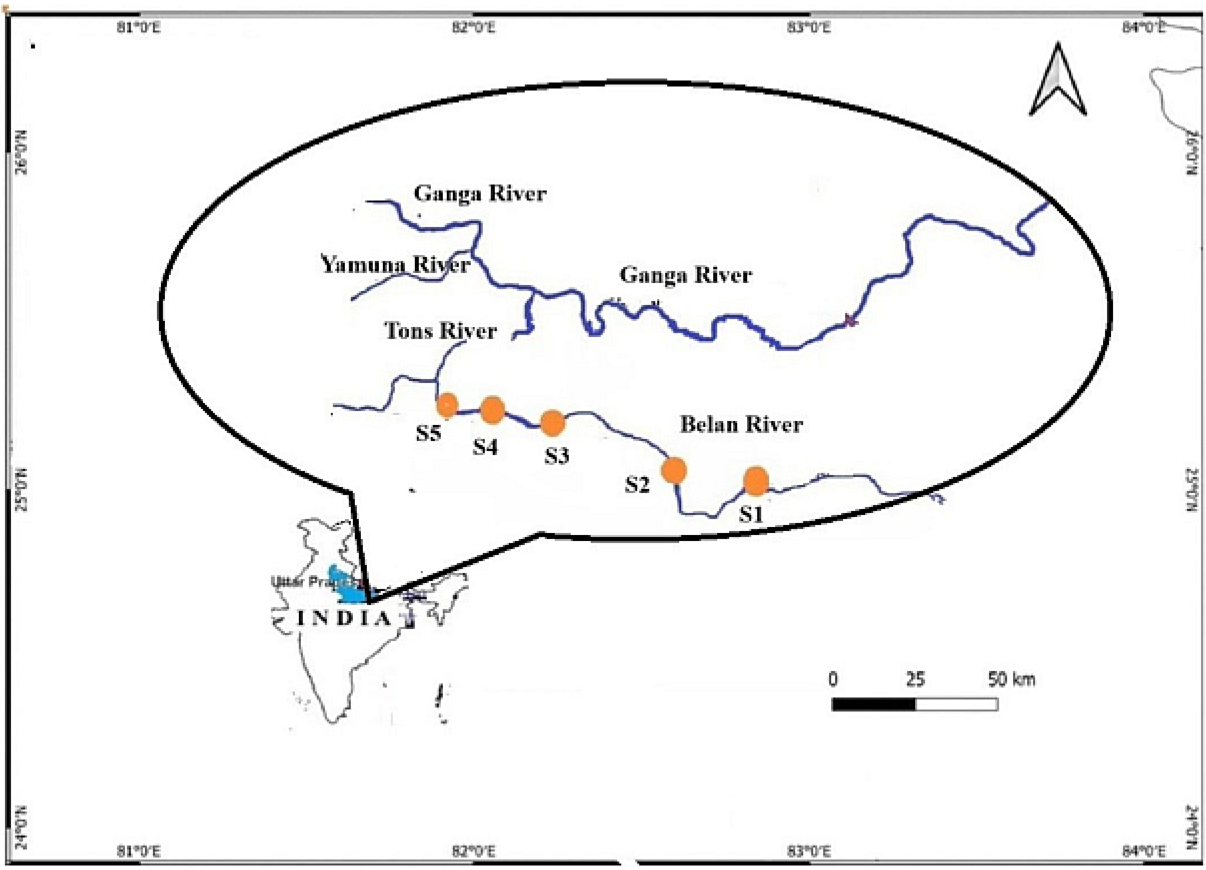


Figure 1. Geographical location of the river Belan in India and sampling stations S1 to S5

(Krammer and Lange-Bertalot 1986-1991, Taylor et al. 2007, Karthick et al. 2013).

Principal component analysis (PCA; CANOCO Ver. 4.5) was applied to determine the characteristic taxa at each station and season (ter Braak 2002). Cluster analysis has been drawn using a hierarchical clustering method based on counts data of diatom species to classify stations by Ward method using Euclidean Linkage distance ('R' ver. 4.3.3 Package Vegan). The OMNIDIA software ver. 6.0.9 was used to determine the river's ecological condition (Lecointe et al. 1993). The ecologic values viz., pH, salinity (S), nitrogen uptake (NU), oxygen requirements (OR), saprobity (SP) and trophic state (TS) of the diatom community were assessed (van Dam et al. 1994). The saprobic and trophic states indicate the water quality. van Dam et al. (1994) parameter is measured on a scale of 1-7. Diatom indices used in the biological assessment of running water quality. The indices are such as Indices Biologique Diatomee (IBD – Lenoir and Coste 1996), Specific Pollution Sensitivity Index (IPS – Cemagreff 1982), Trophic Diatom Index (TDI – Kelly and Whitton 1995). The indicator diatom taxa were observed by using 'R' ver. 4.3.3 (Package Indic species) software at various stations and seasons.

RESULTS AND DISCUSSION

The physicochemical parameters such as water temperature, pH, electrical conductivity, total hardness, free CO_2, total alkalinity, nitrate, phosphate, and silicate showed an increasing trend from S1 to S5. In contrast, dissolved oxygen,

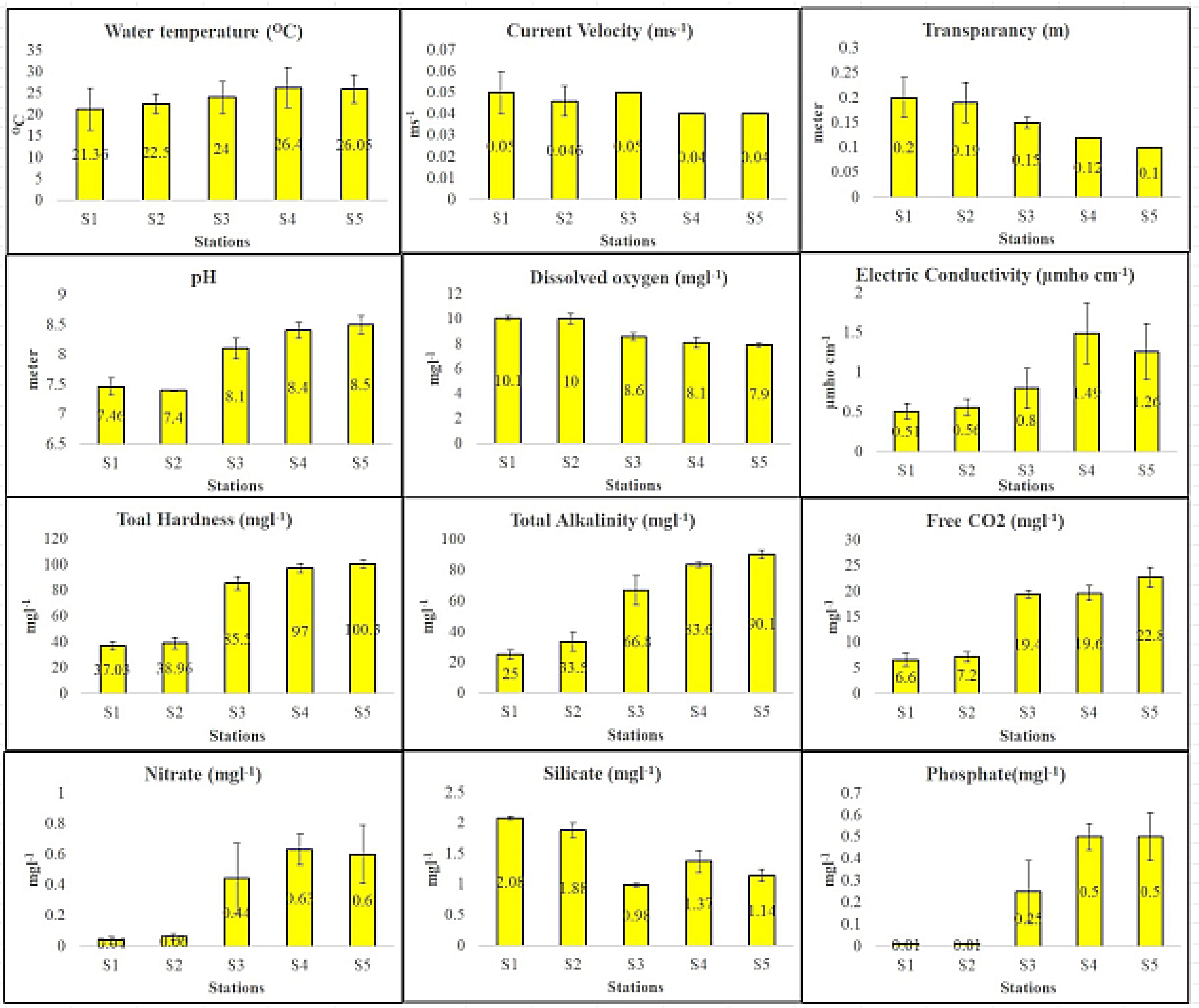
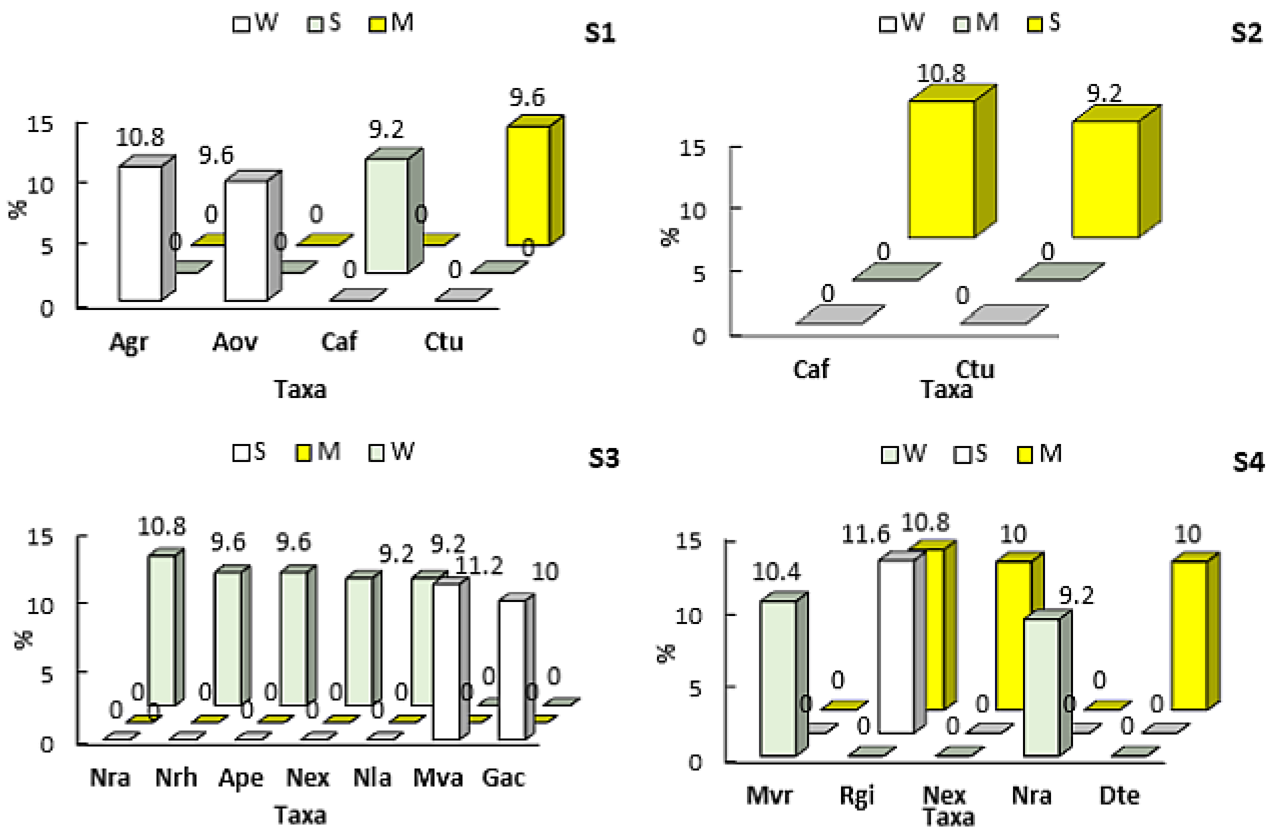


Figure 2. Mean value of physico-chemical parameters of the river Belan at various stations S1 to S5

transparency, and current velocity decreased from S1 to S5 (Fig. 2). The rise in water temperature downstream reflects seasonal variations and geographical influences (Rajasekaran and Raja 2017). The reduction in current velocity downstream is attributed to alterations in channel morphology, along with an increase in depth and flow dynamics of the rivers (Olsen et al. 2012, Nautiyal and Mishra 2012). The increase in pH from S1 to S5 likely indicates a shift toward alkalinity downstream (Nautiyal et al. 2017). The observed decrease in dissolved oxygen is probably due to oxygen depletion downstream, which correlates with the rise in water temperature (Mishra et al. 2024, Mishra and Nautiyal 2013). Similarly, Kalyoncu and Serbetcihe (2013) noted significant increases in conductivity, nitrate, phosphate, chloride, and BOD downstream in Dari Stream, Turkey, and in the Narmada River, India (Rajasekaran and Raja 2017). Also, free CO_2 was higher at S5 and lower at S1, likely influenced by organic matter decomposition and changes in flow dynamics throughout the river course (Shah and Joshi



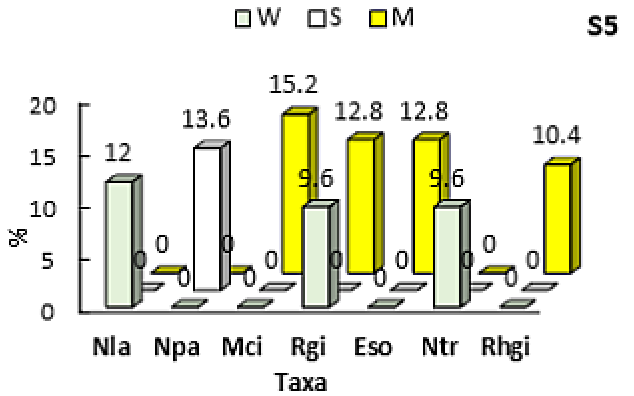


Figure 3. Abunadant diatom species at various staions with respect to season. Acronyms: Agr - *Aulacoseira granulata,* Aov -*Amphora ovalis*, Caf -*Cymbella affinis*, Ctu -*Cymbella tumida*, Nra- *Navicula radiosa*, Nrh- *Navicula rhyncocephala*, Ape- *Amphora pediculus*, Nex- *Navicula exilis*, Nla- *Navicula lanceolata*, Mva- *Melosira varians*, Gac- *Gyrosigma acuminatum*, Rgi- *Rhopalodia gibba*, Dte- *Denticula tenius*, Npa- *Nitzschia paleacea*, Mci- *Meridon circulare*, Eso- *Epithemia sorex*, Ntr- *Navicula trivalis*

2017, Shukla et al. 2022).

Seasonal variation in abundance of benthic diatom

The abundance of the diatom community varied among the sampling stations depending on the season (Fig. 3). At station S1, *Aulacoseira granulata* (Ehrenberg) Simonsen was the most prevalent taxon in winter (10.8%). In comparison, *Cymbella affinis* Kützing (9.2%) dominated in summer, and *Cymbella tumida* (Brébisson in Kützing) van Heurck (9.6%) was most abundant during the monsoon season. Similarly, at station S2, *Cymbella affinis* Kützing (10.8%) was the leading taxon in summer, though no species exhibited significant abundance in winter or monsoon. At S3, *Navicula radiosa* Kützing (10.8%) and *Melosira varians* Agardh (11.2%) were the most abundant taxa during winter and summer, respectively, with no dominant species during the monsoon. At station S4, *Melosira varians* Agardh (10.4%) was the most abundant taxa in winter, while *Rhopalodia gibba* (Ehrenberg) O. Müller was the dominant species in both summer (11.6%) and monsoon (10.8%). In contrast, station S5 displayed a winter dominance of *Nitzschia lanceolata* W. Smith (12%), with *Nitzschia paleacea* (Kützing) W. Smith (13.6%) in summer and *Meridion circulare* (Greville) Agardh (15.2%) in monsoon. Tiwari et al. (2023) noted that the dominant taxa in the central Indian River, the Belan, included *Navicula* sp., *Nitzschia* sp., *Achnanthidium* sp., *Gomphonema* sp., *Cymbella* sp., and *Amphora* sp. Additionally, *Rhopalodia* sp. was prevalent in the Sone River in central India (Pandey et al. 2015), while the abundance of *Meridion circulare* was also reported in the Chambal River (Grover et al. 2017). The Naviculaceae family is abundant in the central Indian rivers: the Ken, Paisuni, and Tons (Verma and Nautiyal 2010, Mishra et al. 2017).

Characteristic diatom taxa with respect to season

PCA revealed seasonal variations in diatom species across various stations. During the winter, axes 1 and 2 accounted for 65.5 and 21.9% of the variance, respectively. Characteristic taxa observed at S1 and S2 included *Amphora ovalis, Cymbella tumida, Cymbella excisiformis, Nitzschia paleaceae, Achnanthidium minutissimum*, and *Navicula capitatoradiata*. Notably, no distinctive taxa were found at S4 (Table 2, Fig. 4a). In the summer season, axes 1 and 2 contributed 50.7 and 34.8% variance, respectively, with characteristic taxa identified as *Achnanthidium exile, Aulacoseira granulata, Nitzschia constricta, Cymbella tumida*, and *Cocconeis pediculus* at S1. At the same time, *Navicula rhyncocephala* was specific to S2 (Table 2, Fig. 4b). Other stations also displayed variations in their characteristic taxa.

During the monsoon season, axes 1 and 2 explained 50.0 and 36.0% variance, respectively. *Aulacoseira ambigua* and *Cocconeis pediculus* emerged as characteristic taxa at S1, with *Diploneis boldtiana* at S2, *Achnanthidium neomicrocephalum* and *Gomphonema parvulum* at S3. At the same time, *Epithemia sorex, Navicula pseudobryophila, Epithemia argus*, and *Gomphonema affine* were characteristic taxa at S4 and S5 (Table 2, Fig. 4c). Blanco et al. (2012) documented a prevalence of *Amphora veneta* in alkaline, nutrient-rich environments. Conversely, Taylor et al. (2007) reported a dominance of *Aulacoseira granulata* and *Nitzschia constricta* in regions with high silica content and low to moderate nutrient levels. Jüttner and Cox (2001) noted an abundance of *Gomphonema parvulum* primarily in disturbed habitats. Nuatiyal et al. (2015) highlighted the varying characteristics of taxa during winter, with *Synedra ulna* var. *dorsiventralis* and *Gomphonema parvulum*, and in summer, *Rhoicosphenia abbreviata* and *Nitzschia fonticola*.

Cluster analysis

The dendrogram revealed three distinct clusters of stations. Cluster I includes stations S1 and S2, while Cluster II is represented by station S3, and Cluster III comprises stations S4 and S5 (Fig. 5). Cluster I, encompassing stations S1 and S2, shows consistent diatom abundance across summer, winter, and monsoon seasons. This consistency suggests stable environmental conditions that favour the growth of species like *Achnanthidium minutissimum* and *Fragilaria capucina*, which thrive in nutrient-rich habitats (Krammer and Lange-Bertalot 1991). In contrast, Cluster II, representing station S3, harbours unique diatom taxa that specific local conditions may influence. Here, species such as *Gomphonema gracile* and *Cymbella alpestris*, known for their

Table 2. Principal Component Analysis (PCA) indicated characteristic taxa at each station (S1 to S5) and season (winter, summer and monsoon) in the Belan River. These taxa were associated with particular station and season

Station	Season	Characteristic taxa
S1	Winter	*Amphora ovalis, Cymbella tumida, Cymbella excisiformis, Nitzschia paleaceae, Achnanthidium minutissimum, Navicula capitatoradiata*
	Summer	*Achnanthidium exile, Aulacoseira granulata, Nitzschia constricta, Cymbella tumida, Cocconeis pediculus*
	Monsoon	*Aulacoseira ambigua and Cocconeis pediculus*
S2	Winter	*Amphora ovalis, Cymbella tumida, Cymbella excisiformis, Nitzschia paleaceae, Achnanthidium minutissimum, Navicula capitatoradiata*
	Summer	*Navicula rhyncocephala*
	Monsoon	*Diploneis boldtiana*
S3	Winter	*Navicula exilis*
	Summer	*Fallacia monoculata and Achnanthdium macrocephalum*
	Monsoon	*Navicula punctate, Achnanthidium neomicrocephalum, Gomphonema parvulum*
S4	Winter	No taxa
	Summer	*Navicula veneta, Diadesmis confervacea, Nitzschia obtusa, Nitzschia frustulum, Amphora veneta*
	Monsoon	*Epithemia sorex, Navicula pseudobryophila, Epithemia argus, Gomphonema affine*
S5	Winter	*Amphora veneta and Amphora montana*
	Summer	*Navicula veneta, Diadesmis confervacea, Nitzschia obtusa, Nitzschia frustulum, Amphora veneta*
	Monsoon	*Epithemia sorex, Navicula pseudobryophila, Epithemia argus, Gomphonema affine*

preference for distinct habitat parameters, are likely to be prevalent (Krammer 2002). Finally, Cluster III, consisting of stations S4 and S5, suggests similarities in the environmental factors at these sites. Species such as *Surirella tenera* and *Navicula symmetrica* are likely adapted to the conditions typical of S4 and S5 (Patrick and Reimer 1966). These clustering patterns offer valuable insights into how diatom communities respond to varying environmental conditions across different locations and seasons within the river ecosystem.

River health

The Belan River exhibited alkaliphilic characteristics from S1 to S5, although there was no discernible pattern of increase or decrease in this trait. In contrast, the oligohalobous nature of salinity displayed a declining trend, moving from 67.3% at S1 to 51.2% at S5, except S2, which recorded 71.8%. Nitrogen uptake in the river water remained tolerant and N-autotrophic from S1 to S4, but at S5, it became sensitive and N-autotrophic. The oxygen requirement was polyoxybiontic throughout all sampling stations, maintaining 100% saturation, yet no clear increasing or decreasing trend was observed. Saprobity levels were classified as β-mesosaprobous from S1 to S5, with an increase from 36.8% at S1 to 40.9% at S3, followed by a decline at S4 (39.5%) and S5 (32.8%). The river's trophic status was consistently eutrophic across all stations (S1 to S5). The alkaliphilic nature of the water suggested the presence of alkaliphilic taxa, while salinity remained predominantly oligohalobous, indicative of freshwater environments. Tolerant N-autotrophic taxa were predominant in nitrogen uptake at most stations, except at S5, where sensitive N-autotrophic taxa were more prevalent.

Polyoxybiontic taxa indicate elevated levels of dissolved oxygen. The saprobity classification was β-mesosaprobous, suggesting a moderate level of organic pollution. At the same time, the trophic state consistently categorised the environment as

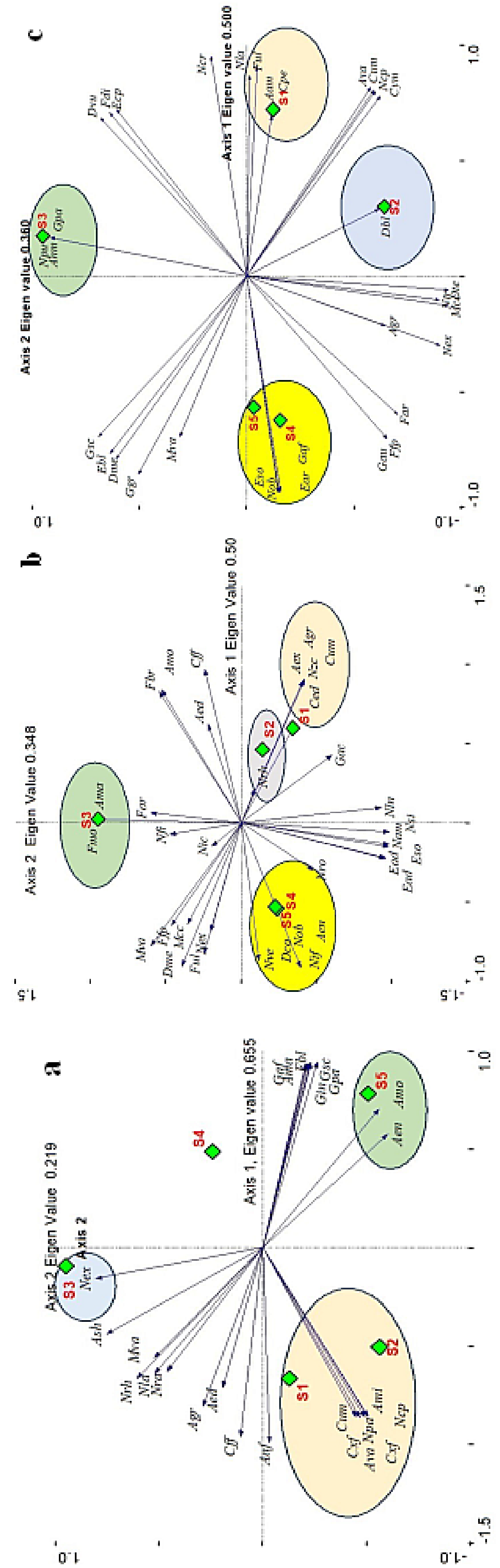


Figure 4. PCA indicates characteristic diatom species at each station in winter season (a), summer season (b), and monsoon season (c). The encircled species show association with respective station in circle and length of the arrow represent strength of association. Acronyms: Ava- *Amphora ovalis*, Cum- *Cymbella tumida*, Cxf- *Cymbella excisiformis*, Ncp- *Nitzschia paleaceae*, Ami- *Achnanthidium minutissimum*, Ncp- *Navicula capitatoradiata*, Aen- *Amphora veneta* and Amo- *Amphora montana*, Ava- *Amphora ovalis*, Cum- *Cymbella tumida*, Cxf- *Cymbella excisiformis*, Ncp-*Nitzschia paleaceae*, Ami- *Achnanthidium minutissimum*, Ncp- *Navicula capitatoradiata*, Aen- *Amphora veneta* and Amo- *Amphora montana*

eutrophic, indicative of nutrient-rich conditions along the river (van Dam et al. 1994). Cantonati et al. (2001) found that in the Himalaya 30-46% of diatom taxa were alkaliphilous, 38-46% were circumneutral, 49% thrived in wet environments, 11-19% were mesoeutraphentic, and 13-25% were eutraphentic. Nautiyal and Mishra (2013) documented characteristics of alkaliphilic diatoms in the Khanda Gad spring, noting fresh-brackish water conditions, β-mesosaprobic saprobity, and eutraphentic trophic status, all influenced by anthropogenic factors. Nautiyal et al. (2015) reported on the health of the benthic diatom assemblage in the lower stretch of the glacier-fed Mandakini River in the lesser Himalaya. Trábert et al. (2020) observed alkaliphilic conditions in the River Danube near Budapest, noting the presence of tolerant N-autotrophic diatoms and a moderate oxygen requirement alongside β-mesosaprobic and eutrophic conditions in the river. Kumar and Nautiyal (2024) utilised van Dam ecological values to assess diatom abundance, revealing conditions consistent with the current state of the riverine ecosystem in the Bhagirathi River.

Indices of Biological Diversity (IBD) indicated greater biodiversity at stations S1 (15.3) and S3 (15.5), suggesting that these locations host the most diverse diatom communities. In contrast, S4 (12.9) exhibited the lowest station diversity (Table 3). The Diatom Specific Pollution (IDS/E) analysis revealed that only S1, S3, and S5 were classified as low pollution stations. At the same time, S2 and S4 were deemed pollution-free (Table 3, Fig. 6). The Indices of Polluted Sensitive Species (IPS) recorded their highest values at S1 and S5, both showing a value of 14, further indicating that the River Belan is free from pollution and supports a significant number of pollution-sensitive diatom taxa (Table 3, Fig. 6). The Trophic Diatom Index (TDI)

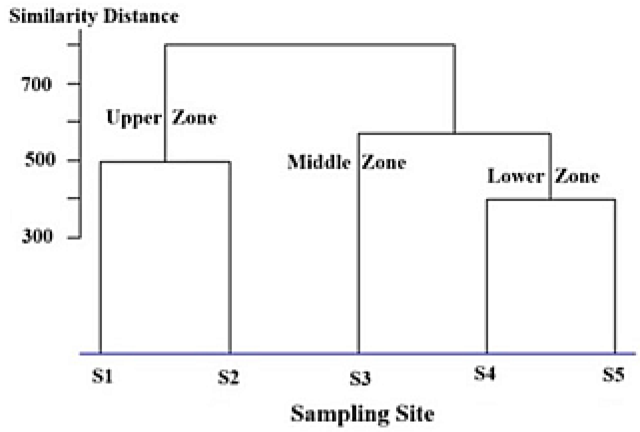


Figure 5. Dendrogram using hierarchical clustering method based on counts data of diatom species to classify stations by Ward method using Euclidean Linkage distance

also aligned with these findings, reflecting pollution-free stations in the River Belan, as the highest value recorded was 10.3 at S5, suggesting minimal eutrophication (Table 3, Fig. 6). The indicator species analysis identified diatom species such as *Gomphonema laticollum, Navicula symmetrica, Diploneis subovalis, Adalfia suchlandtii, Gomphonema gracile, Cymbella alpestris, Surirella tenera*, and *Achananthidium saprophilum* as indicators at stations S3 and S4 during the winter season. Conversely, *Achnanthidium minitisimum, Cymbella cymbiformis, Fragilaria capucina, Fragilaria elliptica, Navicula capitatoradiata, Navicula viridula, Nitzschia paleacea, Cymbella exicisiformis, Cymbella tumida, Amphora ovalis*, and

Table 3. OMNIDIA ver 6.09 calculated the ecological requirements of benthic diatoms in the river Belan at various stations. The evaluation values of pH, salinity (S), nitrogen uptake (NU), oxygen requirements (OR), saprobity (SP) and trophic state (TS) from van Dam et al. (1994) states the ecological conditions of the river at every station

S.No.	Parameters	S1	S2	S3	S4	S5
1.	pH	4 (65.9%)	4 (68.5%)	4 (42.6%)	4 (58.9%)	4 (43.7%)
2.	Salinity (S)	3 (67.3%)	3 (71.8%)	3 (63.7%)	3 (62.0%)	3 (51.2%)
3.	N, Uptake (NU)	3 (46.7%)	3 (53.4%)	3 (39.1%)	3 (32.6%)	2 (33.8%)
4.	O, requirements (OR)	2 (34.6%)	2 (30.2%)	2 (32.2%)	2 (31.8%)	2 (36.7%)
5.	Saprobity (SP)	3 (36.8%)	3 (42.8%)	3 (40.9%)	3 (39.5%)	3 (32.8%)
6.	Trophic state (TS)	6 (38.2%)	6 (41.2%)	6 (32.6%)	6 (44.4%)	6 (38.9%)

Evaluation of values from above given table (van Dam et al. 1994)

pH	4	Alkaliphilic
Salinity	3	Oligohalobous
N,	2	Sensitive N-autotrophictolerant
	3	N- autotrophic
O,	2	Polyoxybiontic
Saprobity	3	Â-mesosaprobous (BOD: 2-4 mg L^{-1})
Trophic state	6	Eutrophic

Reference table for health assessment (OMNIDIA ver. 6.09)

Sr. No.	Index names	Values	Analysis
1.	Biological Diversity Index-IBD	1-7	Worst to best
2.	Specific Pollution Sensitivity index-IPS	1-5	Worst to best
3.	Generic Diatom Index-IDG	1-5	Worst to best
4.	Index of Saprobity Eutrophication-IDE/S	3.5-4.5	Low pollution
5.	Trophic Diatom Index-TDI	20-40	low pollution
		41-60	Moderate polluted
		>61	Heavily polluted

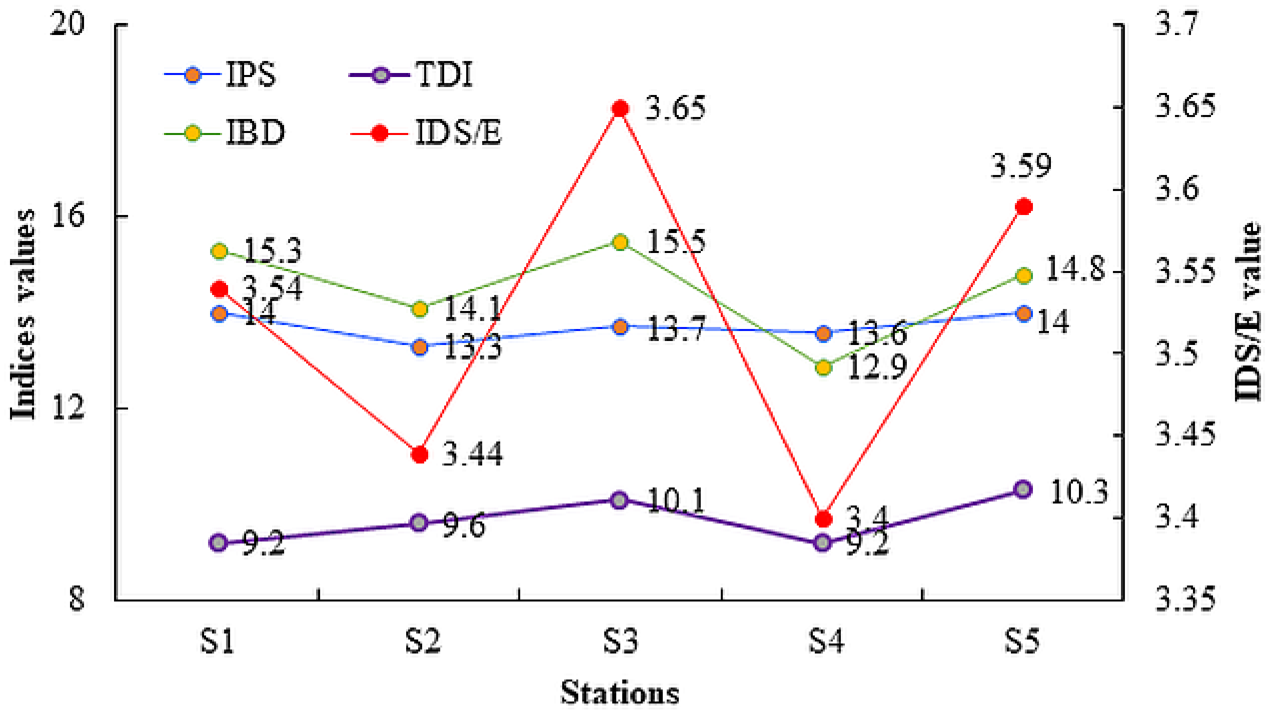


Figure 6. Diatom based indices for pollution, degradation and eutrophication predicting water quality in the Belan River (S1 to S5). Acronyms IBD - Biological Diatom Index, IDS/E - Index of Saprobity/ Eutrophication, IPS - Specific Pollution Sensitivity Index, TDI - Trophic Diatom Index

Fragilaria tenera served as indicator species at S1 and S2 during the winter and monsoon seasons (Table 4). Notably, no indicator species were identified during the summer season.

CONCLUSIONS

The present study concluded that the abundance of taxa varied among the stations depending on the season. Additionally, the characteristic diatom species differed across the various stations. However, during certain seasons, a few taxa were consistently observed across two to three stations collectively. The dendrogram analysis revealed that the stations were grouped into three distinct clusters. The health assessment of the Belan River indicated that little to

Table 4. Indicator diatom species at different station and season determined by using 'R' ver. 4.3.3 (Package Indic species). **Acronyms:** W-Winter, S-Summer, M-Monsoon, ADMI- *Achnanthidium minitisimum*, CCYM- *Cymbella cymbiformis*, FCVT- *Fragilaria capucina*, FELL- *Fragilaria elliptica*, NCPR- *Navicula capitatoradiata,* NVIR- *Naviculla viridula*, NPAE- *Nitzschia paleacea*, CEXF- *Cymbella exicisiformis*, CTUM- *Cymbella tumida*, AOVA- *Amphora ovalis* and FTEN- *Fragilaria tenera.* S1, S2, S3, S4, S5 are sampling stations as given in Table 1

Group	Site	Indicator species
1	W_S1, W_S2, M_S1, M_S2	ADMI, CCYM, FCVT, FELL, NCPR, NVIR, NPAE, CEXF, CTUM, AOVA, FTEN
2	W_S3, W_S4,	GLTC, NSYM, DSBO, ADFS, GGRA, CYAL, SUTE, ADSA
3	W_S5, S_S1, S_S2, S_S3, S_S4, S_S5, M_S3, M_S4, M_S5,	No taxa recorded

no pollution was observed at most stations; however, if anthropogenic activities were to increase, the river's health could deteriorate from its current state.

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