# Diatom Assemblages in The Natural, Impounded And Regulated Sections of The Tons River (Uttarakhand)

**Swati Sharma[1*] • Rachna Nautiyal[2]**

[1]*Department of Zoology Shri Gulab Singh Govt. Degree college Chakrata, Dehradun 248123.*
[2]*Higher Education Department, Govt. of Uttarakhand, Dehradun.*
*Corresponding Author Email: swatisharma9381@gmail.com

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**Abstract:** The purpose of the study is to examine the difference in diatom community, assemblages and their diversity with respect to the natural and regulated section of montane river Tons (Yamuna basin) in Himalaya. Diatom samples were collected at 4 stations from upstream to downstream; TR1 to TR4 at regular monthly basis and preserved in 4% formaldehyde solution. The permanent mounts were prepared in naphrax and examined for recording the flora under the bright field using Nikon Japan 80i trinuclear research microscope. The number of diatom taxa decreased from natural to regulated section. The continuity was impaired in this stretch as only 42 of 116 species and 14 of 24 genera occurred at all the stations. The species richness was highest in the natural upstream section TR 1(96 from 21 genera). It declined at TR2 (59 species-18 genera) and increased mildly at TR3 (63 species-15 genera) and TR4 (69 species,15 genera). Four genera (*Denticula, Hantzschia*, *Hippodonta* and *Adlafia*) were totally absent in downstream section. *Didymosphenia* and *Melosira* were recorded only at the dam location, exhibiting restricted distribution. Dominant taxa varied and amounted to 4 taxa for TR1 and TR2, only 2 taxa for TR3. No diatom taxon was at dominant at TR 4. *Cymbella* was recorded as the most species rich genera. Species richness decreased from TR1 to TR4. Consequently, the assemblages differed in natural, impounded and regulated sections of the Tons R.Vast variations in the flora, species richness and assemblages suggest a severe impact on the Tons R. ecosystem.

**Keywords:** Indicator • Distribution • Species richness • discharge-starved • connectivity • Wetland

## Introduction

Freshwater diatom assemblages are highly diverse, ubiquitous, and consistently correlate with environmental variables. Diatoms, the primary producers are useful bio-monitors. Attached diatom assemblages are useful as environmental indicator for both flowing and standing water (Watanabe 1985, 1990, Watanabe et al 1986, 1999). Dam is one of the major reason for adverse environmental condition, disruption of habitat connectivity for migratory species (Ward and Stanford, 1995), and alteration of flow regimes in which aquatic species' life history strategies had evolved (Bunn and Arthington, 2002). Dam alters the water flow, its chemistry and demolishes the ecosystem. Damming has fragmented major habitat and created millions of impoundments of various sizes. (Lehner et al 2011, Zarfl et al 2015). Dam construction decreased the water fungal biomass and richness in reservoirs and downstream reaches, but increased the amount of soil microorganisms in downstream lake wetlands. Dam construction has altered wetland ecosystems more extensively than other anthropogenic activities (Lees et al, 2016).

Research on diatoms in reservoirs has not been as extensive as research conducted in lakes and rivers. The impacts of river regulation remain uninvestigated for the installed hydro- power projects of the Yamuna basin. Hydro technical regulation of montane streams and rivers facilitates the utilization of their water resources, however at the same time it interferes with natural biocoeneses whose value is some time unique in the biological sense. In ecological terms the hydropower projects fragment the lotic ecosystem, damages bio-integrity or the eco-health of the riverine ecosystems. Creation of a barrage / dam regulates the natural flow which is known to affect the biota, their diversity and the communities in rivers. The structure of communities is known to differ radically in the impounded and regulated zone depending on the grade of organisms; protist (includes diatoms, algae), invertebrate, vertebrate (Badoni et al 1997, Bahuguna et al 2004, Bhatt et al 1997, 2000, Kishor et al 1997, 1998, Nautiyal et al 1997, Nautiyal 2014).

Diatoms are an important group of indicator organisms and their utility as indicators of water quality, with reference to organic pollution is well documented (Lange-Bertalot, 1979, Sladeck, 1986, Prygiel and Coste, 1993, Sabatier et al 1987). The study has been designed to draw inferences on the effect of river regulation on diatom flora, its assemblages, diversity and species richness. The spatial and temporal pattern of diatom distribution in an impounded montane river (Yamuna basin) in Himalaya is still unknown.

## Study area

For the present investigation the diversion dam, built on river Tons, near village Koti was selected. The distance from the diversion dam to Dakpatthar is ca. 40 km. by State Highway (SH 1) that connects with NH 123 before Kalsi. The dam diverts the water to the Chhivrau Power Station (240 MW) which is then returned to the Tons River before being fed to the Khodri Power Station (120 MW). The primary purpose of the dam is diversion for hydroelectric power production. In view of these modifications four stations were sampled on river Tons to study impacts in the natural, impounded and regulated sections of the Tons R. The stations in d/s section were considerably far from the dam and power house so as to know the state of modified flowing sections of the river. Sites for the present work are located between 30º38'40.67"-30º31'46.95"l N and 77º47'09.67"-77º49'29.96" E and elevation ranges from 740 to 472 masl.

**Fig. 1a TR 1. Semi-natural unregulated section of Tons R u/s of the Koti dam reservoir.**

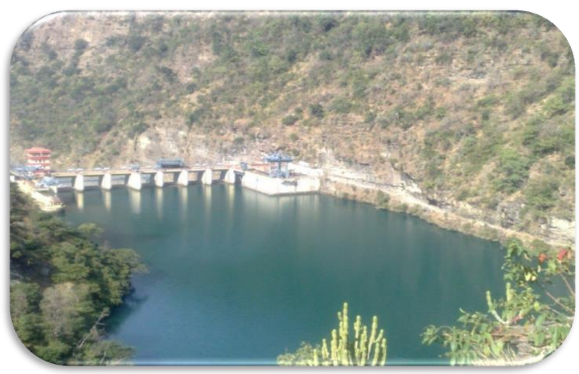

**Fig. 1b.TR 2 Koti dam reservoir on the Tons R.**

**Fig. 1 c TR 3. Regulated stretch 20 km d/s of Koti Dam (close to Chhivrau PH)**

**Fig. 1 d TR 4 Regulated stretch 8 km d/s of Chhivrau PH (cumulative distance 28 km)**

**TR 1-** This station is located 11 km upstream to Koti dam site on the river Tons. The site is a semi-natural /reference location as the river has natural flow and the human interference is least. The channel is wide as in lower stretch of the mountain rivers The cobbles and pebbles characterize the substratum. The river is not easily approachable at this point as the slopes are steep along the banks (Fig. 1a).

**TR 2-** The dam is located on river Tons (Fig. 1a) downstream of junction of Dhawadgad-nala and about 28 km. upstream of confluence of river Tons with river Yamuna. There was no flow as water is stored for diversion. The dam (a straight gravity dam) is 155 m wide, 59.25 meters high above the deepest foundation with a live storage capacity of 5.11 million m³. Due to storage the water column is deep and soft sediments are expected at the bottom.

**TR 3-** The station is located 20 km downstream to Koti diversion dam. It was very close to Chhivrau power station. A prominent geological feature is the bend of rock. The natural flow of the river is disturbed by power generation related activities and regulation of discharges of the powerhouse. The substratum was sandy and with small cobbles and pebbles. Short riffles and long pools were present at TR 3 (Fig. 1c).

**TR 4-** The station was 8 km downstream of the Chhivrau PH. It was just before the confluence of river Tons and the Yamuna near village Khodri-Majri on Himanchal Pradesh side and Haripur on Uttarakhand side. The right bank was exclusively rocky. The left bank is characterized by the sand with boulders, cobbles and pebbles. Channel was wide and the river is shallow in this discharge-starved stretch. This facilitates human interference like bathing, washing and other activities. Short riffles and longer pools were present at TR 4 (Fig. 1d).

## Materials and Methods

Sampling for diatom assemblages was performed at regular monthly basis for one year. Sampling was performed along the banks at the depth of 15-30 cm. Diatom samples were collected by scratching the cobbles with a brush of hard bristles in order to dislodge diatoms from crevices and minute cavities on the boulder surface from an area of 3 x 3 $cm^2$, using a sharp-edged razor. The scrapings from each cobble were collected in a petri dish and transferred to storage vials.

Samples were preserved in 4% formaldehyde solution. The preserved samples were processed for preparing Naphrax mount for light microscopy according to Reimer (1962) method adopted earlier also (Nautiyal and Nautiyal 1999, 2002). Each sample was examined for making species count using oil immersion lens (bright field - x100magnification, NIKON JAPAN 80i Trinocular Research Microscope). Counts were recorded for each species till 300-400 valves were counted. Relative abundance (as %) of various ditaom species in the sample was obtained for determining the assembalges defined by considering doimnants (taxa with highest abundance among those with >10% abundance).

## Result

### Species-richness and Diversity

The Species Richness, Range and Margalef Index decreased substantially from TR1 to TR2 and increased marginally at TR3 and TR4 in the downstream section. Species diversity and Evenness (H and E) exhibited a gradual increase from TR1 to TR4. All other indices show a similar trend (Table 1). A total of 116 taxa belonging to 24 genera were recorded in the hydropower impacted zone of the river Tons. The species richness was highest in the natural upstream section TR1 (96 taxa). In respect of TR1, declined to 59 (62%), 63 (66%) and 69 taxa (72%) at TR2, TR3 and TR4 respectively. Considerable decline was also observed in respect of richness at genera level; 21 at TR1 to 18 at TR2, 15 both at TR3 and TR4 amounting to 86% and 72%, respectively.

**Table 1. Variation in the alpha diversity attributes in hydropower impacted stretch (TR1-TR4) of the Tons. R.Variation in the alpha diversity attributes among the stations TR1-TR4.**

| | TR 1 | TR2 | TR 3 | TR 4 |
|---|---|---|---|---|
| Richness: Species/Genera. | 96/21 | 59/18 | 63/15 | 69/15 |
| Range | 4.51-8.48 | 3.75-7.22 | 3.3-6.3 | 4.9-6.5 |
| Margalef D Index | 11.6 | 7.545 | 7.795 | 8.347 |
| Simpsons D Index | 17.63 | 23.58 | 26.07 | 28.03 |
| B-P Dominance Index | 0.1091 | 0.09174 | 0.07276 | 0.06198 |
| Pileou J(All samples) Index | 0.7233 | 0.7578 | 0.7761 | 0.7935 |
| Simpson E Index | 0.1837 | 0.3997 | 0.4138 | 0.4063 |
| H | 3.301 | 3.459 | 3.543 | 3.622 |

**Table 2. Distribution of genera in the hydropower impacted stretch (TR1-TR4).**

| S. No. | Genera | No. of Species | TR 1 | TR2 | TR 3 | TR 4 |
|---|---|---|---|---|---|---|
| 1. | *Cymbella* | 29 | + | + | + | + |
| 2. | *Navicula* | 14 | + | + | + | + |
| 3. | *Achnanthidium* | 12 | + | + | + | + |
| 4. | *Nitzschia* | 11 | + | + | + | + |
| 5. | *Gomphonema* | 10 | + | + | + | + |
| 6. | *Achnanthes* | 5 | + | + | + | + |
| 7. | *Fragilaria* | 5 | + | + | + | + |
| 8. | *Coccconeis* | 3 | + | + | + | + |
| 9. | *Diatoma* | 3 | + | + | + | + |
| 10. | *Synedra* | 3 | + | + | + | + |
| 11. | *Encyonema* | 2 | + | + | + | + |
| 12. | *Planothidium* | 2 | + | + | + | + |

| S. No. | Genera | No. of Species | TR 1 | TR2 | TR 3 | TR 4 |
|---|---|---|---|---|---|---|
| 13. | *Sellaphora* | 2 | + | + | + | + |
| 14. | *Rsossthidium* | 1 | + | + | + | + |
| 15. | *Cymbopleura* | 3 | + | | + | |
| 16. | *Gyrosigma* | 1 | + | + | | |
| 17. | *Cyclotella* | 1 | + | + | | |
| 18. | *Denticula* | 2 | + | | | |
| 19. | *Cymbopleura* | 3 | + | | + | |
| 20. | *Didymosphenia* | 1 | + | | | |
| 21. | *Hantzschia* | 1 | + | | | |
| 22. | *Hippodonta* | 1 | + | | | |
| 23. | *Adlafia* | 1 | + | | | |
| 24. | *Melosira* | 1 | | + | | |
| 25. | *Craticula* | 1 | | | | + |

**Table 3. Distribution of assemblages (with % relative abundance) in hydropower impacted stretch (TR1-TR4).**

| Month | Assemblage forming species and their share at stations | | | | | | |
|---|---|---|---|---|---|---|---|
| | TR1 | | TR2 | | TR3 | | TR4 |
| | Taxa | % | Taxa | % | Taxa | % | |
| October | *Ce-Ct-Am* | 12.1-10.5-10.3 | nil | nil | nil | | nil |
| November | *Am-Np* | 11.7 each | *Cexg* | 10.1 | nil | | nil |
| December | *Ct-Am-Ab* | 16.4-11.6-11.4 | nil | nil | *Ce* | 12.2 | nil |
| January | *Ct* | 14.8 | *Cexg* | 10.3 | nil | | nil |
| February | *Ce-Ct-Cexg* | 12.5-12.1-11.1 | *Cexg* | 10.97 | nil | | nil |
| March | *Np-Cexg* | 14.1-11.2 | *Cexg* | 12.2 | nil | | nil |
| April | nil | nil | *Em-Cexg-Ct* | 17.3-11.5-10.5 | nil | | nil |
| May | *Np;* | 10.8 | *Ce* | 11.2 | *Su* | 11.5 | nil |
| June | nil | nil | *Ct* | 10 | *Ct* | 12.4 | nil |

**Punctuated and Restricted distribution**

Only 42 taxa from 14 genera constituting 36% in species and 58% genera were common at all the stations. Rest exhibited punctuated or restricted distribution (Table 2). Four genera *Denticula*, *Hantzschia*, *Hippodonta*, and *Adlaphia* were totally absent in the dam site and downstream section of river and recorded only for TR1 (Table 2). *Gyrosigma* and *Cyclotella* occurred in the natural (TR1) and impounded , (RT2) stretch but were absent in both downstream sections (TR3, TR4). *Cymbopleura* was the only genus found at TR1 and TR3. *Didymosphenia* and *Melosira* were present at dam site only. *Craticula* was present only at TR4. *Cymbella* was the most species rich genera (29 species) at all the stations followed by *Navicula* (14 species), *Achnanthidium* (12 species), *Nitzschia* (11 species) and *Gomphonema* (10 species).

Consequently, their species were also distributed in a punctuated or restricted fashion.

This study revealed temporal (monthly) variations in the assemblage at each station. Consequently, a variety of assemblage were observed at TR1 (Table 3). At this station the only similarity was dominance of *Cymbella excisa* in October and February, *Cymbella tumida* in December-January and *Nitzschia palea* in March and May.This resulted in peculiar assemblage represented by separate dominant-subdominant(s) comprising 3-taxa, 2-taxa and 1-taxon assemblage at TR1 and single dominant assemblage at TR3 (*C. excisa* in December*, Synedra ulna* in May and *C. tumida* in June. In contrast *Cymbella exigua* dominated assembalge occurred at station TR2 during November and January to March. Exclusive dominance was also observed in May-June compared to *Encyonema minutum-C. exigua-C. tumida* in April. As no taxa attained 10% relative abundance no assemblage was assigned to it. The relative abundance of *Navicula capitatoradiata* ranged from 6.3 to 8.9% from January to June. *S. ulna* exhibited 5-8% relative abundance from December to May and <5% in other months.

**Discussion**

Hydrological linkages have significant effects on the structure and function of river organisms (Kobayashi et al 1998, Tang et al 2006). All parts of a river ecosystem are inter-connected and any disturbance to one part will create a greater or lesser impact on the whole system (Wu et al 2010). As the longitudinal connectivity is mediated by flows, it is a major determinant of physical habitat in rivers that is impaired by construction of the dams and barrages, which in turn is the major determinant of biotic composition, as it brings the food down from upstream. Numerous studies show that flow velocity greatly influences the diatom community (Munteanu and Maly 1981, Plenković et al. 2008).

The Tons R. remains discharge - starved because the Koti Dam diverts the major discharge to the Chhivrau and Khodri Power House. This discharge does not return to the river Tons, instead it is delivered to the Yamuna just above the Dakpatthar barrage. In this study we examine the changes in diatom flora, their diversity and assemblages in the natural, impounded and regulated section of the river. The observations revealed a substantial loss in the flora as evidenced by the Species Richness; only 36% in species and 58% genera were common to all four stations. As expected, the Richness was highest in the natural upstream section TR1 which declined by 50% at TR2 and increased mildly to 54% at TR3 and 60% at TR4, compared to richness at TR1 (83% of total flora). Considerable decline was also observed in respect of richness at genera level; 21 at TR1 to 18 at TR2 and 15 at TR3 and TR4. Thus, the diatom taxa decreased from natural upstream TR1 to regulated section d/s of TR3. The lowest number of taxa were observed at dam location TR2. Consequently, some genera became restricted to different sections; *Denticula*, *Hantzschia*, *Hippodonta* and *Adlafia* were restricted to TR1. *Didymosphenia* and *Melosira* were present only at the dam site (TR2). *Gyrosigma* and *Cyclotella* occurred in the natural (TR1) and impounded stretch (TR2) only. *Cymbopleura* was restricted to TR1 and TR3, while *Craticula* to TR4 only. Thus, hydropower development adversely impacted the lower stretch evidenced by fragmented distribution of above said components of the flora.

*Cymbella* (29) was the most species-rich genera at all the stations followed by *Navicula* (14), *Achnanthidium* (12), *Nitzschia* (11) and *Gpmphonema* (10). Nautiyal R and Nautiyal P (1999) and Nautiyal et al (2004 a) observed that *Navicula* s.l. and *Achnanthes* s.l. were the most species- rich genera. *Achnanthes* (33, 38 taxa) was species-rich than *Navicula* (25, 28 taxa) in the Alaknanda-Ganga and Mandakini basin, respectively. Together, the flora from both these basins resulted in *Navicula* s.l. as species-rich taxa (Nautiyal 2004 b). In the flora of plateau (Bundelkhand) rivers *Navicula*, followed by *Nitzschia* and *Cymbella* were most species-rich genera in the Vindhya while in the Himalayan rivers *Navicula* and *Achnanthidium* were species-rich except the Alaknanda where the order was *Navicula*, *Cymbella* and *Achnanthidium* (Verma and Nautiyal 2011).

Construction of a dam fragments and modifies the free-flowing natural habitat. At the dam site the water column turns deep and static, while hard substratum is covered by soft sediments. Downstream of the dam the river becomes discharge-deficient reducing the wetted perimeter and the flows get modified. Only few taxa (36% of total observed flora) were found to survive in such condition's d/s of TR1 and were considered as "tolerant" forms. Sensitive taxa failed to survive resulting in punctuated and restricted distribution belonging to genera with identical distribution (Table 2).

However, investigations on the diatom community features reveal a peculiar trend with respect to assemblage. The lower zone of Tons R. was characterised by the presence of *Cymbella* as a species-rich genera. This was well reflected in the assemblages dominated by its species, the prominent being *C. excisa*, *C. exigua* and *C. tumida*. Of 11 types, 7 assemblages comprising 64% were formed by species of *Cymbella*. This is in contrast to other Himalayan rivers like Mandakini where assemblages were dominated by species of *Achnanthidium minutissimum or Achnanthidium biasolettiana* complex (Nautiyal and Mishra 2015). *Cymbella affinis* assemblages were recorded from springfed Khanda Gad (Nautiyal and Mishra 2013).

Different taxa become abundant at different locations, attributed to modified and regulated discharge by the creation of barrage rather than altitude. The dominant taxa of natural upstream TR 1 were different to the regulated section TR 2 and downstream TR3 section. *Achnanthidium minutissimum* was the common assemblage at TR1 but not in downstream. *Cymbella exigua* and *Cymbella excisa* formed the common assemblage at TR2. Totally different assemblage (*Navicula capitatoradiata* - *Cymbella tumida* - *Synedra ulna*) occurred in the downstream segment of river. The differences in assemblages could be due to a suite of physical and chemical factors influenced by modified flows.This does not seem to be influenced by altitude as it varied from 742 to 400 m asl only which is in contrast to role of altitude discussed below. In the lesser Himalayan glacier-fed river, Mandakini, the diatom assemblages varied with respect to season and flows as *Achnanthidium biasolettianum* and *Achnanthidium minutissimum* were co-dominants (Nautiyal and Mishra 2015).

Some studies show that flow velocity greatly influences the diatom community (Munteanu and Maly 1981, Plenković et al. 2008). Altitude is known to structure the diatom assemblages. According to Ormerod et al. (1994), altitude provided a stronger correlate than any other variable. Nautiyal (2005) also detected different assemblages at different altitudes in the mountain river Alaknanda. The low altitude assemblages were clearly separated from higher altitude. Nautiyal and Mishra (2013) noted that there was a gradual transition in the dominants in the assemblages from the upper to the lower stretch of the stream, showing more of altitudinal rather than longitudinal change.

*Achnanthidium minutissimum*, *Staurosirella pinnata* and *Nitzschia alpina* occurred as the most abundant species in at least eight of the 11

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investigated lakes in the high arctic aquatic habitats of northern Spitsbergen (Svalbard; Zgrundo et al (2017). In earlier studies also its found that *A. minutissima* assemblage were common in hill streams from different regions. Jesse et al (2005) also found *Achnanthidium minutissimum* as the most common species in Tillamook and Kilchis subbasin. *A. minutissimum* is considered to be an early successional species, typical of recently disturbed or stressful environments. Wojtal and Sobezyk (2012) carried out research in the springs finding that *Achnanthidium minutissimum* was the most represented taxon in both of the systems (fast and slow) and on the natural and the artificial substrate. *Achnanthidium minutissimum* competes successfully at low resource/high physical stress levels and is replaced by other species when resources (e.g., inorganic nutrients and light) become more abundant or habitat becomes more stable (Biggs et al. 1998). Singh et al (2017) observed unique assemblages in the spring habitats of Doon. Few springs were characterized by presence of *A. minutissimum* as dominant (SP4) or as subdominant at SP2 and SP5. These taxa were present at remaining locations also, but in low abundance.

Interruption of the river longitudinal connectivity through construction of barriers, such as hydroelectric power plants, dams, weirs and bridges, is one of the most serious and widespread modification of running water ecosystems (Ward, Stanford 1979, Welcomme 1994, JungWirth 1998, Nilssonet al. 2005). Dams impair the flow, impede the flux of water; sediments, biota and nutrients, and can fundamentally change the structure and dynamics of upstream and downstream aquatic and riparian habitats, and associated biotic communities (Ward and Stanford 1979, Petts 1984, Poff et al 1997, Poff and Zimmerman 2010). However, in a reservoir recurrent variable dewatering disturbance has the potential to influence community structure in river (Robson and Matthews 2004).

**Conclusions**

The lower/mouth zone of the Tons R. is characterized by *Cymbella* as the most species rich genera. The hydropower development has impaired the various community features of the Tons R. ecosystem. Only 56% of the genera and 36% of the species are common reflecting restricted and punctuated distribution not only at species but genera itself, amounting to a high degree impact. Most notable is the presence of invasive *Didymosphenia* at the dam site. The species richness decreased from TR1 to TR4. The assemblage differed in natural, impounded and regulated sections of the Tons R. No dominance was observed at last d/s section. Vast variations in the flora, species richness and assemblages suggest a severe impact on the Tons R. ecosystem.

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