

Original Article

Diatom community structure along physicochemical gradients in upland river segments of Tamiraparani river system, South India

Meenakshisundaram Amutha, Murugan Muralidharan*

Sri Paramakalyani Centre for Environmental Sciences, Manonmaniam Sundaranar University, Alwarkurichi, 627 412, Tamilnadu, India.

Abstract: This study examines the diversity and distributional patterns of benthic diatom assemblages in the upland streams of Tamiraparani River system, southern part of Western Ghats of Peninsular India. A total of 168 benthic diatoms representing 16 orders, 32 families, and 47 genera were enumerated. Structuring of diatom community was dependent on the environmental conditions of the respective habitats. Canonical correspondence analysis described both physical habitat quality and water parameter gradient and factors that correlated significantly were substrate type, water temperature, dissolved oxygen and nitrate content. *Gomphonema gandhii*, *Cocconeis placentula* and *Navicula cuspidata* were strongly associated with sites with embedded substrates and clear water. Diatoms could be effective in assessing physical habitat alterations in streams.

Article history:

Received 25 September 2016

Accepted 9 January 2017

Available online 25 February 2017

Keywords:

Benthic diatoms

Water quality

Streams

Tamiraparani River

Introduction

Aquatic systems are complex with heterogeneous habitats to support a variety of biota having unique features and occupying specific niche (Dudgeon et al., 2006). Structural characteristics in running waters are important as they define the organisms that are associated with. Unfortunately the increased dependability on freshwater resources for various human needs has immensely impacted the systems and organisms. Biodiversity loss has also been enhanced by the policies that permit infrastructure development in various sectors that rely on lotic systems (Andres et al., 2012). Though these impacts are increasingly recognized, it has become essential to quantify the biotic responses to the altered conditions and propose better management options (Bunn and Davies, 2000). Considerable progress has been made over the past four decades in designing and developing tools to monitor the contamination and potential sources of pollution of water bodies, however all such attempts are regarded incomplete without biological assessment to estimate the ecological damage of the systems (Barbour et al.,

1999; Karr, 2006).

Periphytons are among the few ecologically sensitive organisms that serve as indicators of system health and troves of biodiversity (Taylor et al., 2007; Larned, 2010; Bere and Mangadze, 2014). Diatoms constitute integral part in most stream food webs (Wehr and Sheath, 2003) serving as primary food source and habitat for many invertebrates and juvenile fishes (Lowe and Pan, 1996, Stevenson and Pan, 1999). Furthermore, they are regarded as good indicators to predict the ecological health of lotic systems because they occupy variety of habitats (Cantonati and Lowe, 2001; Potapova and Charles, 2005), sensitive to even subtle changes in the environmental conditions and also for their being easier to sample.

Streams and rivers are dynamic systems with inherent variability leading to temporal and spatial variation in water quality (Palmer and Poff, 1997; Grubbs et al., 2007). The quality of a stream is generally determined by the factors influencing it, which also reflects the biological diversity depending on it. This forms the basis for predicting

* Corresponding author: Murugan Muralidharan
E-mail address: muralisteam@gmail.com

the quality of water by the type of biota that it supports (Camargo and Jimenez, 2007). Diatoms are responsive to changes in the water chemistry and hence their distribution and abundance are influenced by environmental conditions (Kelly, 1998; Hering et al., 2006; Urrea and Sabatar, 2009). The other factors to influence diatom composition are the flow pattern and substrate type, characteristic of lotic ecosystems, wherein high and low flows have the potential to alter ecosystem structure (Francoeur and Biggs, 2006). Habitats of diatoms are diverse (Kelly, 1998) and unique for certain species (Tang et al., 2006) as the reason all species found are not available everywhere but occur in different micro habitats (Stevenson and Pan, 1999; Rimet, 2012). Traits such as preferential colonization and ability to react to changing nutrient levels make diatoms effective candidates indicating water quality (Hering et al., 2006; Neustupa et al., 2013; Fidlerová and Hlúbíková, 2016). Diatoms like fishes and other aquatic insects can be utilized for a basin-wide monitoring which further could be an essential part of comprehensive monitoring programme. Head water reaches of river systems are critical, the disturbances that occur in this region could be detrimental to the ecological health of downstream.

Survey and studies on diatoms of Indian peninsula is limited to few river systems and water bodies of some selected states with varied physiography (Nandan and Patel, 1984; Mishra and Saksena, 1993; Trivedy and Khataavkar, 1996; Nautiyal et al., 2004; Sharma et al., 2007; Nautiyal and Verma, 2009; Ramanujam and Siangbood, 2009; Sah and Hema, 2010; Baba et al., 2011; Siangbood and Ramanujam, 2014; Dwivedi and Misra, 2015). Despite the reason that sufficient works on periphyton are available and are being undertaken in waterbodies of southern India, most of them are related to diversity of algal community (Suresh et al., 2011; Selvin-Samuel et al., 2012), except for a few that also discuss the ecological aspects of the species and the systems (Venkatachalapathy and Karthikeyan, 2012; Venkatachalapathy et al., 2013). Yet a lacuna remains on the ecology of diatoms and

their ability to predict habitat integrity. Data on the distribution of aquatic diversity at spatial and temporal scales and changes in the communities in relation to the perturbances would enable effective understanding of the consequent biological integrity. Thus, the objective of this study was to explore and document the community composition of the benthic diatoms and to determine their relationship with environmental variables at various spatial reaches of the upland part along the main river and the tributaries of the Tamiraparani river system of Southern part of India.

Materials and Methods

Study area: Tamiraparani, medium sized perennial river basin in peninsular India, but a major river system in southern Tamil Nadu originates from the Agasthiyamalai or Pothigai hills in the Southern Western Ghats, flows eastwardly to an extent of 120 km to drain into the Bay of Bengal. The study sites include small rivers forming sub-basins (Manimuthar, Gadanathi, Karupanathi, Gundar and Chittar) and the main river system (Servalar and Karaiyar). Epilithic and epiphytic diatoms were sampled from eleven sites of Tamiraparani river over a period of eight months during August 2013-April 2014. Site selection was aimed at having comparison of upstream river sections of tributaries and the main river of the system (Fig. 1).

Diatom sample collection: Sampling was carried out in completely open to partially open canopy segments of the river. Sampling area in a particular river stretch was selected in such a way that it had rapids and care was taken to collect samples away from the bank to avoid aerophilous diatoms. Samples were collected from five or more cobbles (>64 and <256 mm diameter) or small boulders (>256 mm) from a reach of at least 10 m in the river. Substrata were placed in a tray, along with approximately 50 ml of river water. Diatoms were removed by vigorously scrubbing the upper surface (the side exposed to flowing water) of the substratum with a brush to dislodge the diatoms. Collection of epiphytic desmids was made by vigorously shaking

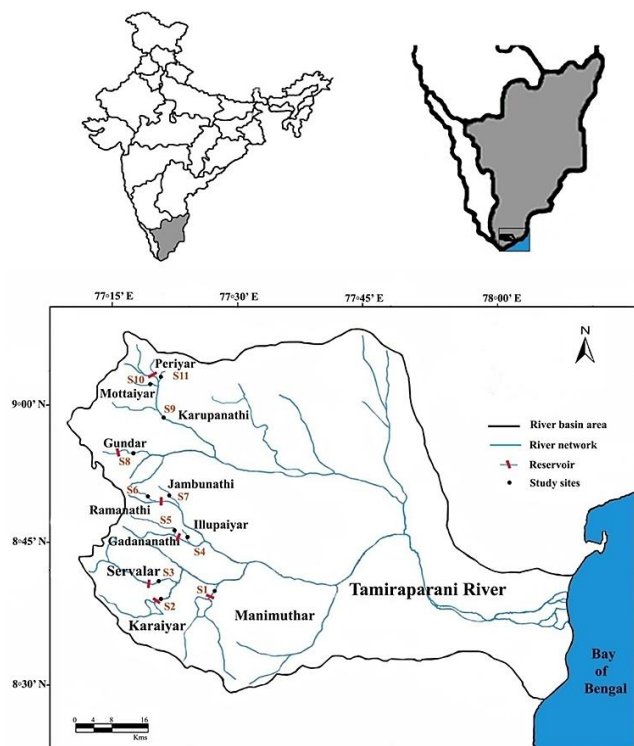


Figure 1. Detailed map of the site distribution in the upland part of Tamiraparani River system.

macropytes followed by plant squeezing or careful brushing in a plastic bag with 50 ml of stream water and the resulting brown suspension poured into a sample bottle. Samples were resuspended by thoroughly mixing and 20 ml of stock sample was transferred into a clean 150 ml beaker. Approximately 10 ml of concentrated HNO_3 was added (a pinch of $\text{K}_2\text{Cr}_2\text{O}_7$ was added, if the sample was rich in organic content). The beaker was placed onto a hot plate, covered with watch glass and digested. Samples were boiled until the total volume of the treated sample was reduced to 10-15 ml. The samples were further transferred to a 15 ml centrifuge tube. The volume of the samples was adjusted to 15 ml by adding distilled water. It was further centrifuged at 1700 ppm for 10 min. The supernatant was discarded. The washing and centrifuging processes were repeated for 5-6 times so as to get pellet, free of acid.

Clean coverslip was placed on a slide-drying table with diatoms allowing the coverslip to dry after which the diatom-coated coverslips were allowed to cool and then one or two drops of mountant were

placed onto each by means of a glass rod or pipette. Mountant on the coverslips were heated gently for 30 seconds to 1 min. A previously cleaned glass slide was then lowered onto the coverslip, inverted, and then heated at 90-120°C on a hot plate until the mounting medium 'boils' and all the solvent evaporates within two to five minutes. After mounting, the hot slide was quickly removed from the hot plate, and laid on the work bench, the coverslip adjusted into position, the slide is ready for microscopic examination. The permanent slide of diatom samples was viewed at a 100X with an oil immersion. Per sample 200, 300, 400 valves were counted and their relative abundance calculated diatom cells were counted at random. Identification of diatoms to the species level was done based on Gandhi (1955), Barber (198), Beaver (1981) Krammer (1980) Krammer and Lange-Bertalot (1985) and Karthick et al. (2013).

Physico-chemical variables: Water samples were collected (in 2L PVC container) at each site at a depth of 20-30 cm below the surface of the water during the day. Physical and chemical variables, including pH, temperature, turbidity, conductivity, alkalinity, dissolved oxygen, biological oxygen demand, chemical oxygen demand, total solids, phosphate, nitrate and chloride of the stream water at each pre-selected sampling sites were determined based on APHA (2005). Other environmental determinants observed and noted were water velocity, mean depth, embeddedness and substrate composition (%fines and sand, %gravel, %cobble, %boulder).

Data analysis: Detrended correspondence analysis (DCA) was used to determine gradient lengths of the biological data. Canonical correspondence analysis (CCA) was employed to establish the relationship between algal assemblages and environmental parameters. Prior to the analysis, the parameters were log transformed and diatom taxa were square root transformed to meet the assumptions of homoscedasticity. The statistical mean of each variable was tested with a Monte Carlo permutation test (500 permutations). Analyses were performed

using PAST (2.15) (Hammer et al., 2001).

Results

Diatom assemblages: The samplings made during this study yielded 168 species representing 47 genera, 32 families and 16 orders comprising both epilithic and epiphytic diatoms from 11 upland river stretches that included the main river and the tributaries of River Tamiraparani. Diversity varied with the stream habitats which ranged from 57 to 92 species. Sample collections were species-rich, mostly containing a minimum of 40 species to a maximum of 90 species. The greatest number of species per site was from Mottaiar (S11) with 92 species and least species count of 57 was from Karupanathi (S9). The most speciose genera were *Cymbella* and *Navicula* each representing 14 species followed by *Nitzschia* and *Amphipora* with 12 and 11 species, respectively. Taxa prevalent irrespective of stream habitat conditions were *Achnanthes exigua*, *A. inflata*, *Achnantheidium saprophilum*, *Amphora coffeaeformis*, *A. sabiniana*, *Cocconeis placentula* v. *euglypta*, *C. placentula* v. *lineata*, *Cyclotella meneghiniana*, *Cymbella parva*, *C. pusilla*, *C. turgidula*, *Gomphonema angustatum*, *G. gandhii*, *G. insigne*, *G. olivaceum*, *G. pseudosphaerophorum*, *G. pseudoaugur*, *Navicula dicephala*, *N. gallica*, *N. heimansioodes*, *N. angusta*, *N. cuspidata*, *N. lanceolata*, *N. rostellata*, *Nitzschia obtusa* var. *kurzii* and *N. scalpeliformis*. *Diatoma vulgaris* was sensitive to fine sediment whereas *Achnantheidium minutissimum*, *C. placentula*, *C. meneghiniana*, *C. tumida*, *Gomphonema parvulum*, *N. palea*, and *Rhopalodia gibba* also occupied sites influenced of some activities. Diatom diversity in most of the sites studied was equably high due to heterogeneity of microhabitats except few.

Water quality and environmental variables: Relative abundance data of diatoms were used for DCA, eigen values for first two DCA axes ($\lambda_1=0.43$, $\lambda_2=0.19$) accounted for 35% variation (Fig. 2, Table 1). The CCA detected patterns within species and sites based on the influencing environmental variables. The

species–environment variance was explained by the first axis 29.4% and second axis 23.9% with eigen values 0.32 and 0.26, respectively. Proportion of substrate type and the presence of fine substrate were influential in the structuring of diatom community. The first axis described both physical habitat quality and water parameter gradient distinguishing between sites based on the proportion of sand among the substrates and hardness of the water. The diversity and abundance of diatoms corresponded to water temperature and increasing proportion of boulder and cobble substrates, and decreasing proportions of sand. Further, the increasing abundance of diatoms increased with the proportion of habitat dominated by embedded cobbles and gravels. The placement of a species in the CCA ordination plane represented the environmental optima for the particular species relative to the other taxa.

Water temperature (0.75, $P<0.05$), %sandy substrate (0.69, $P<0.05$), dissolved oxygen (0.66) and Chloride (0.60) were highly loaded variables in the first two components, other variables were not significant. The second CCA axis described the water quality gradient. Sites and species were placed in the ordination plane according to the loadings of the factors. Sites S9 and S11 were characterized by higher values for temperature, %sandy substrate and Chloride and other chemical parameters Alkalinity, hardness, conductivity and pH (Fig. 3). Predominant diatoms that occurred in these streams were *C. parva*, *G. pseudoaugur*, *N. rostellata*, *C. pediculus* and *G. parvulam*. Anthropogenic disturbance observed in the sites were diversion of stream for washing, bathing and agricultural activities. Nitrate levels determined the placement of sites and clustering of species in the right side of the CCA plot accordingly Manimuthar (S1), Ramanathi (S6), and Jambunathi (S7) are placed closer. *Aulacoseira granulata*, *A. ambigua*, *A. fogediana*, *C. meneghiniana*, *Eunotia valida*, *Fragilaria ungeriana*, *N. dicephala*, *Pinnularia acrosphaeria* were species prevalent in sites with higher levels of nitrate (Fig. 2).

Water temperature was low in sampling stations S2 and S3, perhaps at a higher altitude than other

Table 1. Relative abundance data of diatoms used for Detrended Canonical Analysis (* 1-5%, ** 6-10%, *** 11-20%).

Species/Sites	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
<i>Achnanthes exigua</i> Grun (Ae)	*	*	*	*	*	*	*	-	-	**	*
<i>Achnanthes inflata</i> (Kutzing) Grunow (Ai)	*	*	*	*	*	*	*	-	-	***	-
<i>Achnanthes microcephala</i> Kutzing (Am)	-	*	-	-	-	***	***	-	-	-	*
<i>Achnanthidium minutissimum</i> (Kutzing) Czarnecki (Amt)	*	*	*	-	*	***	-	-	*	-	-
<i>Achnanthidium saprophilum</i> Round and Bukhtiyarova (As)	*	*	*	**	*	*	**	*	*	*	-
<i>Aulacoseira ambigua</i> (Grunow) Simonsen (Aam)	***	*	-	-	**	**	*	-	-	*	*
<i>Aulacoseira granulata</i> (Ehrenberg) Simonsen (Agr)	**	*	*	-	**	-	-	*	-	*	*
<i>Brachysira microcephala</i> (Grunow) Compere (Bmi)	-	***	-	-	**	*	*	-	-	*	-
<i>Brachysira wygaschii</i> Lange-Bertalot (Bwy)	*	**	-	-	***	*	*	*	-	-	-
<i>Cocconeis pediculus</i> Ehrenberg (Cpd)	*	*	**	-	*	*	*	-	*	*	*
<i>Cocconeis placentula</i> Ehrenberg (Cpl)	*	*	***	-	*	*	*	-	*	*	*
<i>Cyclotella meneghiniana</i> Kutz. (Cme)	-	*	-	*	*	*	**	-	*	*	*
<i>Eunotia minor</i> (Kutzing) Grunow (Emi)	*	-	-	*	-	*	-	-	-	-	**
<i>Fragilaria crotonensis</i> Kitton (Fcr)	*	**	-	-	*	*	*	-	-	*	*
<i>Fragilaria ungeriana</i> Grunow (Fun)	*	*	-	-	-	**	*	-	*	*	*
<i>Gomphonema affine</i> Kutzing (Gaf)	-	*	**	-	-	-	-	*	*	-	-
<i>Gomphonema gandhii</i> Karthick and Kociolek (Gga)	-	*	*	***	*	*	**	*	-	-	*
<i>Gomphonema parvulam</i> Kutz. (Gpa)	-	*	-	**	-	-	*	***	**	*	*
<i>Gomphonema pseudoaugur</i> Lang. (Gps)	*	*	*	*	*	-	*	**	**	**	*
<i>Gomphonema pseudosphaerophorum</i> (Gpp)	*	*	**	*	-	*	*	*	*	-	*
<i>Navicula rostellata</i> Kutzing (Nro)	-	*	-	*	*	*	-	*	**	*	*
<i>Planothidium rostratum</i> Lange-Bertalot (Pro)	-	-	-	-	*	*	-	-	***	-	*
<i>Pseudostaurosira tenuis</i> Morales and Edlund (Pte)	-	-	-	-	-	*	-	***	-	-	-
<i>Ulnaria acus</i> (Kutzing) Aboal (Uac)	*	*	-	*	-	*	**	-	-	*	*

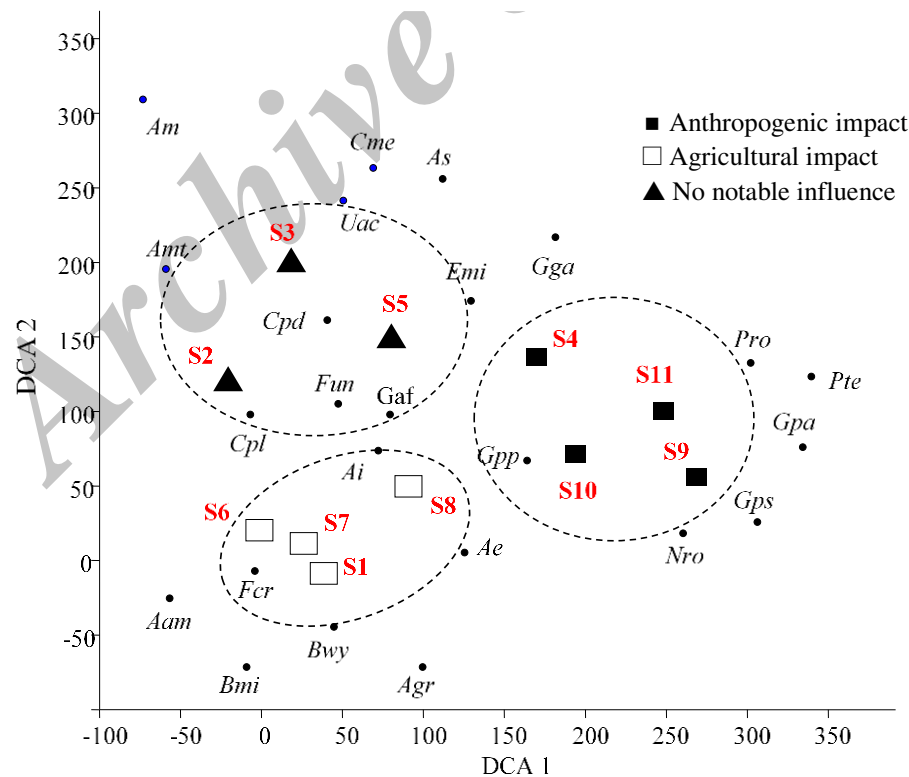


Figure 2. Detrended correspondence analysis (DCA) showing the distribution of species in sites. **Aam**: *Aulacoseira ambigua*, **Ae**: *Achnanthes exigua*, **Ai**: *Achnanthes inflata*, **Agr**: *Aulacoseira granulata*, **Am**: *Achnanthes microcephala*, **Amt**: *Achnanthidium minutissimum*, **As**: *Achnanthidium saprophilum*, **Bmi**: *Brachysira microcephala*, **Bwy**: *Brachysira wygaschii*, **Cme**: *Cyclotella meneghiniana*, **Cpl**: *Cocconeis placentula*, **Cpd**: *Cocconeis pediculus*, **Emi**: *Eunotia minor*, **Fcr**: *Fragilaria crotonensis*, **Fun**: *Fragilaria ungeriana*, **Gaf**: *Gomphonema affine*, **Gga**: *Gomphonema gandhii*, **Gpa**: *Gomphonema parvulam*, **Gps**: *Gomphonema pseudoaugur*, **Gpp**: *Gomphonema pseudosphaerophorum*, **Nro**: *Navicula rostellata*, **Pro**: *Planothidium rostratum*, **Pte**: *Pseudostaurosira tenuis* and **Uac**: *Ulnaria acus*.

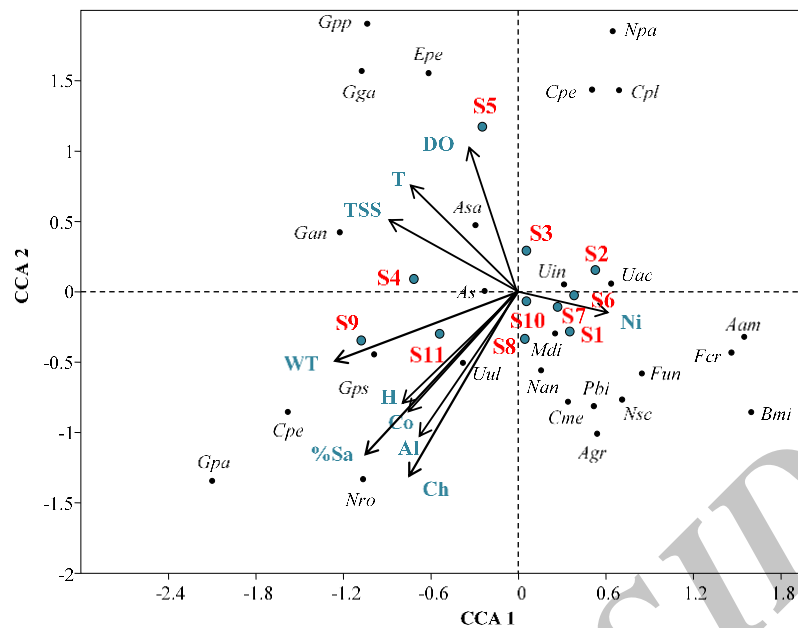


Figure 3. Canonical correspondence analysis (CCA) biplot of sites showing their relationships with environmental gradients.

sites, the quality was also soft marked by the lower values for alkalinity and hardness. *Encyonema sillessiacum*, *Frustulia rhomboids*, *Halarnphora veneta*, *Pinnularia streptoraphe* and *Ulnaria acus* were abundant in these sites. Prevalence of *G. gandhii*, *C. placentula* and *N. cuspidata* could be associated with the higher proportion of embedded substrates and lower proportion of fine substrates. These species are known to prefer water enriched with oxygen which is related to the high values for dissolved oxygen in the respective sites (Fig. 3). *Gomphonema parvulam* Kutz., *G. pseudoaugur* Lang. *Nitzschia palea* were abundant in S9 and S11. Similarity across streams with respect to diatom diversity was not evident, even though the sites were spatially closer, but the diversity of diatom community differed relative to the environmental factors that characterize that particular site (Figs. 2, 3).

Discussion

Distribution of diatoms in lotic systems, constantly under influence by flow modifications, is intriguing. Streams and small river networks and the topography of the regions they flow through determine the quality of the river system and the biota they support (Brown, 2000). The presence and distribution of

diatom taxa collected during this study was in relation to the in-stream habitat features, accordingly epilithon abundance was observed in cobbles and boulders dominated river segments and epiphyton representation was high in sites with submerged plants. Apart from rocky surfaces and macrophytes, fine and coarse sand also influenced the prevalence of species and hence the composition of species varied corresponding to the proportion of sandy surface. *Achnanthes minutissimum* was more abundant in S2 where the sandy substrate is periodically influenced by water flow from reservoir, similar such observation has been reported in unstable sandy substrates (Passy and Bode, 2004). *Diatoma vulgare* is sensitive to sediment and was found only in sites that had least proportion of fine sand (S5).

The preferential pattern in diatom distribution with regard to the quality of water has been specific, whereby the sensitive species occupy only the clear undisturbed areas and the tolerant group of species survives even in disturbed segments (Potapova and Charles, 2005). *Cymbella parva*, *G. pseudoaugur*, *N. rostellata*, *C. pediculus* and *G. parvulam* were abundantly colonized in Karuppanathi (S9) and Periyar (S10) with comparatively high ionic strength, high conductivity, high alkalinity and

hardness. Richness of diatom communities has been observed to be correlated with ionic composition (Leland et al., 2001) and distribution pattern differed along different TDS gradients (Tudor et al., 1991, Stevenson and Pan, 1999). Human mediated disturbances could alter both the water quality as well as the habitat of the diatoms. Removal of gravel and sand, channelization of streams, embankments across flow direction were some reasons observed in the sites that could severely impact on diatom colonization. Localities S1, S6 and S7 were characterized by the influence of agricultural activities in the vicinity of the sites and the frequent draining of run-off in the river stretches as evident from the grouping in DCA. Interestingly, Illupaiyar (S4) stream though flows through cultivated land had minimal influence on the water quality but for the slight increase in TSS.

Cyclotella meneghiniana, *G. parvulum* and *N. palea* regarded as tolerant species were present in both the disturbed sites and sites that had minimum influence, however with variation in the abundance this could be an indication that the streams that presently seems undisturbed could have some been subjected to anthropogenic impact in the recent past. *N. palea* occurs in organically polluted waters (Fore and Grafe, 2002) and colonizes in greatest proportions in the deforested streams (Bellinger et al., 2006). The quality and quantity of fresh water resources are critically affected by alterations in land use and land cover which could substantially alter algal diversity (Li et al., 2008; Walsh and Wepener, 2009). Stream diatom assemblages generally are associated to physical habitat conditions, much accounted for variables like riparian conditions, in-stream habitat and channel morphology (Pan et al., 2006; Veselá and Johansen, 2009). However, there are studies that show nutrients and salinity as the influencing factors than physical conditions (Leland et al., 2001).

Physiochemical parameters such as dissolved oxygen, conductivity and dissolved solids fluctuate between sites are dependent on flow and the organic matter content at the particular site, thus could vary

between sites and rivers (Zheng and Stevenson, 2006; Walker and Pan, 2006; Shetty et al., 2015). This was true with respect to the sites sampled and variations observed in the parameters were related to the in-stream structure. The rapids, characteristic of upland rivers, frequently agitate along their course enriching with rich quotient of dissolved oxygen, the problem is that they are also bound to carry organic load in the form of drift and dissolved solids. Similar condition was observed in Illupaiyar (S4) that had higher values for dissolved oxygen and dissolved solids. During the course of establishing the relationship between environmental conditions and diatom diversity, we indented to verify whether diatom community composition in each site could explain the alterations to the habitat. DCA effectively segregated the sites into three divisions accordingly a group comprised habitats under anthropogenic influence (S9, S10, S11), the next group had sites influenced by agricultural activities (S1, S6, S7, S8) and the other uncategorised (S2, S3, S4, S5) with respect to the influence based on physico-chemical quality of the respective streams and tributaries of the river system. Dynamic streams without human mediated disturbances could better maintain complexity and integrity among lotic systems (Palmer et al., 2005). However, disturbed sites tend to show more diatom diversity than less influenced sites which is due to the presence and abundance of both moderately sensitive and tolerant species (Yu and Lin, 2009). Apart from variations in environmental features, the diversity of macrophytes define the diversity of epiphytons which was beyond the scope of this study.

References

- Andres S.M., Mir L.C., van den Bergh J.C.J.M, Ring I., Verburg P.H. (2012). Ineffective biodiversity policy due to five rebound effects. *Ecosystem Services*, 1: 101-110.
- APHA (2005). *Standard Methods for the Examination of Water and Wastewater*. 21st ed. APHA, AWWA and WEF, American Public Health Association, Washington D.C.
- Baba A.I., Aadil H.S., Bhat S.U., Pandit A.K. (2011).

- Periphytic algae of river Sindh in the Sonamarg area of Kashmir valley. *Journal of Phytology*, 3: 1-12.
- Barber H.G., Haworth E.Y. 1981. A guide to the morphology of the diatom Frustule. Freshwater Biological Association Scientific publication No. 44. 112 p.
- Barbour M.T., Gerritsen J., Synder B.D., Stribling J.B. (1999). Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates and fish, 2nd ed. Environmental Protection agency Publication No. 841-B-99-002.
- Bellinger B.J., Cocquyt C., O'Reilly C.M. (2006). Benthic diatoms as indicators of eutrophication in tropical streams. *Hydrobiologia*, 573: 75-87
- Bere T., Mangadze T. (2014). Diatom communities in streams draining urban areas: community structure in relation to environmental variables. *Tropical Ecology*, 55(2): 271-281.
- Beaver J. (1981). Apparent Ecological Characteristics of Some Common Freshwater Diatoms. Ontario Ministry of the Environment, Rexdale, Ontario, Canada. 517 p.
- Brown L.R. (2000). Fish communities and their associations with environmental variables, lower San Joaquin River Drainage, California. *Environmental Biology of Fishes*, 57: 251-269.
- Bunn S.E., Davies P.M. (2000). Biological processes in running waters and their implications for the assessment of ecological integrity. *Hydrobiologia*, 422/423: 61-70.
- Camargo J.A., Jimenez A. (2007). Ecological responses of epilithic diatoms and aquatic macrophytes to fish farm pollution in a Spanish river. *Anal del Jardin Botanico de Madrid*, 64: 213-219.
- Cantonati M., Lowe R.L. (2014). Lake benthic algae: Toward an understanding of their ecology. *Freshwater Science*, 33: 475-486.
- Dudgeon D., Arthington A.H., Gessner M.O., Kawabata Z., Knowler D.J., Le'vé'que C., Naiman R.J., Prieur-Richard A., Soto D., Stiassny M.L.J., Sullivan C.A. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews* 81: 163-182.
- Dwivedi R.K., Misra P.K. (2015). Freshwater Diatoms from Himalayan State Himachal Pradesh, India. *Phykos*, 45(1): 30-39.
- Fidlerová D., Hlúbíková D. (2016). Relationships between benthic diatom assemblages' structure and selected environmental parameters in Slovak water reservoirs (Slovakia, Europe). *Knowledge and Management of Aquatic Ecosystems*, 417: 27.
- Fore L.S., Grafe C. (2002). Using diatoms to assess the biological condition of large rivers in Idaho (USA). *Freshwater Biology*, 47: 2015-2037.
- Francoeur S.N., Biggs B.J.F. (2006). Short-term effects of elevated velocity and sediment abrasion on benthic algal communities. *Hydrobiologia*, 516: 59-69.
- Gandhi H.P. (1955). A contribution to our knowledge of the freshwater diatoms of Partabgarh Rajasthan. *Journal of the Indian Botanical Society*, 34(4): 307-338.
- Grubbs S.A., Meier O.W., Meier A.J. (2007). Longitudinal patterns of fish assemblages in small unregulated sub basins: evaluating reach and watershed-scale parameters. *Hydrobiologia*, 592: 211-223
- Hammer Ø., Harper D.A.T., Ryan D.D. (2001). PAST: Paleontological statistics software package for education and Data analysis. *Paleontologia Electronica*, 4: 9 p.
- Hering D., Johnson R.K., Kramm S., Schmutz S., Szoszkiewicz K., Verdonschot P.F.M. (2006). Assessment of European streams with diatoms, macrophytes, macroinvertebrates and fish: a comparative metric-based analysis of organism response to stress. *Freshwater Biology*, 51: 1757-1785.
- Jena M., Ratha S.K., Adhikary S.P. (2005). Algal diversity changes in Kathajodi River after receiving sewage of Cuttack and its ecological implications. *Indian Hydrobiology*, 8(1): 67-74.
- Karr J.R. (2006). Seven foundations of biological monitoring and assessment. *Biological Ambientale*, 20: 7-18.
- Karthick B., Hamilton P.B., Kociolek J.P. (2013). An illustrated guide to common diatoms of Peninsular India. Gubbi Labs. Gubbi. 206 p.
- Kelly M.G. (1998). Use of the trophic diatom index to monitor eutrophication in rivers. *Water Research*, 32: 236-42.
- Krammer K. (1980). Morphological and taxonomic investigations of some freshwater species of the diatom genus *Amphora* Ehr. *Bacillaria*, 6: 197-226.
- Krammer K., Lange-Bertalot H. (1985). *Naviculaceae. Bibliotheca Diatomologia*, Band 9. J. Cramer, Berlin-Stuttgart. 230 p.
- Larned S.T. (2010). A prospectus for periphyton: recent

- and future ecological research. *Journal of North American Benthological Society*, 29: 182-206.
- Leland H.V., Brown L.R., Mueller D.K. (2001). Distribution of algae in the San Joaquin River, California, in relation to nutrient supply, salinity and other environmental factors. *Freshwater Biology*, 46: 1139-1167.
- Li S., Gu S., Liu W., Han H., Zhang Q. (2008). Water quality in relation to land use and land cover in the Upper Han River Basin, China, *Catena*, 75: 216-222.
- Lowe R.L., Pan Y. (1996). Benthic algal communities and biological monitors. In: R.J. Stevenson, M. Bothwell, R.L. Lowe (Eds.). *Algal Ecology: Freshwater Benthic Ecosystems*, San Diego, CA: Academic Press. pp: 705-39.
- Mishra S.R., Saksena D.N. (1993). Phytoplanktonic composition of sewage polluted Morar (Kalpi) river in Gwalior, Madhya Pradesh, *Environment and Ecology*, 11: 625-629.
- Nandan S.N., Patel R.J. (1984). Ecological studies on algal flora of Vishwamitri River, Baroda, Gujarat. *Indian Journal of Plant Nature*, 1: 17-32.
- Nautiyal P., Verma J. (2009). Taxonomic richness and diversity of the epilithic diatom flora of the two biogeographic regions of the Indian subcontinent. *Bulletin of the National Institute of Ecology*, 19: 1-4.
- Nautiyal P., Nautiyal R., Kala K., Verma J. (2004). Taxonomic richness in the diatom flora of Himalayan streams (Garhwal, India). *Diatom*, 20: 123-132.
- Neustupa J., Veselá J., Šťastný J. (2013). Differential cell size structure of desmids and diatoms in the phytobenthos of peatlands. *Hydrobiologia*, 709: 159-171.
- Palmer M.A., Poff N.L. (1997). The influence of environmental heterogeneity on patterns and processes in streams. *Journal of the North American Benthological Society*, 16: 169-173.
- Palmer M.A., Bernhardt E.S., Allan J.D., Lake P.S., Alexander G., Brooks S., Carr J., Clayton S., Dahm C.N., Follstad Shah J., Galat D.L., Gloss S., Goodwin P., Hart D.D., Hassett B., Jenkinson R., Kondolf G.M., Lave R., Meyer J.L., O'Donnell T.K., Pagano L., Sudduth E. (2005). Standards for ecologically successful river restoration. *Journal of Applied Ecology*, 42: 208-217.
- Pan Y., Hill B.H., Husby P., Hall R.K., Kaufmann P.R. (2006). Relationships between environmental variables and benthic diatom assemblages in California Central Valley streams (USA). *Hydrobiologia*, 561: 119-130.
- Passy S.I., Bode R.W. (2004). Diatom model affinity (DMA), a new index for water quality assessment. *Hydrobiologia*, 524: 241-51.
- Poff N.L., Allan J.D., Bain M.B., Karr J.R., Prestegard K.L., Richter B.D., Sparks R.E., Stromberg J.C. (1997). The natural flow regime: a paradigm for river conservation and restoration. *BioScience*, 47: 769-783.
- Potapova M.G., Charles D.F. (2005). Choice of substrate in algae-based water quality assessment. *Journal of North American Benthological Society*, 24: 415-427.
- Ramanujam P., Siangbood H. (2009). Diversity of algal communities in Umiew River, Meghalaya. *Indian Hydrobiology*, 12: 65-73.
- Rimet F. (2012). Recent views on river pollution and diatoms. *Hydrobiologia* 683:1-24.
- Sah N., Hema H. (2010). Algal biodiversity and physico-chemical characteristics of River Kosi in Almora District. *Bioscience Guardian an International Journal*, 231-235.
- Selvin-Samuel A., Martin P., Mary C.R., Manthikumar R.A. (2012). A study of phytoplankton in river Tamiraparani. *Indian Hydrobiology* 14(2): 31-138.
- Sharma A., Sharma R.C., Anthwal A. (2007). Monitoring phytoplanktonic diversity in the hill stream Chandrabhaga of Garhwal Himalaya. *Life Science Journal*, 4: 1: 80-84.
- Shetty A., Venkateshwarlu M., Muralidharan M. (2015). Effect of water quality on the composition of fish communities in three coastal rivers of Karnataka, India. *International Journal of Aquatic Biology*, 3(1): 42-51.
- Siangbood H., Ramanujam P. (2014). Effect of anthropogenic activities on algal assemblages in Umiew River, Meghalaya. *Phykos*, 44(1): 41-51.
- Stevenson R.J., Pan Y. (1999). Monitoring environmental changes using diatoms in stream and river communities. In: E.F. Stoermer, J.P. Smol (Eds.). *The diatoms: applications to environmental and earth sciences*. Cambridge University Press. pp: 11-40.
- Suresh B., Manjappa S., Puttaiah E.T. (2011). Seasonal variation of phytoplankton in Tungabhadra River near Harihar, Karnataka. *Research Journal of Biological Sciences*, 6(2): 65-68.
- Tang T., Cai Q.H., Liu J.K. (2006). Using epilithic diatom communities to assess ecological condition of Xiangxi

- River system. Environmental Monitoring and Assessment, 112: 347-361.
- Taylor J.C., Janse van Vuuren M.S., Pieterse A.J.H. (2007). The application and testing of diatom-based indices in the Vaal and Wilge Rivers, South Africa. Water SA, 33(1): 51-60.
- Tudor E.R., Blinn D.W., Churchill D.M. (1991). Distribution of diatoms in the northern Kimberley region, Western Australia in relation to water chemistry. Journal of Royal Society of Western Australia., 73(3): 93-99.
- Trivedy R.K., Khatavkar S.D. (1996). Phytoplankton ecology of the river Krishna in Maharashtra with reference to bioindicators of pollution, In: S.R. Mishra (Ed.). Assessment of Water Pollution, APH Publishing Corporation, New Delhi. pp: 299-328
- Urrea G., Sabater S. (2009). Epilithic diatom assemblages and their relationship to environmental characteristics in an agricultural watershed (Guadiana River, SW Spain). Ecological Indicators, 9: 693-703.
- Venkatachalapathy R., Karthikeyan P. (2012). Environmental impact assessment of Cauvery River with diatoms at Bhavani, Tamil Nadu, India, International Journal of Geology, Earth and Environmental Sciences, 2(3): 36-42.
- Venkatachalapathy R., Nandhakumar G., Karthikeyan P. (2013). Diatoms Community Structure in Relation to Physico-Chemical Factors in Yercaud Lake, Salem District, Tamil Nadu, India. International Journal of Innovative Technology and Exploring Engineering, 2(4): 220-222.
- Veselá J., Johansen J.R. (2009). The diatom flora of ephemeral headwater streams in the Elbsandsteingebirge region of the Czech Republic. Diatom Research, 24: 443-477.
- Walker C.E., Pan Y. (2006). Using diatom assemblages to assess urban stream conditions. Hydrobiologia, 516: 179-189.
- Walsh G., Wepener V. (2009). The influence of land use on water quality and diatom community structures in urban and agriculturally stressed rivers. Water SA, 35(5): 579-594.
- Wehr J.D., Sheath R.G. (2003). Freshwater Algae of North America, Ecology and Classification. Academic Press, San Diego, CA, USA. 1066 p.
- Yu S.F., Lin H.J. (2009). Effects of agriculture on the abundance and community structure of epilithic algae in mountain streams of subtropical Taiwan. Botanical Studies, 50: 73-87.
- Zheng L., Stevenson R.J. (2006). Algal assemblages in multiple habitats of restored and extant wetlands. Hydrobiologia, 561: 221-238.