**Int. J. Aquat. Biol.** (2017) 5(1): 12-21
ISSN: 2322-5270; P-ISSN: 2383-0956
Journal homepage: www.ij-aquaticbiology.com


Original Article

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

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**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

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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 Hlúbiková, 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 Khatavkar, 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 Agasthiamalai 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, Gadananathi, 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

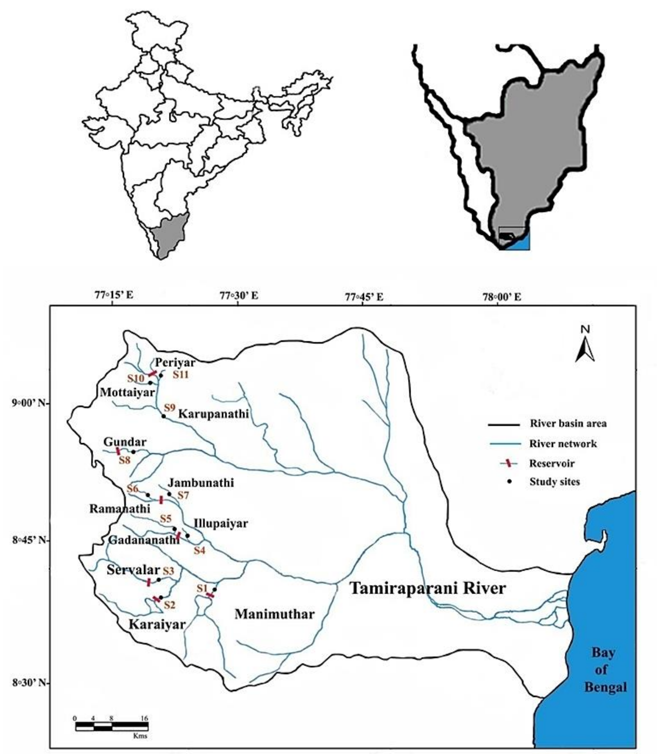


Figure 1. Detailed map of the site distribution in the upland part of Tamiraparani River system.

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 $K_2Cr_2O_7$ 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 homoscedasicity. 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*, *Achnanthidium saprophilum, Amphora coffeaeformis, A. sabiniana, Cocconeis placentula v. euglypta, C. placentula v. lineata, Cyclotella meneghiniana, Cymbella parva, C. pusilla, C. turgidula, Gomphonema angutastum, G. gandhii, G. insigne, G. olivaceum, G. pseubsphaerophorum, 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 *Achnanthidium 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Achnanthes exigua* Grun (Ae) | * | * | * | * | * | * | * | - | - | ** | * |
| *Achnanthes inflata* (Kutzing) Grunow (Ai) | * | * | * | * | * | * | * | - | - | *** | - |
| *Achnanthes microcphala* Kutzing (Am) | - | * | - | - | - | *** | *** | - | - | - | * |
| *Achnanthidium minutissimum* (Kutzing) Czarnecki (Amt) | * | * | * | - | * | *** | - | - | * | - | - |
| *Achnanthidium saprophilum* Round and Bukhtiyarova (As) | * | * | * | ** | * | * | ** | * | * | * | - |
| *Aulacoseira ambigua* (Grunow) Simonsen (Aam) | *** | * | - | - | ** | ** | * | - | - | * | * |
| *Aulacoseira granulata* (Ehrenberg) Simonsen (Agr) | ** | * | * | - | ** | - | - | * | - | * | * |
| *Brachysira microcephala* (Grunow) Compere (Bmi) | - | *** | - | - | ** | * | * | - | - | * | - |
| *Brachysira wygaschii* Lange-Bertalot (Bwy) | * | ** | - | - | *** | * | * | * | - | - | - |
| *Cocconeis pediculus* Ehrenberg (Cpd) | * | * | ** | - | * | * | * | - | * | * | * |
| *Cocconeis placentula* Ehrenberg (Cpl) | * | * | *** | - | * | * | * | - | * | * | * |
| *Cyclotella meneghiniana* Kutz. (Cme) | - | * | - | * | * | * | ** | - | * | * | * |
| *Eunotia minor* (Kutzing) Grunow (Emi) | * | - | - | * | - | * | - | - | - | - | ** |
| *Fragilaria crotonensis* Kitton (Fcr) | * | ** | - | - | * | * | * | - | - | * | * |
| *Fragilaria ungeriana* Grunow (Fun) | * | * | - | - | - | ** | * | - | * | * | * |
| *Gomphonema affine* Kutzing (Gaf) | - | * | ** | - | - | - | - | * | * | - | - |
| *Gomphonema gandhii* Karthick and Kociolek (Gga) | - | * | * | *** | * | * | ** | * | - | - | * |
| *Gomphonema parvulam* Kutz. (Gpa) | - | * | - | ** | - | - | * | *** | ** | * | * |
| *Gomphonema pseudoaugur* Lang. (Gps) | * | * | * | * | * | - | * | ** | ** | ** | * |
| *Gomphonema pseudosphaerophorum* (Gpp) | * | * | ** | * | - | * | * | * | * | - | * |
| *Navicula rostellata* Kutzing (Nro) | - | * | - | * | * | * | - | * | ** | * | * |
| *Planothidium rostratum* Lange-Bertalot (Pro) | - | - | - | - | * | * | - | - | *** | - | * |
| *Pseudostaurosira tenuis* Morales and Edlund (Pte) | - | - | - | - | - | * | - | *** | - | - | - |
| *Ulnaria acus* (Kutzing) Aboal (Uac) | * | * | - | * | - | * | ** | - | - | * | * |

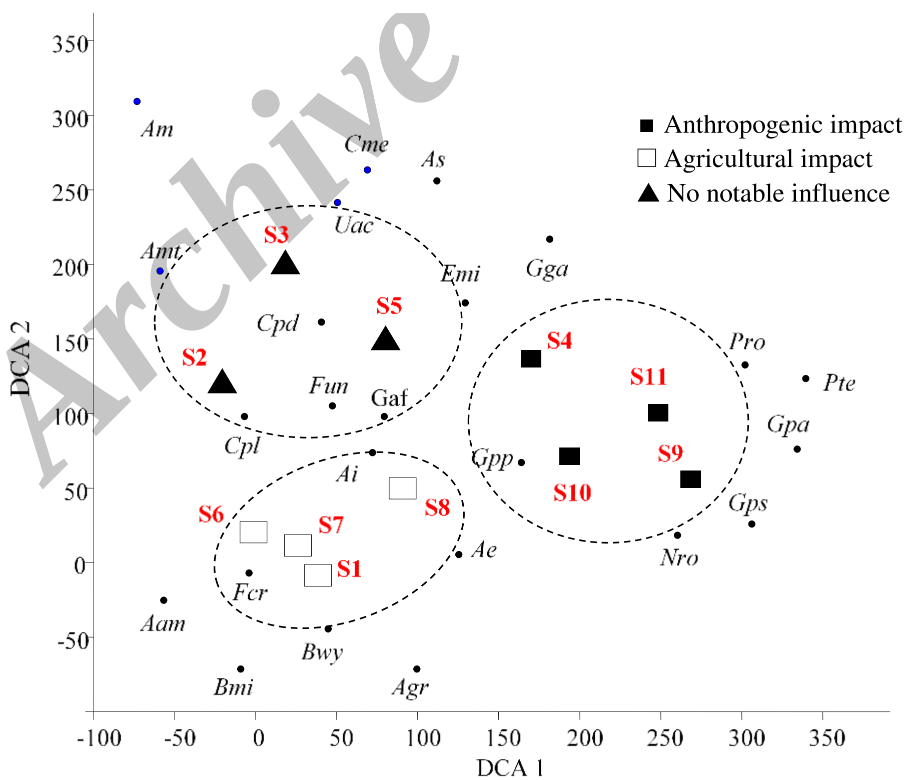


Figure 2. Detrended correspondence analysis (DCA) showing the distribution of species in sites. ***Aam***: *Aulacoseira ambigua*, ***Ae***: *Achnanthes exigua*, ***Ai***: *Achnanthes inflata*, ***Agr***: *Aulacoseira granulata*, ***Am***: *Achnanthes microcphala*, ***Amt***: *Achnanthidium minutissimum*, ***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.*

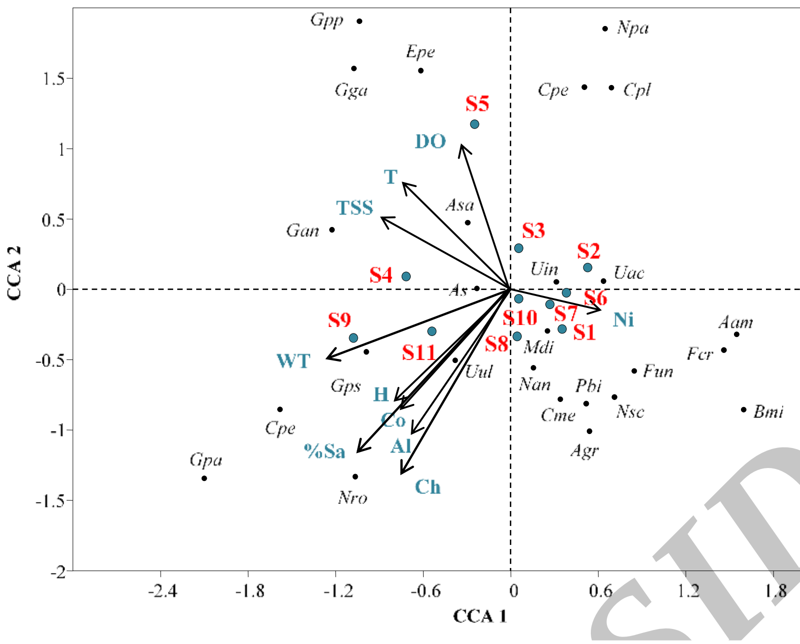


Figure 3. Canonical correspondence analysis (CCA) biplot of sites showing their relationships with environmental gradients.

sites, the quality was also soft marked by the lower values for alkalinity and hardness. *Encyonema silessiacum, Frustulia rhomboids, Halamphora 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-steam 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. *Achnanthidium 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 vulgaris* is sensitive to sediment and was found only in sites that had least proportion of find 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.

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