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Distribution of the Diatoms and Water Quality Assessment of the Thamirabarani River, Tamil Nadu, South India

Madhu Madhankumar * and Raju Venkatachalapathy

Department of Geology, Periyar University, Salem-636 011, Tamil Nadu, India
**Corresponding author: madhangeo@gmail.com*

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Abstract. The diatoms are one of the most significant organisms beneficial for biomonitoring investigations. The present study deals with the diatom and water samples collected from 10 different localities in the Thamirabarani River, Southern India. Diatom samples were collected by scraping stones with a toothbrush and squeezing macrophytes. Study of diatom valve morphology and measurements of diatoms were carried out using an optical miccroscope. The present study recorded 58 diatom taxa belonging to 25 genera. Among the diatoms, the taxonomical characters of 20 abundant diatom taxa viz. *Aulacoseira granulata, Discostella stelligera, Navicula cryptocephala, Encyonema minutum, Gomphonema gandhii, Eunotia asterionelloides, Gomphonema parvulum, Brachysira neglectissima, Aulacoseira ambigua, Diadesmis confervacea, Nitzschia palea, Nitzschia amphibia, Sellaphora Americana, Staurosirella pinnata, Gomphonema affine, Fragilaria pararumpens, Eunotia incisa, Navicula erifuga, Navicula cryptotenella* and *Navicula rostellata are* described and illustrated. In the present study abundant diatom genera were observed such as *Aulacoseira, Discostella, Navicula, Encyonema, Gomphonema, Brachysira, Nitzschia, Sellaphora, Staurosirella, Fragilaria* and *Eunotia*. In abundant diatom taxa such as *Aulacoseira granulate, Discostella stelligera, Gomphonema gandhii, Fragilaria pararumpens, Navicula cryptocephala, Navicula rostellata, Staurosirella pinnata* water quality index values between 21-42 were recorded at Sites 1-9, which indicates unpolluted water. The abundant diatom taxa *Diadesmis confervacea, Nitzschia palea,* and *Gomphonema parvulum we*re present at Site 10 and a water quality index value of 101 was recorded, indicating water polluted due to anthropogenic activity. The diatom assemblage of the present study was compared with various river systems to understand the environmental condition assessment. The water samples were analysed for assessment of the water quality.

Keywords: Diatoms, Thamirabarani River, Water quality, Field Emission Scanning Electron Microscopy (FESEM), India, Light Microscopy.

Розподіл діатомових водоростей і оцінка якості води з річки Тхамірабарані, Таміл Наду, Південна Індія

Мадху Мадханкумар, Раджу Венкатачалапаті

Університет Періяр, кафедра геології, Салем, Таміл Наду, Індія, madhangeo@gmail.com

Анотація. Діатомові водорості є одними з найважливіших організмів, корисних для дослідження біомоніторингу. У цьому дослідженні розглядаються зразки діатомових водоростей і води, зібрані в 10 різних місцях річки Тхамірабарані, Південна Індія. Зразки діатомових водоростей збирали шляхом зіскрібання каменів зубною щіткою та вилучення макрофітів. За допомогою оптичного мікроскопа було проведено дослідження морфології та вимірювання стулок діатомових водоростей. У цьому дослідженні зареєстровано 58 таксонів діатомових водоростей, що належать до 25 родів. Серед діатомових водоростей таксономічні характеристики 20 таксонів діатомових водоростей, а саме *Aulacoseira granulata, Discostella stelligera, Navicula cryptocephala, Encyonema minutum, Gomphonema gandhii, Eunotia asterionelloides, Gomphonema parvulum, Brachysira neglectissima, Aulacoseira ambigua, Diadesmis confervacea, Nitzschia palea, Nitzschia amphibia, Sellaphora Americana, Staurosirella pinnata, Gomphonema affine, Fragilaria pararumpens, Eunotia incisa, Navicula erifuga, Navicula cryptotenella* and *Navicula rostellata описані та проілюстровані*. У цій роботі встановлені численні види діатомових водоростей, наприклад *Aulacoseira, Discostella, Navicula, Encyonema, Gomphonema, Brachysira, Nitzschia, Sellaphora, Staurosirella, Fragilaria* and *Eunotia*. У численних таксонах діатомових водоростей, таких як Aulacoseira granulate, Discostella stelligera, Gomphonema gandhii, Fragilaria pararumpens,

Navicula cryptocephala, Navicula rostellata, Staurosirella pinnata були зареєстровані значення індексу якості води між 21-42 на ділянках 1-9, що вказує на незабрудненість вод. Численні таксони діатомових водоростей Diadesmis confervacea, Nitzschia palea та Gomphonema parvulum присутні на ділянці 10, де було зареєстровано значення індексу якості води 101, що вказує на те, що вода забруднена через антропогенну діяльність. Угрупування діатомових водоростей у цьому дослідженні порівнювали з різними річковими системами, щоб зрозуміти оцінку екологічного стану. Проби води досліджено для оцінки якості води.

Ключові слова: діатомові водорості, річка Тхамірабарані, якість води, польова емісійна скануюча електронна мікроскопія (FESEM), Індія, світлова мікроскопія.

Introduction

Diatoms in India have been the subject of a considerable amount of research since the nineteenth century. Gandhi (1920-2008) was the pioneer in recording the freshwater diatoms across Western India besides contributing to the study of fossil and estuarine diatoms. Gupta and Das 2020 have provided a checklist of diatoms from all possible habitats: freshwater, marine, brackish water and terrestrial ecosystem. Diatoms are single-celled organisms abundantly distributed in all aquatic environments (Spaulding, Edlund, 2008). Diatoms are also biological indicators because of their specific tolerance to the environmental variables, response to ecological changes, anthropogenic and climate change (Schonfelder, Gelbrecht, Schonfelder, Steinberg, 2002). These organisms are useful in monitoring an ecosystem's water quality, environmental conditions and indicators of water pollution in many countries (Acs, Szabo, Kiss, Tooth, Zaray, Kiss, 2006; Gosselain, Coste, Campeau, Ector, Fauville, Delmas, Descy, 2005). The diatom is highly sensitive to ecological changes and can be an essential tool for monitoring surface water conditions (Venkatachalapathy, Karthikeyan, 2015). These organisms can be used for general aquatic biological assessment, using species richness and abundance to assess the impact of humans on the global aquatic environment and global biodiversity changes (Stoermer, Smol, 1999). Diatom-based river health assessment indexes are considered to have universal applicability across geographic regions and environments (Harding, Adolf, Mallonee, Miller, Gallegos, Perry, Johnson, Sellner, Paerl, 2015). These organism studies help detect water eutrophication gradients and their responses to environmental changes due to their short generation times (Morin, Gomez, Tornes, Licursi, Rosebery, 2016). According to Morin et al. 2016, many diatom species are known to have broad distributions; others seem limited to specific climatic zones or geographical regions or are endemic to a particular habitat. Although the benthic diatoms are well known as biomonitors, their application in several countries on the regional and local level is still limited. Diatoms are widely used to determine a water body's environment and are found at almost all levels of effluence. They are widely distributed, with a high reproduction rate and sensitivity of the distinct species towards organic effluence (Rimet, 2012). The Water Quality Index (WQI) has been used to give a quantitative measurement of the physical-chemical character of water (Hanh, Sthiannopkao, Ba, Kim, 2011; Cude, 2001). The water quality index is one of the most effective methods of communicating water quality information to decision makers. The WQI values range between 0 and 300 and display the water quality as a number, with lower numbers indicating better water quality. However, water quality is not simply expressed in terms of physical and chemical indicators, regardless of whether it is favourable or bad. Water quality or environmental circumstances are reflected in the responses of a diverse group of aquatic creatures, particularly those known to be sensitive to changes in ecological conditions, such as diatoms, zooplankton, and macro invertebrates (Chen, Zhou, Pickett, Li, Han, Ren, 2016). Karthick, Hamilton, Kociolek, 2013 described and illustrated the most common diatom species in Peninsular India. Work on the Indian rivers viz. Damodar River-Rachnanautiyal and Prakashnautiyal, 1999, Mahanadi River – Unni and Pawar, 2000, Kabini River – Maishale and Ulavi., 2015, Goriganga River – Kumar, 2015, Shivna River – Mitra and Reddy, 2015, Chambal River – Grover et al. 2017, Thamirabarani River (upland river segments)-Amutha and Muralidharan, 2017, Cauvery River – Karthikeyan et al. 2018, Ghaggar River- Pareek et al. 2018, Amba River – Karthik et al. 2020 and Narmada River – Chawla and Patel, 2020 recorded the distribution of diatoms in river systems. The present study aims to assess the distribution of diatom taxa in macrophytic, epiphytic and water quality assessment from the Thamirabarani River. The Thamirabarani is a major river in southern India and a medium-sized perennial river basin in peninsular India.

Material and Methods

Study area. The Thamirabarani is a perennial river that originates at an altitude of 2,000 m above mean sea level on the Agastyarkoodam peak of the Pothigai Hills, in the evergreen forests of the Western Ghats,

and drains into the Bay of Bengal near Punnaikayal in the Gulf of Mannar , as shown in Fig.1. The total length of the river is 120km traversing through the Tirunelveli and Tuticorin districts of Tamil Nadu. The Thamiraparani river basin falls within 8°30′ to 9°15′N – 77°10′ to 78°10′ E, covered by hills in the west, pediplain areas in the middle and an extended coastal area in the east. The Thamirabarani River receives rain from the southwest monsoon, early showers and later rains of the northeast monsoon. The annual precipitation in the river is 814.8 mm. Tamirabarani river water is helpful for various purposes such as agricultural, industrial, household and environmental purposes.

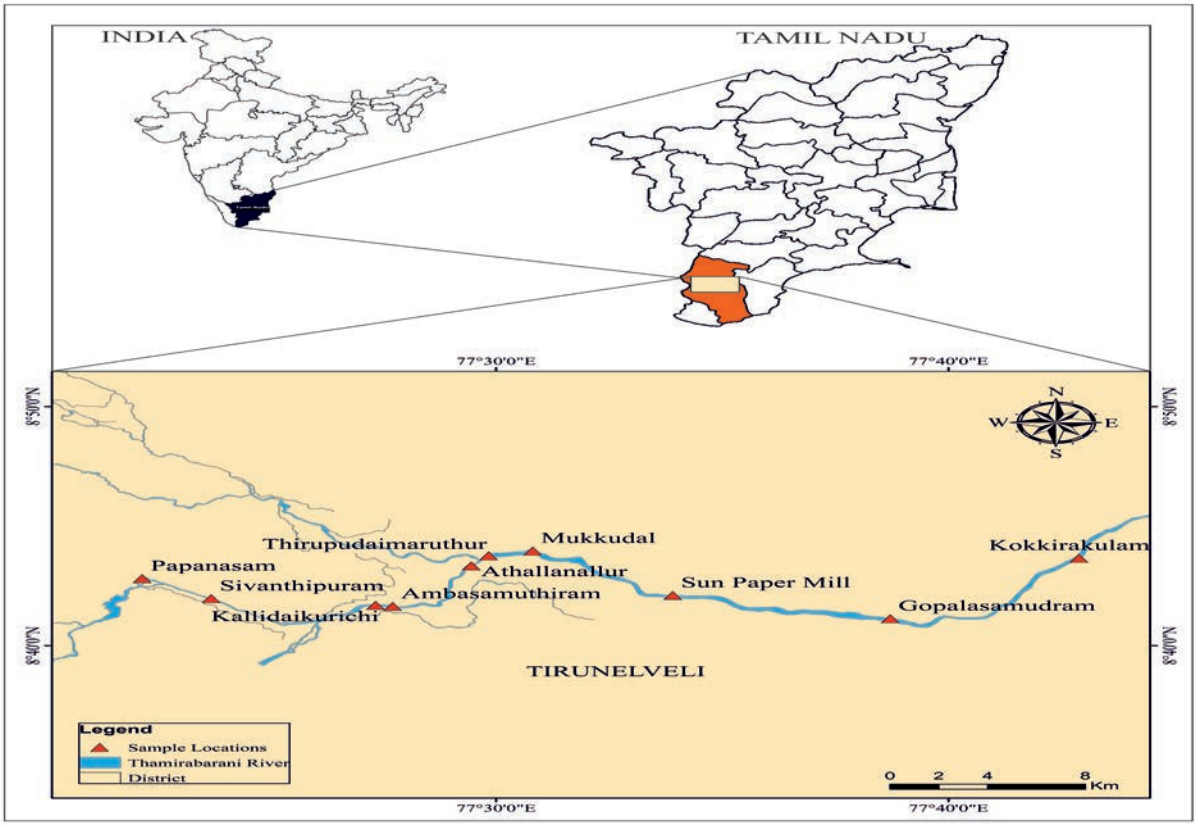


Fig. 1. Sample locations in Thamirabarani River, Tirunelveli District, Tamil Nadu

Sample collections

A total of ten (10) samples macrophytes (plant), epilithic (Stone) and water samples were collected from 10 different locations in the Thamirabarani River, Tirunelveli District, Tamil Nadu (Fig.1). Epilithic habitats were scraped using a knife or spoon and plant materials along with water were collected in a clean polythene bag. The sample was shaken vigorously to dislodge the diatoms attached to the surface of the plant material. Global Positioning System (GPS) recorded the geographical coordinates at each sampling point. In the laboratory, diatom samples were oxidized using Nitric Acid (HNO_3) at 90℃ for about 1-3 hours to remove organic matter. The suspension was cleaned by boiling in concentrated Nitric Acid (HNO_3) to oxidize organic matter. The resulting material was alternately centrifuged subsequently and washed with distilled water several times until the sample reached a neutral p^H. The cleaned suspension was air–dried onto coverslips and mounted with a Naphrax® mounting vehicle for prepare super durable slides. The light microscopy (LM) observations were made with an Olympus B.X.53 (Tokyo, Japan) magnifying lens, outfitted with Difference Interfering Contrast optics with a 100X 1.4 oil drenching and objective pictures caught with an Olympus D.P. 73 computerized camera with cellSens standard 1.16 imaging programming. Light microscopic plates were prepared using GIMP (version 2.8.14) and Inkscape (version 0.91), free and open-source software. The Field Emission Scanning Electron Microscope (FESEM) Observation finished with washed examples air-dried on cover glasses, associated to aluminum nails, filter covered through 10 nm of Au-Pd and inspected in high vacuum mode with a JSM-6480LV (LVSEM) at 15 kV, with a spot size of 30 working distance of 10 mm (FESEM).

Results and Discussion

The analysis of diatom samples shows the presence of 58 taxa belonging to 25 genera recorded from 10 different sites in the Thamirabarani River, Tirunelveli District, Tamil Nadu. Among the diatom taxa, five (5) are centric and fifty-three (53) are pennate diatoms. The diatom taxa recorded in the present study are as follows: *Aulacoseira granulata* (Ehrenberg), *A. ambigua* (Grunow), *Achnanthidium catenatum* (Bily & Marvan), *A.minutissimum* (Kützing), *Brachysira neglectissima* (Lange-Bertalot), *Cyclotella meneghiniana* (Kützing), *Caloneis silicula* (Ehrenberg), *C.bacillum* (Grunow), *Cocconeis placentula* (Ehrenberg), *Cymbella tumida* (Van Heurck), *Discostella stelligera* (Cleve and Grunow), *Diadesmis confervacea* (Kützing), *Eunotia asterionelloides* (Hustedt), *E. minor* (Kützing), *E. incisa* (Gregory), *Encyonema minutum* (Hilse), *E.silesiacum* (Mann), *E, keshrii* (Roy), *E. neogracile* (Krammer), *E. mesianum* (Cholnoky), *E. menezesiae* (Silva & Souza), *Frustulia crassinervia* (Brébisson), *Fragilaria socia* (Wallace), *F.ungeriana* (Grunow), *F.pararumpens* (Lange-Bertalot, G. Hofmann & Werum), *Gomphonema parvulum* (Kützing), *G. gandhii* (Karthick & Kociolek), *G. affine* (Kützing), *G. lagenula* (Kützing), *G. duplipunctatum* (Lange-Bertalot & Reichardt), *G. lacusrankaloides* (Karthick & Kociolek), *G. pseudoaugur* (Lange-Bertalot), *G. insularum* (Kociolek, Woodward and Graeff) *G. graciledictum* (Reichardt), *G.exilissimum* (Grunow), *Nitzschia gracilis* (Hantzsch), *N. palea* (Kützing), *N.clausii* (Hantzsch), *N. amphibia* (Grunow), *Navicula cryptocephala* (Kützing), *N.antonii* (Lange-Bert), *N.erifuga* (Lange-Bertalot), *N. rostellata* (Kützing), *N.notha* (Wallace), *N.cryptotenella* (Lange-Bertalot), *N.escambia* (Patrick), *Neidium gracile* (Hustedt), *Oricymba japonica* (Reichelt), *Planothidium rostratum* (Østrup), *Pinnularia acrosphaeria* (W.Sm), *P. amabilis* (Krammer), *Placoneis clementioides* (Hustedt), *Pseudofallacia tenera* (Hustedt), *Sellaphora americana* (Ehrenberg), *S.pupula* (Kützing), *S.crassulexigua,* (Reichardt), *Staurosirella pinnata* (Ehrenberg) and *Spicaticribra kodaikanaliana* (Karthick & Kociolek). The Scanning Electron Microscope (SEM) diatom taxa are shown in (Fig.2). The abundant diatom taxa presented from the Thamirabarani River are described and illustrated (Fig. 3).

Description of characteristic features of the identified abundant diatom taxa

***Aulacoseira ambigua* (Grunow) Simonsen 1979** (Plate 1, Figs. 1-3)

Ref. Camburn and Charles, 2000, Pl. 1, Figs. 18-22, Faustino et al. 2016, pl. 1, Figs. 2-3 & Kobayasi and Nozawa, 1981, Figs. 1-22, Karthick et al. 2013, pl. 3.

Frustules are cylinder-shaped and form colonies. The valve length is 20-25µm and the width 4 µm. The spiral rows of pervalvar areolae are curved to the right. The areolae have a round to square shape. A spine is located at the end of every pervalvar costa. The linking spines are small, triangular or bifurcated.

Habitat: Kallidaikurichi and Thirupudaimaruthur. Epiphytic.

***Aulacoseira granulata* (Ehrenberg) Simonsen 1979** (Plate 1, Figs 4-6)

Ref. Karthick et al. 2013, Pl. 3, Rai and Khadka, 2017, p.17, Fig.1.

Filamentous colony consists of cylindrical filaments, that join face-to-face and form filamentous colonies. Valves with coarse areolae. Valves are 19-23.5 µm in length, with a width of 3-5 µm. The ratio of mantle height to valve width is generally greater than or equal to 0.8 but not greater than 5. Mantle sides are straight and valve faces are flat. Striae 9/10µm. The mantle areolae are square.

Habitat: Papanasam, Sivanthipuram and Kallidaikurichi. Epiphytic.

***Brachysira neglectissima* (Lange-Bertalot) 2004** (Plate 1, Figs. 7-11)

Ref. Lange-Bertalot et al. 2017, p. 115, Pl. 60, Figs. 1-5.

Valves are lanceolate with continuum outline, observed capitated and gradually protracted with narrow pointed ends. Valve length 22–28µm, width 5–5.4 µm and striae density 38/10 µm.

Habitat: Sivanthipuram. Epiphytic.

***Diadesmis confervacea* Kützing 1844** (Plate 1, Figs. 12-16)

Ref. Kützing 1844: 109, pl. 30: Fig. 8, Krammer & Lange-Bertalot 1986, p. 221, Pl.75, Figs. 29-31, Patrick & Reimer, 1966, p. 476, Pl. 45, Fig. 9, Taylor et al. 2007, Pl. 58.

Valves are elliptic, with apiculate apices. Valve length 13-18 µm, width 4.5-7µm and striae 2/10µm. The central area is broad and rounded. The raphe is straight and filiform, an axial area tapers from the central region, becoming narrower toward the ends. The striae are radiate, punctate, and crossed by longitudinal wavy lines. Striae are variable in length.

Habitat: Kallidaikurichi, Ambasamuthiram, Thirupudaimaruthur, Mukkudal, Gopalasamudram and Kokkirakulam. Epiphytic.

***Discostella stelligera* (Cleve and Grunow) Houk and Klee 2004** (Plate 1, Figs. 17-21)

Ref. Houk et al. 2010, p. 303, Figs. 1-3, Bishop et al. 2017, Pl. 1, Figs. 30-32, Solak et al. 2018, p. 109, Figs.75-78.

Valves are distinct central areas and well-defined marginal rings. Valves are 7-9 µm in width, with striae 14/10µm. More or less concave or convex in the centre. The central area has a stellate pattern of alveoli. The marginal ring has striae of equal length.

Habitat: Papanasam, Sivanthipuram and Athallanallur. Epiphytic.

***Encyonema minutum* (Hilse) Mann 1990** (Plate 2, Figs. 22-24)

Ref. Krammer 1997a, p. 53. Pl. 6, Taylor et al. 2007, Pl. 112, Lange-Bertalot et al. 2017, p. 205, Pl. 89, Figs. 33-40.

Valves strongly dorsiventral, half-elliptic to half-lanceolate, dorsal edge convex, ventral margin feebly convex, sometimes with a slight central area absent. Valve length 16.5-18.5 µm, Width 4-4.5 µm, raphe filiform, rounded. Proximal endings are very small, curved and deflected dorsally. Striae 15/10µm, distal end comma-shaped ventrally deflected.

Habitat: Papanasam. Epiphytic.

***Eunotia asterionelloides* Hustedt 1952** (Plate 2, Figs. 25-27)

Ref. Wetzel et al. 2010, p. 61, Figs. 2-29 & Hustedt 1952, p. 138, Figs. 18-19.

Valves are linear with parallel margins. Valve length 27-36µm, Width 2µm, striae 20/10 µm and 3.2 µm at the poles. Ventral margins are moderately concave at apex, dorsal margin straight to slightly convex, hence slightly arcuated. Striae are parallel and equidistant, becoming radiant toward the extremities.

Habitat: Papanasam. Epiphytic.

***Eunotia incisa* SM ex Greg 1854** (Plate 2, Figs. 28-31)

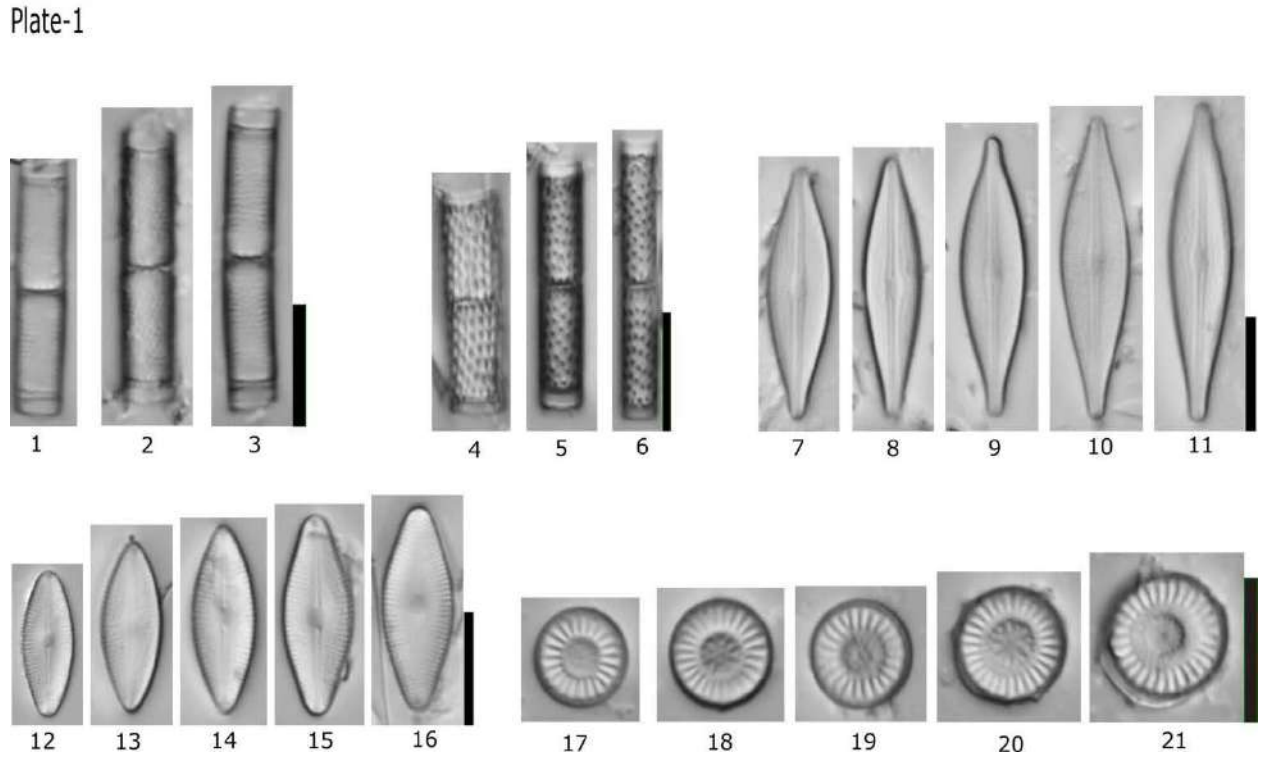
Ref. Krammer & Lange-Bertalot 2004, p. 221, Figs. 161: 8-19, Lange-Bertalot et al. 2017, p. 243, Pl. 17, Figs. 1-4 & Gregory 1854: 25, Pl. 4, Fig. 4.

The ventral line is straight in smaller specimens and feebly concave in larger specimens. The valve length is 28.5-40 µm, width 3.5-4 µm and striae is 20/10µm. The dorsal edge is convex. The apices are highly rounded. The raphe's distal ends are on the valve mantle, and the raphe's terminal nodules are well-formed from the apices.

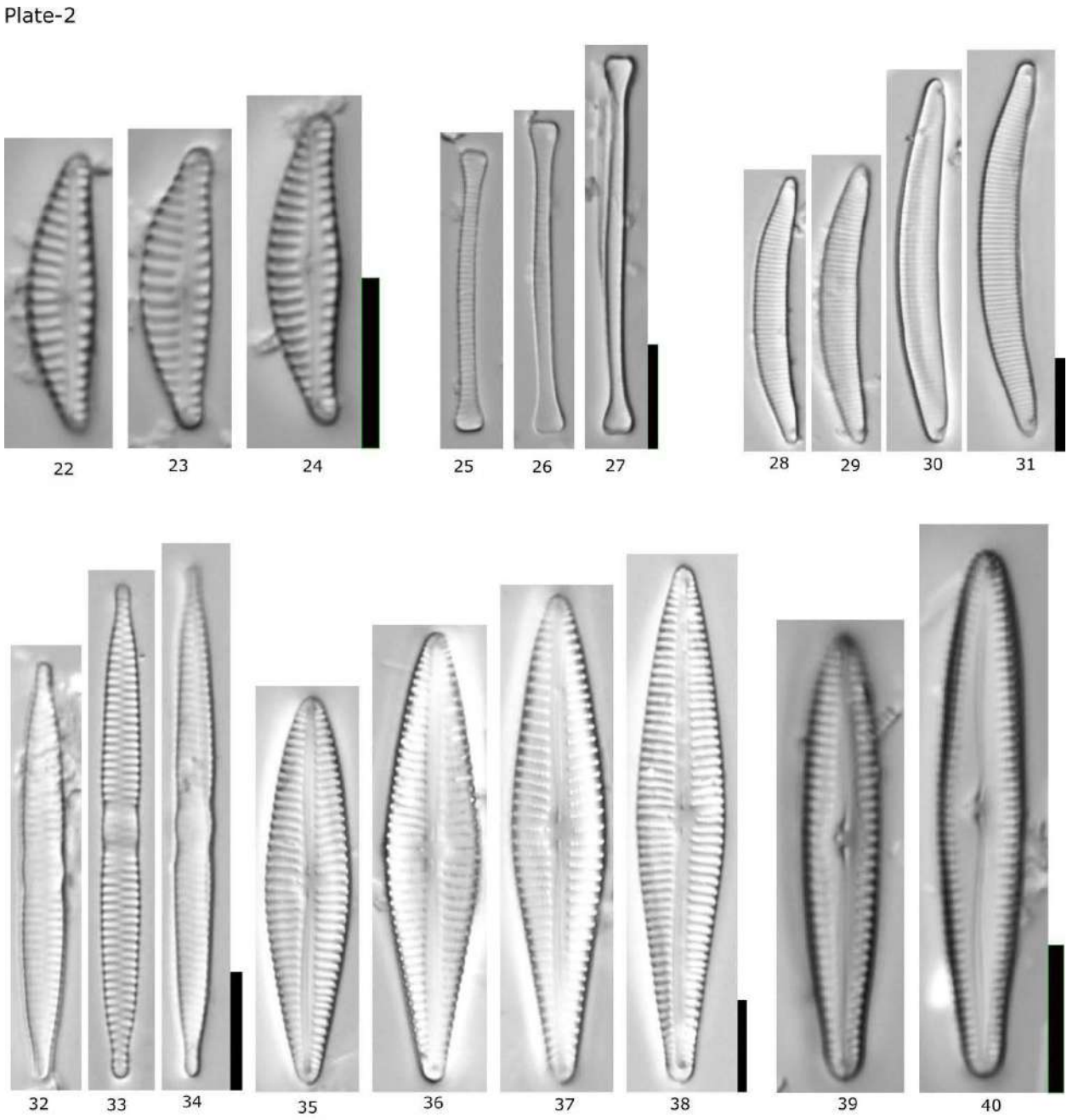
Habitat: Mukkudal. Epiphytic.

***Fragilaria pararumpens* Lange-Bertalot, Hofmann & Werum 2011** (Plate 2, Figs. 32-34)

Ref. Lange-Bertalot et al. 2011: 269, Pl. 8, Figs. 4-10, Lange-Bertalot et al. 2017, p. 271, Pl. 9, Figs. 9-14.



Light microscopy (LM) micrographs: Illustration of the abundant diatom taxa, Fig. 1-3, *Aulacoseira ambigua* (Grunow) Simonsen, Fig. 4-6, *Aulacoseira granulata* (Ehrenberg) Simonsen, Fig. 7-11, *Brachysira neglectissima* (Lange-Bertalot), Fig. 12-16, *Diadesmis confervacea* (kutzing), Fig. 17-21, *Discostella stelligera* (Cleve and Grunow) Houk and Klee. Scale bar =10 µm.



Light microscopy (LM) micrographs: Illustration of the abundant diatom taxa, Fig. 22-24, *Encyonema minutum* (Hilse) D.G.Mann, Fig. 25-27, Eunotia *asterionelloides* (Hustedt), Fig. 28-31, *Eunotia incisa* (W. Smith ex W.Gregoryprox), Fig. 32-34, *Fragilaria pararumpens* Lange-Bertalot, G. Hofmann et Werum, Fig. 35-38, *Gomphonema affine* (Kützing), Fi.g 39-40, *Gomphonema gandhii* (Karthick & Kociolek). Scale bar = 10 µm.

Valve dimensions Length 35-43 µm, width 2.5-3 µm and striae 16/10µm identical. The species is varied by a distinctive, well-delimited slightly swollen central area, creating band-like colonies and a characteristic division at the valve. The apices between frustules in girdle view.

Habitat: Mukkudal and Sunpapermill. Epiphytic.

Gomphonema affine **Kützing 1844** (Plate 2, Figs. 35-38)

Ref. Karthick et al. 2013, Pl. 77 & Taylor et al. 2007, Pl. 117.

Valves are heteropolar, club-shaped with frankly and sharply curved apices. The valve length is 42.5-56.5 µm and the width- is 9-10µm. The axial part linearly narrows slightly towards the apices. The central part is small, formed by the shortening of the central striae. Striae 10/10µm, Striae radial throughout, becoming strongly radial at the apices.

Habitat: Mukkudal. Epiphytic.

Gomphonema gandhii **Karthick & Kociolek 2011** (Plate 2, Figs. 39-40)

Ref. Karthick et al. 2011, p. 220, Figs. 2-9, Karthick et al. 2013, pl. 81.

Valve apices rounded to narrowly – rounded to acuminate at the head pole, valves linear to linear-lanceolate clavate. Valve length 30-35.5 µm, Width 5-5.5 µm and striae 13/10 µm. The striae are continuous around the head pole, with cuneate frustules. The axial is area-wide, linear-lanceolate with no distinct central part. The outer proximal raphe ends are typically dilated. Striae are punctate and slightly radiate to parallel.

Habitat: Papanasam, Sivanthipuram, Kallidaikurichi and Mukkudal. Epiphytic.

***Gomphonema parvulum* (Kutzing) Kutzing 1849** (Plate 3, Figs. 41-43)

Ref. Lange-Bertalot et al. 2017, p. 315, Pl. 101, Figs. 1-5, Kulikovskiy et al. 2016, p. 213, Pl. 128, Figs. 12-17, Levkov et al. 2016, p. 98, Pl. 348, Figs. 1-19.

Valves are lanceolate and slightly deflected. Valve length 23-27.5 µm, width 5.5-6.5 µm and Striae 14/10µm. Central area asymmetrical, single long striae on one side. The axial part is narrowing and straight. The raphe is straight and slightly undulate with slightly extended proximal ends. More or less parallel throughout the valve and slightly radiate towards the foot pole; striae are more widely paced at the center of the valve.

Habitat: Papanasam, Sivanthipuram, Kallidaikurichi, Ambasamuthiram, Athallanallur, Mukkudal, Sunpapermill, Gopalasamudram and Kokkirakulam. Epiphytic.

***Navicula cryptocephala* Kutzing 1844** (Plate 3, Figs. 44-46)

Ref. Krammer & Lange-Bertalot 1991, p. 376, Fig. 64 & Ehrlich 1995, p. 74, Fig. 20, Lange-Bertalot et al. 2017, p. 386, Pl. 32, Figs. 6-10.

Valves are lanceolate with protracted apices. Valve length 27-39 µm, Width-5-6 µm and Striae 16/10 µm. The axial area is narrow and straight. The central area is big and circular. The raphe is straight, with expanded outer proximal ends that look like drops. Striae radiate around the center, becoming convergent at the apices. The areolae are occasionally visible under Light Microscope.

Habitat: Papanasam and Gopalasamudram. Epiphytic.

***Navicula cryptotenella* Lange-Bertalot 1985** (Plate 3, Figs. 47-49)

Ref. Krammer & Lange-Bertalot 1986, p. 106, Pl. 33, Figs. 9-11 & Lange-Bertalot 2001, p. 28, Pl. 26, Figs. 17-32, 27: 19-22, Lange-Bertalot et al. 2017, p. 387, Pl. 33, Figs. 1-5.

Valves narrow to largely lanceolate and apices intensely rounded. Valve length 27.5-33 µm, width-5µm and striae 16/10µm. The raphe is filiform to feebly lateral, axial area narrow and linear. The central part is small with an uneven border. Striae radiate and are slightly curved at valve centre, becoming convergent.

Habitat: Sunpapermill. Epiphytic.

***Navicula erifuga* Lange-Bertalot in Krammer and Lange-Bertalot 1985** (Plate 3, Figs. 50-53)

Ref. Lange-Bertalot 2017, p. 390, Pl. 39, Figs. 12-16 and Krammer & Lange-Bertalot 1985, Pl. 17, Figs. 10-12.

Valves lanceolate, elliptic-lanceolate to linear-lanceolate. Valve length 30-40µm, Width 6-6.5µm and Striae 14/10µm. The raphe divisions are filiform, with the exterior branch curled to the proximal terminals deflected. The central area is narrow and uneven on one side, rectangular on the side where the pores are deflected and elliptical on the other side. Striae feebly radiate to convergent near the poles.

Habitat: Sunpapermill. Epiphytic.

***Navicula rostellata* (Kutzing) 1844** (Plate 3, Figs. 54-56)

Ref. Foged 1980, p. 654, Pl. 6, Fig. 7 & Rai 2006, p. 89, Pl. 9, Fig. 3, Lange-Bertalot 2017, p. 404, Pl. 38, Figs. 10-14.

Valves are linear to linear-lanceolate with slightly convex to straight margins and sub-rostrate apices. Valve length 37-39µm, Width 9 µm and striae 14/10µm. The axial area is narrow and the central region is elliptical and asymmetric. Striae are curved and radiate around outwards from the center. The striae are more distant near the centre of the valve.

Habitat: Gopalasamudram and Kokkirakulam. Epiphytic.

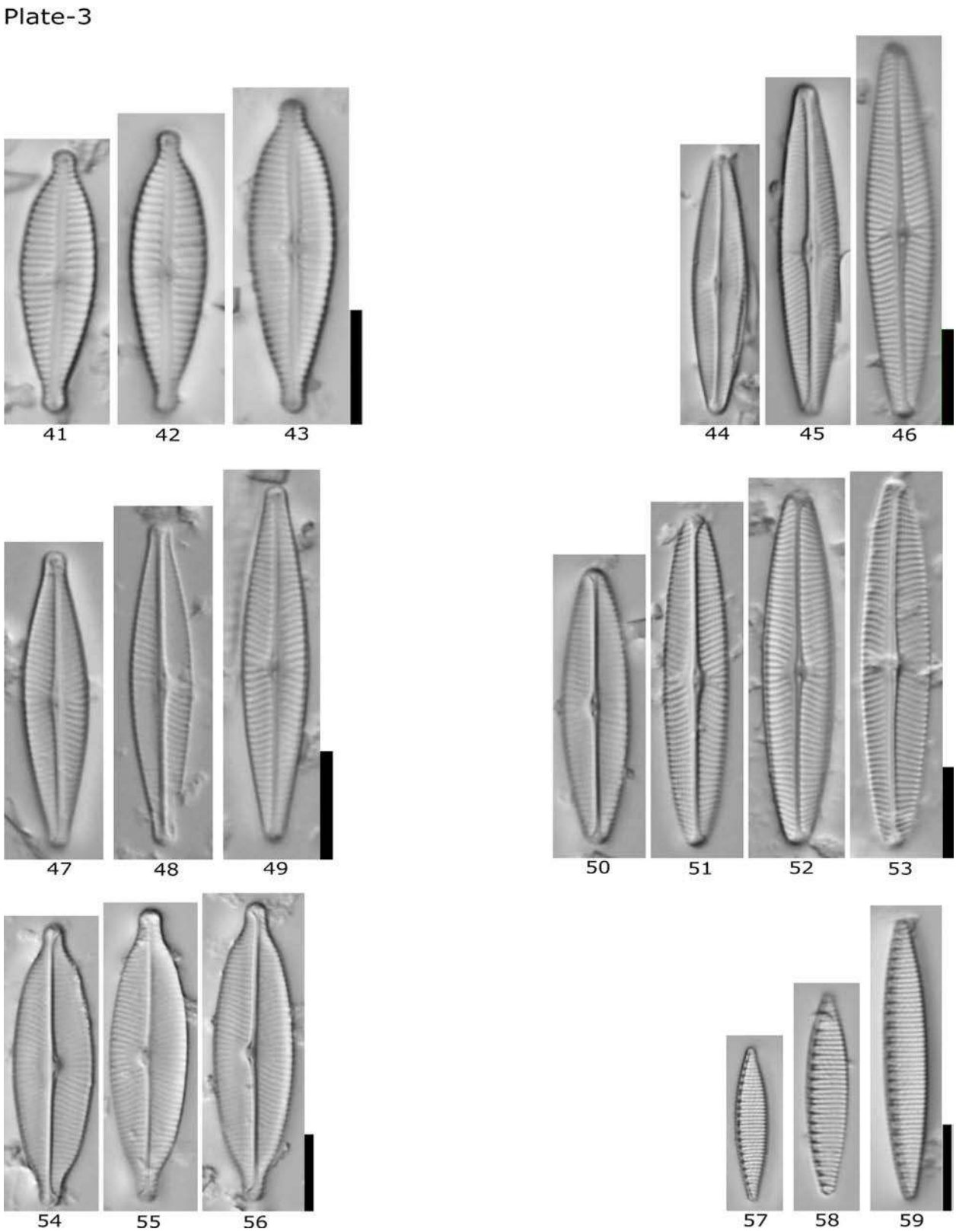
***Nitzschia amphibia* (Grunow) 1862** (Plate 3, Figs. 57-59)

Ref. Grunow 1862, Pl. 28, Fig. 23 and Krammer & Lange-Bertalot 1988, p. 108, Pl. 78, Figs. 13-21, Karthick et al. 2013, pl. 123, Lange-Bertalot 2017, p. 435, pl. 119, figs. 9-15.

Valves are linear to lanceolate. Valve length 18-32.5 µm, Width 3-4 µm and striae 18/10µm. The valves have narrow to bluntly rounded apices. The central nodule is apparent. Striae are characteristically prominent and punctate but not necessarily regularly spaced.

Habitat: Ambasamuthiram. Epiphytic.

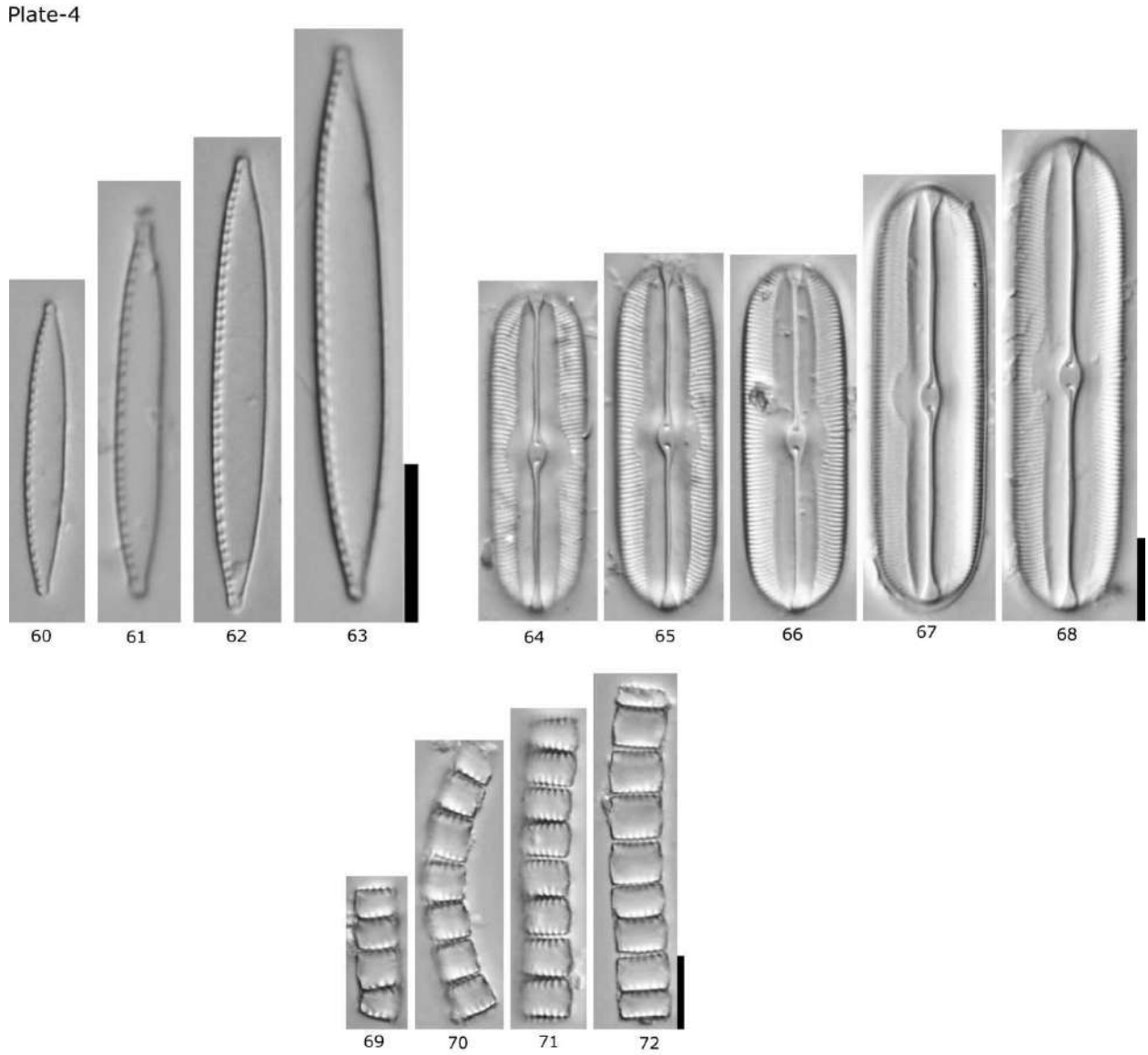
***Nitzschia palea* (Kutzing) Smith 1856** (Plate 4, Figs. 60-63)



Light microscopy (LM) micrographs: Illustration of the abundant diatom taxa, Fig. 41-43, *Gomphonema parvulum* (Kutzing) Kutzing, Fig. 44-46, *Navicula cryptocephala* (Kutzing), Fig. 47-49, *Navicula cryptotenella* (Lange-Bertalot), Fig. 50-53, *Navicula erifuga* (Lange-Bert.in Krammer and Lange-Bertalot), Fig. 54-56, *Navicula rostellata* (Kutzing), Fig. 57-59, *Nitzschia amphibia* (Grunow). Scale bar = 10 μm.

Ref. Bishop et al. 2017, Pl. 138, Figs. 27-30, Ivanov et al. 2006, Pl. 181, Figs. 5-7, Lange-Bertalot et al. 2017, p. 451, Pl. 113, Figs. 1-20.

Valves are linear-lanceolate to lanceolate, rostrate to sub-capitate apices, and parallel margins in the centre. Valve length 18.5-35 μm and width 2.5-4 μm.



Light microscopy (LM) micrographs: Illustration of the abundant diatom taxa, Fig. 60-63, *Nitzschia palea* (Kutzing) W. Smith, Fig 64-68, *Sellaphora Americana* (Ehrenberg) D.G. Mann, Figs. 69-72, *Staurosirella pinnata* (Ehrenberg) D.M. Williams and Round. Scale bar = 10 µm.

The transapical striae are very delicate and difficult to resolve with Light Microscope fibulae 11/10µm and central ones equidistantly spaced.

Habitat: Ambasamuthiram, Thirupudaimaruthur, Sunpapermill, Gopalasamudram and Kokkirakulam. Epiphytic.

***Sellaphora Americana* (Ehrenberg) Mann 1989** (Plate 4, Figs. 64-68)

Ref. Mann 1989, Fig. 58 and Krammer & Lange-Bertalot 1986, p. 188, Pl. 67, Fig. 1.

Valves are broadly linear, with parallel or weakly concave margins**.** Apices are obtusely rounded. Valve length 39-57 µm, Width 12-13.5 µm and striae 17/10µm.The axial area is narrow and undulate, bordered on each side by an extensive conopeum. The centre is broad and rounded. Distal raphe ends are comma-shaped, straight, parallel and shorter central striae.

Habitat: Thirupudaimaruthur. Epiphytic.

***Staurosirella pinnata* (Ehrenberg) Williams et Round 1988** (Plate 4, Figs. 69-72)

Ref. Krammer & Lange-Bertalot 1991a, p. 156, Pl. 112, Figs. 15-16 and Bishop et al. 2017, Pl. 2, Figs. 46-49, Lange-Bertalot et al. 2017, p. 576, Pl. 11, Figs. 30-35.

Valve face flat. Valve length 4-6 µm, Width 5-7 µm and striae 7/10 µm. Frustules are rectangular and form ribbon-like colonies, in girdle view, joined by linking spines. The axial area is linear to lanceolate. Girdle bands are not perforated and are open.

Habitat: Thirupudaimaruthur and Gopalasamudram. Epiphytic.

Water Quality Index (WQI)

The water quality index is a more helpful method for communicating the nature of water assets for application. In recent years many water quality indexes have been formulated by some global establishments for evaluation of water quality in particular specific cases. The water quality index can simplify the information into a single value and express the information in an intelligent and simplified manner. This calculation is based on BIS standards 1998 (Sharma et al. 2014 and Ravikumar et al. 2013) It is shown in Table 1. It computed each of the nine parameters based on an analysis of their physical and chemical characteristics.

$$W_i = w_i / \sum_{i=1}^{n} w_i, \quad (1)$$

where, W_i represents relative weight, w_i representative of each parameter is weighted and n represents the number of parameters. The second step is to assign a quality score to each variable by dividing its concentration in each sample by the quality rating scale qi (BIS 1998) shown in Table 2.

$$q_i = C_i / S_i \times 100, \quad (2)$$

where q_i quality rating, C_i chemical parameter concentration in mg/l (BIS 1998). For the physical-chemical parameter WQI, sub-index (SI) is determined as the first step in calculating the WQI as per the equation.

$$SIi = W_i \times q_i. \quad (3)$$

$$\mathrm{WQI} = \sum SIi. \quad (4)$$

SIi is the sub-index of its parameter, q_i the rating based on concentration (i) and n number of the parameter.

The water quality index is based on <50% excellent water, 50-100 % good water, 100-200 % poor water, 200-300% very poor water, > 300% water unsuitable for domestic purposes. The water quality relative weight is shown in Table 1.

Table 1. Relative weightage of the chemical parameter for water quality index

S.No.	Parameters	BIS Standers (1998)	Weightage (w_i)	Relative weightage $W_i = w_i / \sum_{i=1}^{n} w_i$
1	pH	8.5	4	0.105263158
2	EC	2000	4	0.105263158
3	Total dissolved Solids (TDS)	1000	5	0.131578947
4	Calcium	75	2	0.052631579
5	Magnesium	30	2	0.052631579
6	Chloride	250	3	0.078947368
7	Sulphate	200	4	0.105263158
8	Nitrate	45	5	0.131578947
9	Fluoride	1	5	0.131578947
10	Biological Oxygen Demand (BOD)	2	2	0.052631579
11	Iron	0.3	2	0.052631579
			$\sum wi_{38}$	$\sum Wi_{1.00}$

Table 2. Water quality index value in the Thamirabarani River

SI. No	Water quality indexes	Water quality types	Sample Sites
1	21-42	Excellent water	Papanasam, Sivanthipuram, Kallidaikurichi, Ambasamuthiram, Athallanallur, Thirupudaimaruthur, Mukkudal, Sunpapermill and Gopalasamudram
2	101	Poor water	Kokkirakulam

In the present study, diatom assemblages and water quality index revealed the water quality assessment. The abundant diatom taxa *Aulacoseira granulate, Discostella stelligera*, *Gomphonema gandhi, Fragilaria pararumpens, Navicula cryptocephala, Navicula rostellata*, *Staurosirella pinnata* and the water quality index values between 21- 42 were recorded at the Sites 1-9 respectively shown in Table 2. The abundance of diatom taxa and water quality index value indicate unpolluted water in the study area. The abundant diatom taxa *Diadesmis confervacea, Nitzschia palea*, and *Gomphonema parvulum* were present in the site 10 and water quality index value of 101 were recorded. The above mentioned diatom taxa and water quality index values indicate polluted water due to anthropogenic activity.

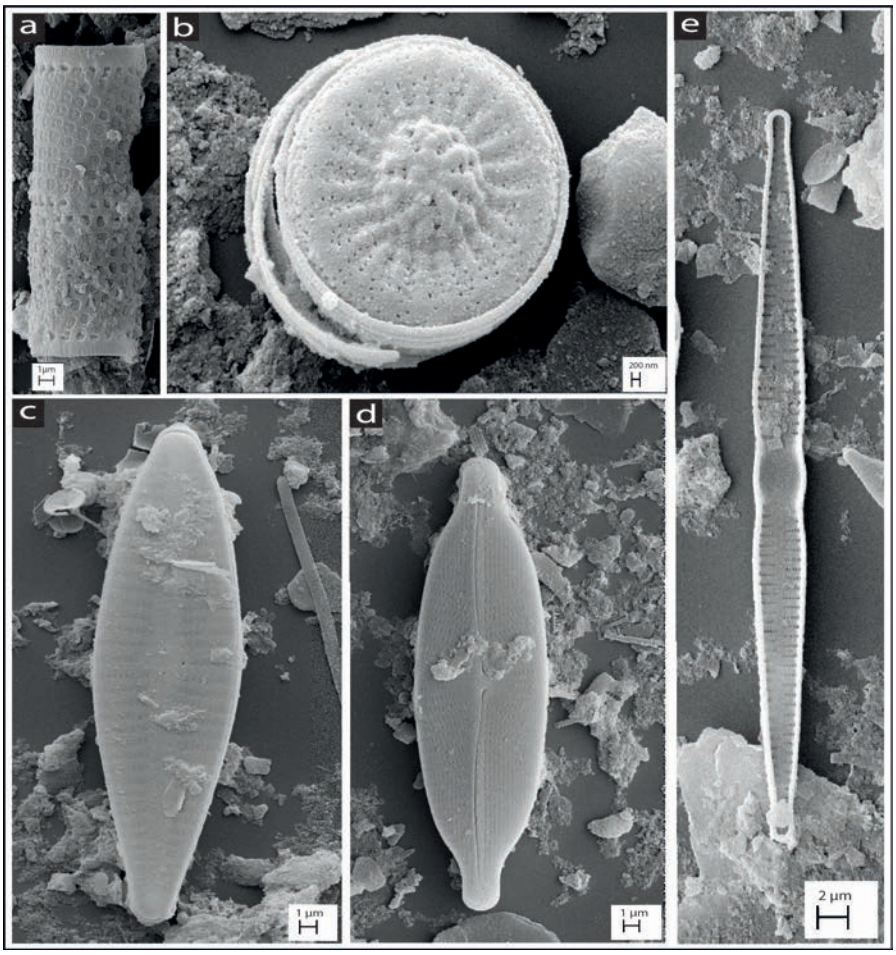


Fig. 2. FESEM external view showing the valve and the long valve extension (a-e), (a) *Aulacoseira granulata,* (b) *Discostella stelligera,* (c) *Gomphonema affine,* (d) *Navicula rostellata* (e) *Fragilaria pararumpens.*

The present study recorded eleven (11) abundant diatom genera in the Thamirabarani River, such as viz. *Aulacoseira, Discostella, Navicula, Encyonema, Gomphonema, Brachysira, Nitzschia, Sellaphora, Staurosirella, Fragilaria* and *Eunotia*. The abundant diatom taxa recorded in the study area were *Aulacoseira ambigua, A. granulata, Brachysira neglectissima, Diadesmis confervacea, Discostella stelligera, Eunotia asterionelloides, E.incisa, Encyonema minutum, Fragilaria pararumpens, Gomphonema gandhii, G. parvulum, G. affine, Navicula erifuga, N. cryptotenella, N.rostellata, N.cryptocephala, Nitzschia palea, N. amphibia, Sellaphora americana* and *Staurosirella pinnata.* The diatom taxa were compared with those of various river systems to understand the environmental condition assessment. The presence of pollution is indicated by diatom taxa such as *Gomphonema parvulum, Diadesmis confervacea* and *Nitzschia palea*, which were observed abundantly in the study area, these due to the combined influence of anthropogenic activity. These recorded diatom taxa are similarly present in the Cauvery River (Karthikeyan and Venkatachalapathy, 2016). The present study abundantly records the freshwater indicative diatom taxa *Aulacoseira granulata, Navicula rostellata, Discostella stelligera, Navicula cryptocephala, Aulacoseira ambigua, Nitzschia amphibia* and *Navicula cryptotenella,* which were present due to good flow of water in the river. These diatom taxa are similarly found in the Iguassu River (Nardellia et al., 2017), the Sakarya River (Solak et al., 2020) and the Bagmati River (Rai and Khadka, 2017).

Conclusion

A study of diatom assemblages and environmental assessment were carried out in the Thamirabarani River, one of the perennial rivers of India. The present study recorded the occurrence of 58 diatom taxa belonging to 25 genera. The abundant diatom genera such as *Aulacoseira, Discostella, Navicula, Encyonema, Gomphonema, Brachysira, Nitzschia, Sellaphora, Staurosirella, Fragilaria* and *Eunotia* were observed in the study area. In the present study, the abundant diatom taxa *Aulacoseira granulata, Discostella stelligera, Gomphonema gandhii, Fragilaria*

pararumpens, Navicula cryptocephala, Navicula rostellata, Staurosirella pinnata associated with water quality index values between 21-42 were recorded at Sites 1-9. The presence of abundant diatom taxa and water quality index value indicates unpolluted status, this being due to the good flow of water in the river. The dominance of diatom taxa *Diadesmis confervacea, Nitzschia palea* and *Gomphonema parvulum was observed* in Site 10 and a water quality index value of 101 was recorded. These indicate that the polluted water is due to the influence of anthropogenic activity in the river. The abundant diatom taxa were compared with other river systems to understand the environmental condition assessment. The diatom taxonomic studies will enable researchers to monitor the potential of diatoms. Investigation of assemblages of diatoms and water quality index are indicator assessments that can be a reliable method for environmental impact assessment in a river system.

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