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Exploring the Diversity of the Bacillariophytes from Meerut and Adjoining Areas of Western Uttar Pradesh, India

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ABSTRACT

The present study examined the diversity of Bacillariophyceae members from four different biotopes in the Meerut and Hastinapur regions of western Uttar Pradesh, India. Since there are no previous records of diatom diversity from Meerut and Hastinapur, this study serves as the first documentation of the diatom flora in these areas. Our investigation reported 33 taxa of diatoms belonging to 6 orders, 9 families, and 12 genera, including: *Achnanthidium exiguum*, *A. subatomus*, *Craticula ambigua*, *C. cuspidata*, *Frustulia rhomboides* var. *crassinervia*, *Navicula capitatoradiata*, *N. cryptotenella*, *N. notha*, *N. pupula*, *N. zanonii*, *Trachyneis aspera*, *Pinnularia dariana*, *P. subcapita*, *P. viridis*, *Ctenophora pulchella*, *Fragilaria capucina*, *F. capucina* var. *rumpens*, *F. intermedia*, *Nitzschia reversa*, *N. acicularis*, *N. baculum*, *N. capitellata*, *N. filiformis*, *N. fruticosa*, *N. linearis*, *N. palea*, *N. constricta*, *Tryblionella hungarica*, *Gomphonema abbreviatum*, *G. constrictum*, *G. truncatum*, and *Tabellaria japonica*. Additionally, wetlands and drains near the Ganga River in Hastinapur were found to host the highest number of species, while the lowest diversity was observed in samples collected from an anthropogenic pond at Chaudhary Charan Singh University, Meerut (U.P.), India.

INTRODUCTION

Algae are very simple, photosynthetic, autotrophic and a diverse group of organisms, and their size ranges from microscopic to macro forms **(Kant *et al*., 2004a; Tandon *et al*., 2014a, b, 2021a, b)**. They are ubiquitous in occurrence and worldwide in distribution **(Kant *et al*., 2006a, b; Singh *et al*., 2008)**. The growth of algae can be observed in almost all types of the known biotopes wherever little light and moisture are available **(Tiwari *et al*., 2007)**. Their habitats include fresh water and marine aquatic, terrestrial, sub-aerial, tree barks, stones, building walls and many other specialized

biotopes viz. thermal springs and cold regions. They contribute significantly in the ecosystem in carbon sequestration, nutrients recycling and as primary colonizer, and play an important role as an ecological indicator **(Saini *et al*., 2022, 2023; Doli *et al*., 2023; Kumar & Kant, 2023; Sarma *et al*., 2023a, b, 2024a, b; Singh *et al*., 2023a, b)**. They share characteristic features with both prokaryotic and eukaryotic organisms. Their thallus organization varies widely, ranging from unicellular to colonial, and includes multicellular filamentous, branched, siphonous, heterotrichous, and parenchymatous forms **(Sarma *et al*., 2020, 2021)**. Based on their photosynthetic pigments and the color of their thallus, they are classified into fourteen phyla, including Blue-green (Cyanophytes), Green (Chlorophytes and Charophytes), Yellow-green (Xanthophytes), Orange (Chrysophytes), Red (Rhodophytes), Brown (Phaeophytes), and Golden-brown algae (Bacillariophytes), among others **(Guiry, 2024)**. The members of Bacillariophytes are commonly known as diatoms.

Diatoms (Neo-Latin *diatoma*) comprises of a large group of several genera of microalgae, found in fresh and marine water bodies including ponds, pools, rivers, oceans, waterways, and soils all over the world **(Alverson, 2014)**. Diatoms are classified as Eukaryotic organisms with a nuclear envelope-bound around the cell that separates them from the prokaryote's archaea and bacteria. They are unicellular organisms occuring either as solitary cells or in colonies, and can attain the shape of ribbons, fans, zigzags, or stars **(Serieyssol, 2011)**. In the presence of adequate nutrients and sunlight, an assemblage of living diatoms doubles approximately on every 24 hours by asexual multiple fission. The maximum life span of individual cells of diatoms is about six days **(Jewson, 1992)**.

Diatoms are of two distinct shapes centric diatoms which are radially symmetric and pennate diatoms which are broadly bilaterally symmetric **(Chepurnov *et al*., 2008)**. The unique feature of diatoms are that they are surrounded by a cell wall made of silica (hydrated silicon dioxide), called a frustules **(Nassif & Livage, 2011)**. These frustules produce structural coloration, prompting them to be described as "jewels of the sea" and "living opals".

The present work focused on exploring the diatoms flora from four different biotopes of Meerut and Hastinapur. From the present study, 33 taxa of diatoms belonging to 6 orders, 9 families and 12 genera *viz. Achnanthidium*, *Craticula*, *Ctenophora*, *Fragilaria*, *Frustulia*, *Gomphonema*, *Navicula*, *Nitzschia*, *Pinnularia*, *Tabellaria*, *Tryblionella* and *Trachyneis* were reported.

MATERIALS AND METHODS

Study sites and sampling areas

The four different biotopes of the present investigation includes CCS University Pond (S-1) and Mawana Pond, Meerut (S-2) along with water logging ditches and drains

near Ganga River (S-3) and Chetawala Village (S-4) of Hastinapur. Details of study area and sampling sites are given in Fig. (1) and Table (1).

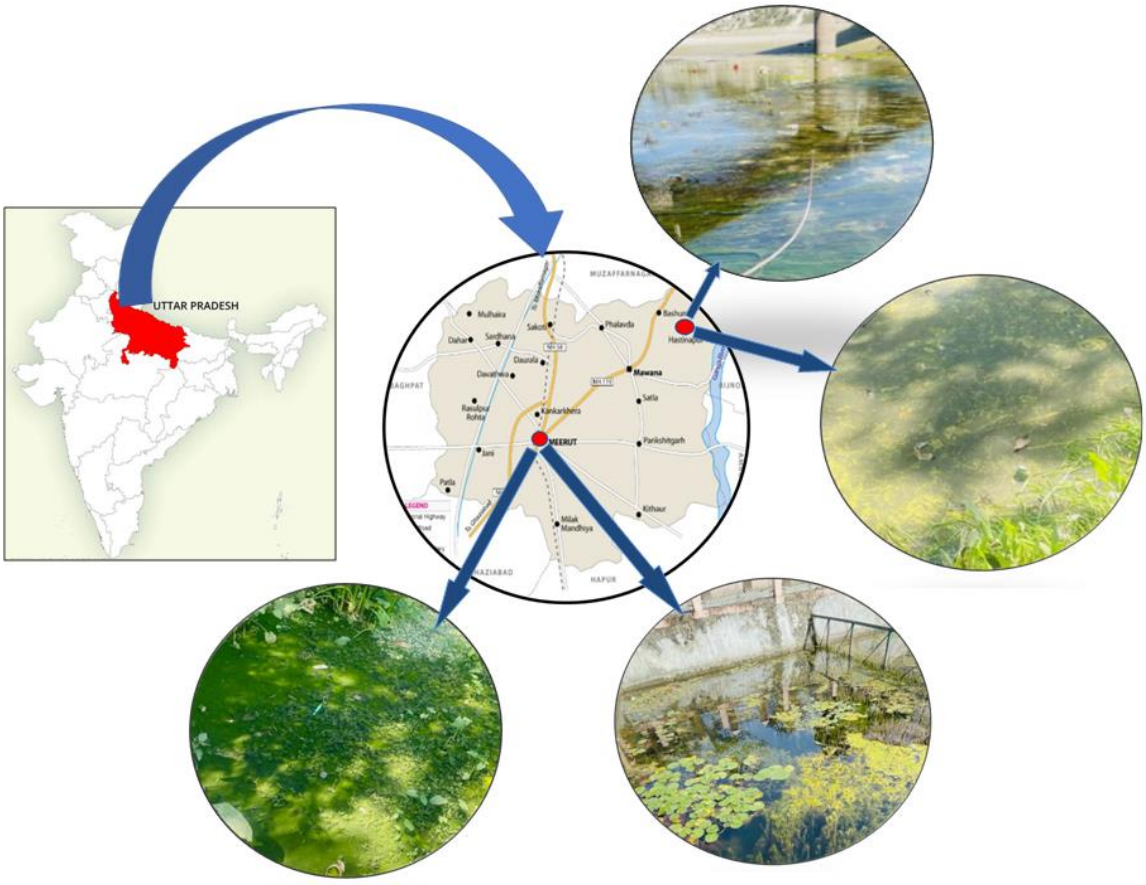

Fig. 1. Map showing four different study sites from Meerut and Hastinapur, U.P., India

Table 1. Characteristics of four different biotopes

Site details	**Characteristics of biotopes**			
Sampling site code	S1	S2	S3	S4
Location	CCS University Pond, Meerut	Mawana Pond Meerut	Wetlands and drains near the Ganga river, Hastinapur	Chetawala Village, Hastinapur
GPS Location	28.96°N, 77.74° E	29.13° N, 77.95° E	29.16° N, 78.02° E	29.15° N, 78.00° E
Water reservoir type	Stagnant	Stagnant	Stagnant	Stagnant
Water source	Pipeline	Household drain wastewater	Ground water and drainage water	Ground and household wastewater
Number of collected samples	17	24	21	18
Voucher number	MT01-MT17	MT18-MT41	MT42-MT62	MT63-MT80
Number of species	15	22	24	19
Date of collection	07th January 2024	22nd January 2024	19th February 2024	16th March 2024

Enrichment culturing

A total of 80 algal growth containing samples were collected from January-March 2024 from all the four different biotopes. Each sample was assigned with a voucher number along with the date of collection, and 5ml from each sample was preserved in 4% v/v formaldehyde and deposited at the Department of Botany, Chaudhary Charan Singh University, Meerut, Uttar Pradesh, India. Additionally, 5ml from each sample was inoculated into the solid/liquid nitrogenous Chu-10 medium **(Chu, 1942)** for enrichment the culturing under controlled conditions (Temperature 28±2ºC, light- 4-6 K Lux, 14:10h light: dark cycle) for seven days, and their unialgal cultures were raised by repeated culturing and sub-culturing methods **(Kant *et al.*, 2003)**.

Microscopic analysis and identification of diatoms

The growth and morphological details of diatoms were observed with the help of a trinocular research microscope (Olympus, CH_{20}i microscope) and a digital camera (Magnus, Magcam DC-10) with software (Magnus Analytics) MagVision, and the morphological observations were recorded. Taxonomic identification of diatoms was based on different morphological characteristics such as size, shape, patterns of frustule, apices, presence or absence of raphe and their ornamentation, etc. All the isolated strains of diatoms were identified up to the species level with the help of available literatures **(Hustedt, 1938, 1959; Tiffany & Britton, 1952; Cholonoky, 1954; Gandhi, 1955, 1956, 1998; Suxena & Venkataswarlu, 1970; Prasad & Mehrotra, 1977; Round *et al.*, 1990; Taylor *et al.*, 2007; Kulikovskiy *et al.*, 2016)**.

RESULTS

Species diversity of diatoms from four different sites

From a total of 80 algal growth samples, 327 strains belonging to 67 genera were identified across three different classes: Cyanophyceae, Chlorophyceae, and Bacillariophyceae. All samples from four distinct sites were analyzed for species diversity within the class Bacillariophyceae. The findings revealed 15 species from CCS University Pond in Meerut, 22 species from Mawana Pond in Meerut, 24 species from wetlands and drains near the Ganga River in Hastinapur, and 19 species from Chetawala Village in Hastinapur. The maximum number of species was observed in samples collected from the wetlands and drains near the Ganga River, while the minimum number was found in CCS University Pond. Detailed results on the percentage of species diversity from all four sites are presented in Fig. (2A). A list of the observed taxa, including their order, family, and availability at different sites, is provided in Table (2).

Table 2. List of observed taxa, their order, family and different sites

S.NO.	Taxon name	Sites			
		S-1	S-2	S-3	S-4
A	**Order Achnanthales**				
	Family: Achnanthidiaceae				
1.	*Achnanthidium exiguum*	-	+	+	-
2.	*A. subatomus*	+	-	+	+
B	**Order Naviculales**				
	a. Family: Stauroneidaceae				
3.	*Craticula ambigua*	-	-	+	+
4.	*C. cuspidate*	+	+	-	+
	b. Family: Amphipleuraceae				
5.	*Frustulia rhomboids* var. *crassinervia*	+	+	+	-
	c. Family: Naviculaceae				
6.	*Navicula capitatoradiata*	-	+	+	-
7.	*N. cryptotenella*	+	+		+
8.	*N. notha*	+	-	+	+
9.	*N. pupula*	+	+	-	-
10.	*N. zanonii*	-	-	+	+
11.	*Trachyneis aspera*	-	+	+	-
	d. Family: Pinnulariaceae				
12.	*Pinnularia dariana*	-	+	-	+
13.	*P. subcapita*	-	-	+	+
14.	*P. viridis*	-	+	+	-
C	**Order Fragilariales**				
	Family: Fragilariaceae				
15.	*Ctenophora pulchella*	+	+	+	-
16.	*Fragilaria capucina*	+	+	+	-
17.	*F. capucina* var.*rumpens*	-	-	+	+
18.	*F. intermedia*	+	+	+	-
D	**Order Bacillariales**				
	Family:Bacillariaceae				
19.	*Nitzschia reversa*	-	+	-	+
20.	*N. acicularis*	+	-	+	+
21.	*N. baculum*	+	-	+	+
22.	*N. capitellata*	+	+	-	+
23.	*N. filiformis*	+	+	+	-
24.	*N. fruticose*	-	+	-	+
25.	*N. linearis*	-	-	+	+
26.	*N. palea*	-	+	-	+
27.	*N. constricta*	-	-	+	+
28.	*N. gracilis*	+	+	+	-
29.	*Tryblionella hungarica*	-	+	-	+
E	**Order Cymbellales**				
	Family:Gomphonemataceae				
30.	*Gomphonema abbreviatum*	+	+	+	-
31.	*G. constrictum*	-	-	+	+
32.	*G. truncatum*	-	+	+	-
F	**Order Tabellarialles**				
	Family:Tabellariaceae				
33.	*Tabellaria japonica*	-	+	+	-

+=Present; -=Absent

Relative abundance of species

From the collected samples, 33 species belonging to 12 genera were identified, including *Achnanthidium*, *Craticula*, *Ctenophora*, *Fragilaria*, *Frustulia*, *Gomphonema*, *Navicula*, *Nitzschia*, *Pinnularia*, *Tabellaria*, *Tryblionella*, and *Trachyneis*. Among the 33 species, ten belong to the genus *Nitzschia*, five to *Navicula*, three each from *Gomphonema* and *Pinnularia*, two each from *Achnanthidium* and *Craticula*, and one species each from *Ctenophora*, *Fragilaria*, *Frustulia*, *Tryblionella*, and *Trachyneis*. The percentage of relative abundance of species belonging to these 12 genera is presented in Fig. (2B).

Morphological observations and taxonomic status

A total of 33 strains of Bacillariophyceae belonging to 6 orders, 9 families and 12 genera and containing *Achnanthidium exiguum*, *A. subatomus*, *Craticula ambigua*, *C.cuspidata*, *Frustulia rhomboides* var. *crassinervia*, *Navicula capitatoradiata*, *N. cryptotenella*, *N. notha*, *N. pupula*, *N. zanonii*, *Trachyneis aspera*, *Pinnularia dariana*, *P. subcapita*, *P. viridis*, *Ctenophora pulchella*, *Fragilaria capucina*, *F. capucina* var. *rumpens*, *F. intermedia*, *Nitzschia reversa*, *N. acicularis*, *N. baculum*, *N. capitellata*, *N. filiformis*, *N. fruticosa*, *N. linearis*, *N. palea*, *N. constricta*, *Tryblionella hungarica*, *Gomphonema abbreviatum*, *G. constrictum*, *G. truncatum* and *Tabellaria japonica* were identified up to species level. Identification and morphological details of all the 33 strains of Bacillariophyceae are described in the present paper.

A. Order: Achnanthales

a. Family: Achnanthidiaceae

[1] *Achnanthidium exiguum* (Grunow) Czarnecki (Fig. 5A, B)

Site of collection: S2, S3

Sample voucher number: MT-19, 20, 22, 29, 31, 38, 47, 50, 51, 56, 62

Dimension: Valves 5-20µm in length

Description: Elliptical valves. Central area comprises of raphe valves in butterfly-shaped. Found in wastewater and effluents flowing water. They can tolerate low intensity of light and withstand temperatures up to 40ºC. Moderate to higher electrolyte content and alkaline water are the most favorable growth conditions.

[2] *Achnanthidium subatomus* (Hustedt) Lange-Bertalot (Fig. 5P)

Site of collection: S1, S3, S4

Sample voucher number: MT- 02, 07, 08, 11, 14, 17, 48, 51, 55, 57, 58, 60

Dimension: Vavles 10-30µm in length.

Description: Cells small elongated, found mostly in both fresh stagnant and flowing water. Cells are small rounded or rhombic. They have bilateral symmetry with isopolar valves. Moreover, they can tolerate low intensity of light and withstand temperatures up to 40ºC.

B. Order: Naviculales

a. Family: Stauroneidaceae

[3] ***Craticula ambigua*** **(Ehrenberg) DG Mann** (Fig. 4I)

Site of collection: S3, S4

Sample voucher number: MT- 43, 44, 47, 49, 51, 65, 69, 71, 77, 79

Dimension: Valve 42-95µm in length and 13-24µm in width. Striae arranged 15-18 in 10µm.

Description: Oval-lanceolate, covered rostrate, sub-capitate apices, middle area absent or slightly expanded in valves. Species is resistant to critical levels of pollution. Moderate to higher electrolyte content in water are most favorable growth conditions.

[4] ***Craticula cuspidata*** **(Kutzing) DG Mann** (Fig. 4J)

Site of collection: S1, S2, S4

Sample voucher number: 03, 04, 11, 16, 18, 19, 21, 27, 28, 32, 34, 41, 63, 64, 67, 70, 72, 73

Dimensions: Length of valve 65-170µm, Width 17-35µm, Striae arranged 11-15 in 10µm.

Description: Valves have broad-lanceolate with covered and rounded apices. Striae equal, convergent near apices. Mostly found in blackish water conditions and can tolerate very heavy pollution.

b. Family: Amphipleuraceae

[5] ***Frustulia rhomboides*** **var.** ***crassinervia*** **(Brébisson ex W.Smith) Ross** (Fig. 4C)

Site of collection: S1, S2, S3

Sample voucher number: 01, 05, 07, 09, 11, 13, 19, 27, 33, 45, 47, 51, 60

Dimensions: Vavles 30-55µm in length, 8-12.5µm in width. Striae arranged 30-35 in 10µm.

Description: Vavles are lanceolate and may be elliptic-lanceolate. Outline is slightly triangulate. Apices are initially sub-rostrate. Mostly found in freshwater rivers and ponds with low electrolyte content and moderately polluted conditions.

c. Family: Naviculaceae

[6] ***Navicula capitatoradiata*** **H. Germin ex Gasse** (Fig. 5F)

Site of collection: S2, S3

Sample voucher number: MT-18, 22, 23, 29, 37, 41, 42, 46, 47, 51, 52, 55, 62

Dimensions: Valves 24-42µm in length and 8-10µm width. Striae arranged 5-6 in 10µm.

Description: Valves are lanceolate, elliptic-lanceolate with covered rostrate apices. In the middle area, a small irregular border is observed with linear, axial basic and thin raphe, striae convergent and radiate toward poles, with longer to broad central area. Mostly found abundantly in freshwater, ponds, eutropic waters and brackish water and can tolerate high pollution conditions.

[7] ***N. cryptotenella*** **Lange-Bertalot** (Fig. 3D)

Site of collection: S1, S2, S4

Sample voucher number: MT- 03, 05, 06, 10, 12, 15, 22, 25, 32, 36, 37, 65, 72, 73, 77, 80

Dimensions: Valves 12-40µm in length and 5-7µm width. Striae radiate and lightly curved.

Description: Valves in the center area becoming convergent to the poles. Mostly found in freshwater biotopes with exceedingly low and high electrolyte content and can tolerate moderate pollution conditions.

[8] ***N. notha*** **J.H. Wallace** (Fig. 5E)

Site of collection: S1, S3, S4

Sample voucher number: 01, 08, 12, 13, 45, 49, 51, 54, 59, 62, 67, 68, 75, 79

Dimensions: Length of valve 19-32µm, Width 4-5µm, Striae arranged 15-17 in 10µm.

Description: Valves constrict lanceolate with highly rounded short covered apices. Raphe filiform, adjacent and endings short deflected. Shape indistinct, constricted axial and central areas. Striae are diffused at the middle area of the valve and convergent in the end poles. Mostly found in freshwater, acidic or circum-neutral waters with poor electrolyte content and can tolerate high pollution conditions.

[9] ***N. pupula*** **Kützing** (Fig. 4L)

Site of collection: S1, S2

Sample voucher number: MT-02, 04, 05, 14, 17, 21, 26, 29, 30, 37

Dimension: Valve 19-32µm in length and 4-5µm in width. Striae arranged 15-17 in 10µm.

Description: Vavles length changeable with age; elliptical to linear-elliptical with covered sub capitate and rounded apices. Striae firmly radiate and curved in the middle area of the cell. Striae thin, in a single row of round puncta. Mostly found in freshwater, electrolyte-rich and heavily polluted conditions.

[10] ***N. zanonii*** **Hustedt** (Fig. 5I)

Site of collection: S3, S4

Sample voucher number: MT-44, 47, 50, 51, 64, 66, 68, 70, 76, 78, 79

Dimensions: Valve 14-26µm in length and 4-5µm in width. Striae arranged 14-16 in 10µm.

Description: Valves lanceolate, covered rostrate, rounded apices. Raphe lateral, axial and linear constricted with middle area weak rhombic. Middle area is convergent towards the poles with protracted radial striae. Found in freshwaters and alkaline waters and heavily polluted conditions.

[11] ***Trachyneis aspera*** **(Ehrenberg) Cleve** (Fig. 3H)

Site of collection: S2, S3

Sample voucher number: MT-19, 22, 24, 27, 29, 30, 32, 35, 37, 40

Dimension: Valves 115-120µm in length and 17-28µm in width. Striae arranged 14-16 in 10µm

Description: Valves elliptic-lanceolate with obtuse apices. Valves in the transapical plane show that each hole opens into a separate compartment within each "stria". Raphe slightly eccentric and oval shaped. Axial area irregularly linear widened towards the central nodule. Found in moderate eutrophic and electrolyte-rich waters and can tolerate moderately polluted conditions.

d. Family: Pinnulariaceae

[12] *Pinnularia dariana* (Schmidt) F.W. Mills (Fig. 5O)

Site of collection: S2, S4

Sample voucher number: MT-19, 23, 26, 29, 34, 63, 68, 74, 78, 79

Dimensions: Valves 170-275µm in length and 35-47µm in width. Striae arranged 12-15 in 10µm.

Description: Valves are linear-lanceolate, barely triundulate, or slightly expanded at mid-value. Apices are broad and rounded. Raphe straight, filiform. The axial area is linear-lanceolate, ¼-⅓ of the valve width and gradually widens into a poorly separated central area. The central area is wider in the primary valve side. Found in freshwaters and electrolyte-rich waters and heavily polluted conditions.

[13] *P. subcapita* W. Gregory (Fig. 3E)

Site of collection: S3, S4

Sample voucher number: MT- 45, 47, 48, 52, 55, 61, 62, 67, 69, 73, 74, 78

Dimensions: Valve 17-57µm in length and 4-8um in width. Striae arranged 10-14 in 10µm.

Description: Valves continuous with parallel, infirm convex or concave limits. Proximal raphe closed deflected, terminal fissures and semi-circular. Apices covered, capitate and rounded. Axial area linear and broaden. The middle area is broad and curved into a fascia. Found in freshwaters, oligotrophic and electrolyte-poor waters.

[14] *P. viridis* (Nitzsch) Eherenberg (Fig. 3K)

Site of collection: S2, S3

Sample voucher number: 43, 46, 50, 53, 59, 62, 67, 69, 70, 74, 79, 80

Dimensions: Valve 40-182µm in length and 21-30µm in width. Striae arranged 6-7 in 10µm.

Description: Valves linear, boundaries parallel, very short weak convex or triangulate contraction towards rounded apices. Lateral raphe and longitudinal lines are observable. Proximal raphe closed, round and deflected toward ends. Found in freshwaters, oligotrophic and electrolyte-poor waters.

C. Order: Fragilariales

a. Family: Fragilariaceae

[15] *Ctenophora pulchella* (Kutzing) D.M. Williams & Round (Fig. 3J)

Site of collection: S1, S2, S3

Sample voucher number: 03, 04, 09, 14, 27, 31, 36, 41, 45, 49, 51, 54, 58

Dimensions: Valve 20-200µm in length and 5- 9µm in width. Striae arranged 9-17 in 10µm.

Description: Valves are long flat, rounded slightly toward covered apices, well clear hyaline area. Ghost striae may be observable in the center. Striae are distinguishable under the light microscope. Found in brackish inland and heavily polluted water.

[16] ***Fragilaria capucina*** **Desmazieres** (Fig. 3C, G)

Site of collection: S1, S2, S3

Sample voucher number: 04, 06, 08, 13, 21, 23, 38, 40, 42, 43, 50, 54, 56

Dimensions: Valves 10-100µm in length and 3-5µm in width. Striae arranged 12-27 in 10µm.

Description: Valves are lanceolate, capitate apices. A specific hyaline area is present in middle, unilaterally or bilaterally turgid. Found in oilgo-to mesotrophic waters with low electrolytes and can tolerate moderate to heavily polluted conditions.

[17] ***F. capucina*** **var.** ***rumpens*** **(Kutzing) Lange-Bertalot ex Bukhtiyarova** (Fig. 3I)

Site of collection: S3, S4

Sample voucher number: MT-43, 46, 47, 49, 52, 58, 64, 66, 70, 77, 80

Dimension: Valves 10-100µm in length and 2-7µm in width. Striae arranged 18-20 in 10µm.

Description: Valves lanceolate, covered and rounded with sub-capitate apices. A specific hyaline area is present in the middle of the cell. Striae are observable. Found in oligotrophic and mesotrophic freshwaters and can withstand moderate to heavily polluted conditions.

[18] ***F. intermedia*** **Grunow (Grunow)** (Fig. 4B)

Site of collection: S1, S2, S3

Sample voucher number: 07, 08, 09, 21, 26, 27, 30, 36, 38, 41, 46, 53, 55, 60, 61

Dimension: Valves 50-200µm in length and 4-14µm in width. Striae arranged 17-20 in 10µm.

Description: Valves are lanceolate and present strongly apiculate ends, rimoportulae occur near the poles (one per valve) and the apical pore fields are rectangular. The central area is unilateral, often expanded just until the sternum and the striation is alternate, parallel to slightly radiate towards the poles striae are observable. Periphytic habitat in freshwater and can also be found in moderately to highly polluted water conditions.

D. Order: Bacillariales

a. Family: Bacillariaceae

[19] ***Nitzschia reversa*** **W. Smith** (Fig. 3M)

Site of collection: S2, S4

Sample voucher number: 18, 23, 26, 29, 30, 35, 64, 68, 70, 71, 74

Dimensions: Valves 40-180µm in length and 5- 9µm in width. Striae arranged 23-28 in 10µm, Fibulae arranged 7-10 in 10µm.

Description: The valve is spindle-shaped shaped with poles deflected in opposite directions. Central fibulae are broadly spread out forming a gap. Striae are not observable under light microscope. Found in freshwater habitats.

[20] ***N. acicularis*** **(Kutzing) W. Smith** (Fig. 3L)

Site of collection: S1, S3, S4

Sample voucher number: MT-06, 08, 14, 15, 17, 44, 45, 50, 52, 59, 63, 67, 68, 72, 79

Dimensions: Valves 30-150µm in length and 2-5µm in width. Striae arranged 60-72 in 10µm, Fibulae arranged 15-22 in 10µm.

Description: Valves is spindle-shaped with extended thin poles, equidistant fibulae. Apex rounded. Striae are not clearly observable under light microscope. Widely distributed in freshwater, eutrophic waters and high electrolyte content water, this species can tolerate heavily polluted conditions.

[21] ***N. baculum*** **Frenguelli** (Fig. 4K)

Site of collection: S1, S3, S4

Sample voucher number: 05, 06, 09, 12, 16, 47, 49, 53, 54, 56, 60, 68, 69, 72, 74, 77, 78

Dimension: Valves 40-180µm in length and 4-8µm in width. Striae arranged 70-98 in 10µm, Fibulae arranged 15-22 in 10µm.

Description: Valves spindle-shaped with extended thin poles, equidistant fibulae. Apex rounded, Striae are not clearly observable in the light microscope. This species is distributed in freshwater, eutrophic waters and higher electrolyte content water, and it can tolerate heavily polluted conditions.

[22] ***N. capitellata*** **Hustedt** (Fig. 3F)

Site of collection: S1, S2, S4

Sample voucher number: 02, 08, 10, 13, 14, 22, 23, 24, 37, 39, 63, 68, 69, 70, 79, 80

Dimensions: Valves 18-70µm in length and 3-7µm in width. Striae arranged 23-40 in 10µm, Fibulae arranged 10-18 in 10µm.

Description: Valves linear to linear-lanceolate growth is observed. Poles are cuneate and in the middle and margins remain more or less concave. Apices are regularly capitate. Small block-shaped fibulae support raphe. It consists of two central fibulae and have additional wide-spaced. Commonly found in high electrolyte and brackish water, this species can tolerate extremely polluted conditions.

[23] ***N. filiformis*** **(W Smith) Van Heurck** (Fig. 4E, F)

Site of collection: S1, S2, S3

Sample voucher number: 02, 06, 09, 10, 17, 21, 23, 34, 38, 43, 49, 51, 53, 60

Dimensions: Valves 40-100µm in length and 4-6µm in width. Striae arranged 25-40 in 10µm, Fibulae arranged 5-11 in 10µm.

Description: Valves linear-lanceolate in growth. Valves are lightly concave in the center from margins. Apices are straight and rounded. Raphe marginal, fibulae irregularly arranged. Striae are weakly observable in the light microscope. Found in high electrolyte

content and brackish waters and can tolerate stronger polluted conditions up to critical levels of pollution.

[24] *N. fruticosa* Hustedt (Fig. 4D)

Site of collection: S2, S4

Sample voucher number: MT-21, 22, 26, 27, 30, 36, 37, 66, 67, 68, 75, 79, 80

Dimensions: Valves 20-80µm in length and 2-5µm in width, Striae arranged 13-18 in 10µm, Fibulae arranged 29-36 in 10µm.

Description: Valves ellipsoidal, linear-lanceolate. Apices are covered, rosette present in shaped appearance. Found in electrolyte- rich waters and can tolerate moderate levels of pollution.

[25] *N. linearis* (Agardh) W. Smith (Fig. 5N)

Site of collection: S3, S4

Sample voucher number: 42, 44, 51, 52, 53, 64, 65, 66, 70, 72, 77, 79

Dimensions: Valve 34-230µm in length and 2-8µm in width. Striae arranged 28-41 in 10µm, Fibulae arranged 8-17 in 10µm.

Description: Valves are undeviating, linear-lanceolate to constrict lanceolate. Poles are cuneate, Apices are capitate in the direction of rostrate. The raphe is slightly concaved and marginal and distinct in the central area. Fibulae are irregularly arranged and narrow with some focal depths and blends in some places. Striae are indistinct to infirm visible. Found in a wide ecological range and oxygen-rich waters with moderate to high electrolyte content and can tolerate moderately polluted conditions.

[26] *N. palea* (Kutzing) W. Smith (Fig. 5J, M)

Site of collection: S2, S4

Sample voucher number: 24, 25, 32, 36, 37, 38, 63, 69, 70, 76, 80

Dimensions: Valves 15-70µm in length and 2-5µm in width. Striae arranged 28-40 in 10µm, Fibulae arranged 9-17 in 10µm.

Description: Valves are linear-lanceolate. Poles are with tapering, cuneate. Apices are highly rounded or infirm capitate. Marginal raphe and spaced fibulae are present. Striae are difficult to observe under light microscope. Found in eutrophic water and with moderate to high electrolyte content and can withstand heavily contaminated and polluted water conditions.

[27] *N. constricta* (Kützing) Ralfs (Fig. 4M)

Site of collection: S3, S4

Sample voucher number: 46, 47, 50, 59, 61, 64, 72, 75, 76

Dimensions: Valves 20-58µm in length and 4-9um in width. Striae arranged 14-20 in 10µm, Fibulae arranged 14-20 in 10µm.

Description: Valves are linear and in the middle weakly incurvate. Apices with tight scant rostrate and shielded. Striae interrupted towards the broad, longitudinal sternum. Fibulae are small stubby. Found in freshwater and electrolyte-rich waters. This species can tolerate stronger polluted conditions.

[28] ***N. gracilis*** **Hantzsch** (Fig. 4A)

Site of collection: S1, S2, S3

Sample voucher number: 01, 07, 08, 15, 17, 26, 27, 36, 38, 41, 47, 49, 58, 59

Dimensions: Length of Valve 30-110µm, Width 2-4µm, Striae arranged 38-42 in 10µm, Fibulae arranged 12-18 in 10µm.

Description: Valves are constricted, linear-lanceolate with poles small toward ends (acicularoid) and shielded. Apices are infirm capitate or infirm rostrate. Raphae are small and unequal fibulae in the central area are absent. Striae are not visible under light microscope. Moderately found in eutrophic and electrolyte-rich waters and can tolerate moderately polluted conditions.

[29] ***Tryblionella hungarica*****(Grunow) Frenguelli** (Fig. 4H)

Site of collection: S2, S4

Sample voucher number: 22, 23, 25, 34, 35, 64, 65, 69, 71, 73, 78

Dimension: Valves 35-100µm in length and 5-9µm in width. Striae arranged 22-27 in 10µm, Fibulae arranged 8-11 in 10µm.

Description: Valves are linear and slightly concave in the middle. The apices are protracted slightly and bluntly rounded. The raphe is excentric. Transapical striae finely punctuate and interrupted along the apical axis by a longitudinal sternum. Striae appear costate, rather than distinctly punctate. A longitudinal fold is present and extends the length of the valve. Found abundantly in fresh water and can tolerate moderately polluted conditions.

E. Order: Cymbellales

a. Family: Gomphonemataceae

[30] ***Gomphonema abbreviatum*** **C. Agardh** (Fig. 5G)

Site of collection: S1, S2, S3

Sample voucher number: 02, 06, 07, 13, 17, 22, 24, 26, 35, 38, 40, 47, 49, 58, 59

Dimensions: Valves 38-67µm in length and 10-16µm in width. Striae arranged 12-15 in 10µm.

Description: Valves heteropolar, valve outline prominent characteristic distinguishes, head-pole and foot pole rounded. Valves in circle view cuneate. Striae punctate. Axial linear, constricting towards the apices, middle area small rounded. Raphe lateral, adjacent, end small, comma-shaped. Found in eutrophication habitats and can tolerate moderately polluted conditions.

[31] ***G. constrictum*** **Ehrenberg** (Fig. 5D)

Site of collection: S3, S4

Sample voucher number: 43, 49, 51, 53, 60, 63, 67, 68, 70, 71, 72, 80

Dimensions: Valves 80-120µm in length and 15-20µm width. Striae arranged 10-15 in 10µm.

Description: Valves are heteropolar, clavate to rhombic with the largest valve width near mid-valve, narrowing toward the rounded apex and basis, apex slightly broader. The axial area is linear narrow, the central area small. Raphe is lateral, slightly undulates with dilated proximal raphe fissures and deflected terminal raphe fissures. Striae are uniseriate, composed of c-shaped areolae occluded by siliceous flaps. Transapical striae are radiate in mid-valve and at headpole, becoming strongly radiate toward the footpole. Found in eutrophicated habitats and can tolerate moderate to highly polluted conditions.

[32] *G. truncatum* Eherenberg (Fig. 5H)

Site of collection: S2, S3

Sample voucher number: MT-19, 21, 24, 27, 31, 36, 37, 38, 39, 42

Dimensions: Valves 26-57µm in length and 9- 14µm in width. Striae arranged 10-12 in 10µm.

Description: Valves clavate, with a tumid center. Constriction at the headpole and broad apex creates a distinctly capitate headpole. The footpole is narrow and rounded. The axial area is straight and expanded on either side of the axial area to form a "bow-tie" shaped central area. Single, rounded external stigma opening is present in the central area. Raphe lateral and undulate, with expanded external proximal ends. Striae are radiate, indistinctly punctate and become parallel toward the headpole. Striae are strongly radiate at the footpole. A distinct apical pore field is present at the footpole. Septa and pseudosepta are present at the poles. Mostly found in eutrophicated habitats and can tolerate moderate to highly polluted conditions.

F. Order Tabellarialles

a. Family: Tabellariaceae

[33] *Tabellaria japonica* H. Tanaka (Fig. 5C)

Site of collection: S2, S3

Sample voucher number: MT-23, 24, 26, 29, 36, 47, 49, 53, 58

Dimensions: Valves 21-30µm in length and 7-8µm in width. Striae arranged 10-13 in 10µm.

Description: Valves elongated, inflated laterally in the middle and at the poles. Septa more than two, longitudinal, straight, perforated, present between girdles, intercalary. The frustules (siliceous cell walls) are attached at the corners so that the colonies assume a zig-zag shape. Found growing epiphytically in streams and can tolerate moderately polluted conditions.

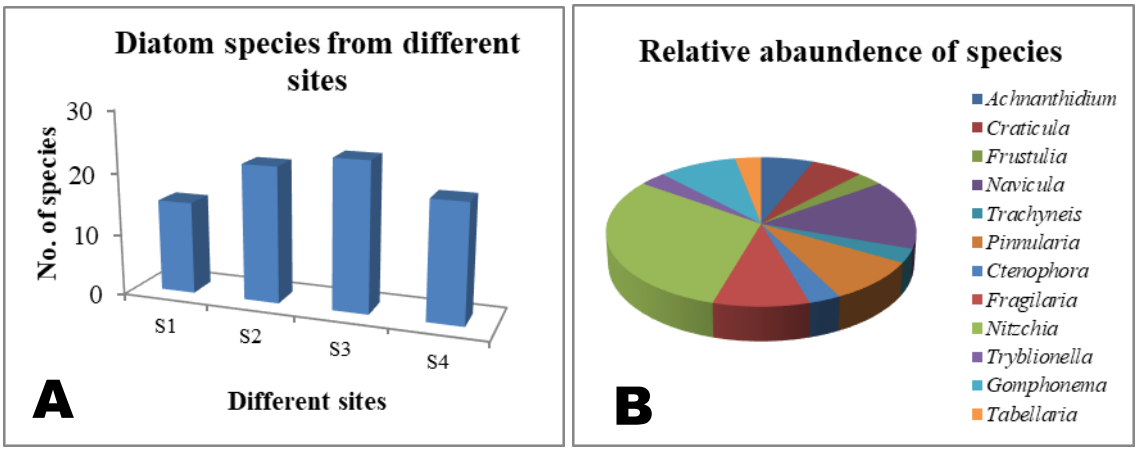

Fig. 2A-B. (A). Number of diatom species from four different sites, **(B).** Percentage of relative abundance of the species belonging to different genera

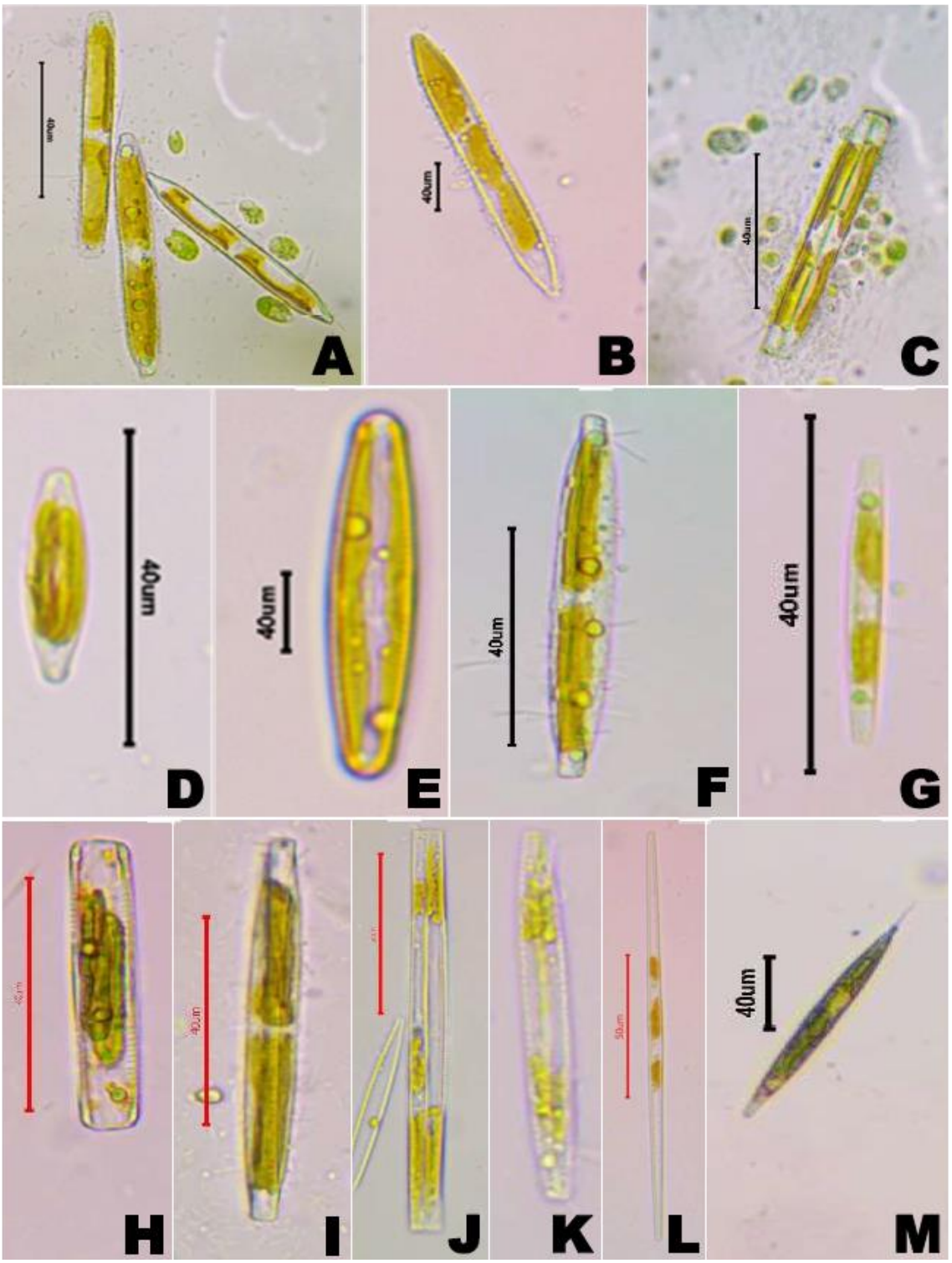

Fig. 3A-M. (A-B) *Tryblionella hungarica*; **(C, G)** *Fragilaria capucina*; **(D)** *Navicula cryptotenella*; **(E)** *Pinnularia subcapita*; **(F)** *Nitzschia capitellata*; **(H)** *Trachyneis aspera*; **(I)** *Fragilaria capucina* var. *rumpens*; **(J)** *Ctenophora pulchella*; **(K)** *Pinnularia viridis*; **(L)** *Nitzschia acicularis*; **(M)** *Nitzchia reversa*

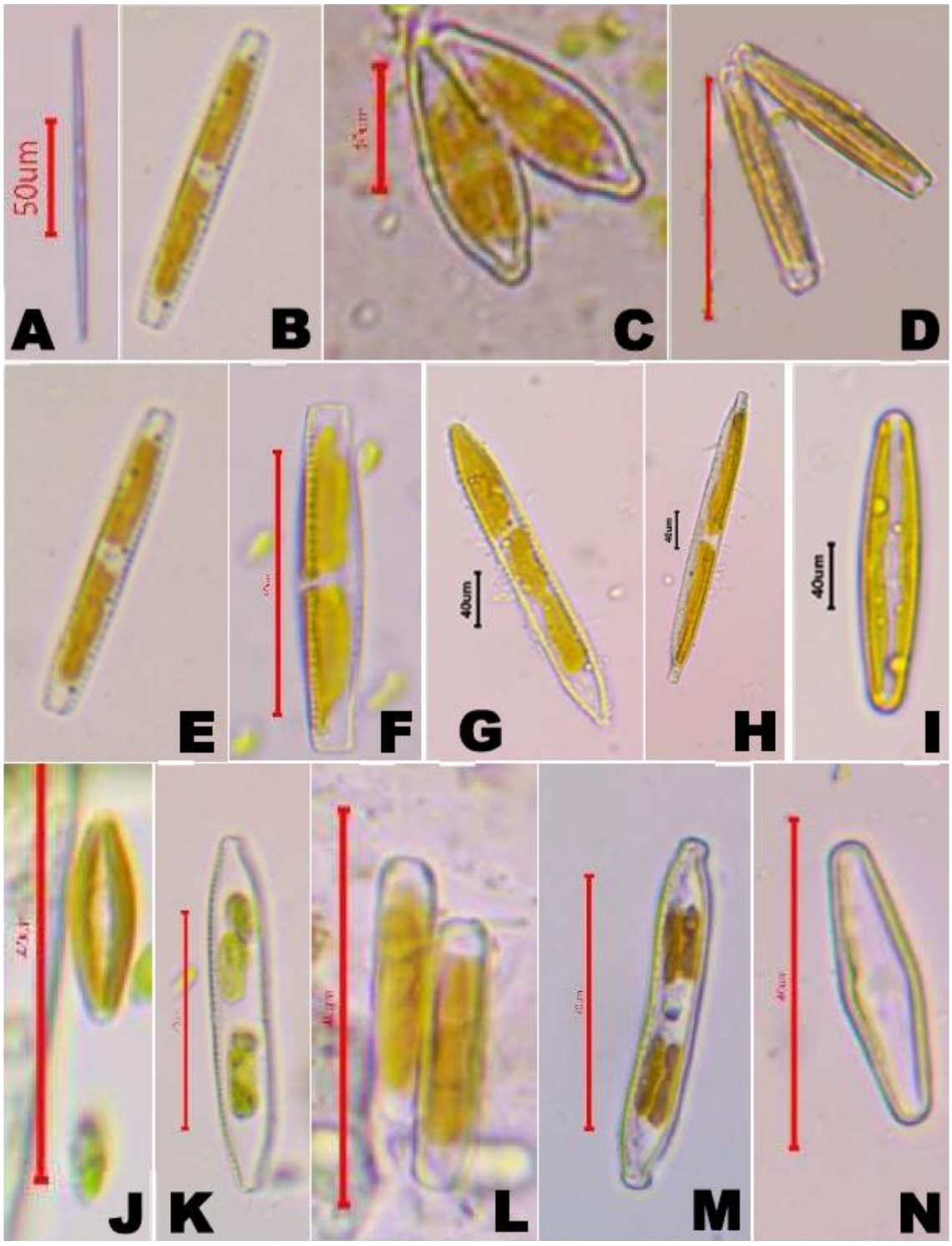

Fig. 4A-N. (A) *Nitzxchia gracilis*; **(B)** *Fragilaria intermedia*; **(C)** *Frustulia rhombodies*; **(D)** *Nitzschia fruticosa*; **(E, F)** *Nitzschia filiformis*; **(G, H)** *Tryblionella hungarica*; **(I)** *Craticula ambigua*; **(J)** *Craticula cuspidate*; **(K)** *Nitzschia baculum*; **(L)** *Navicula pupula*; **(M)** *Nitzxchia constricta*; **(N)** *Craticula ambigua*

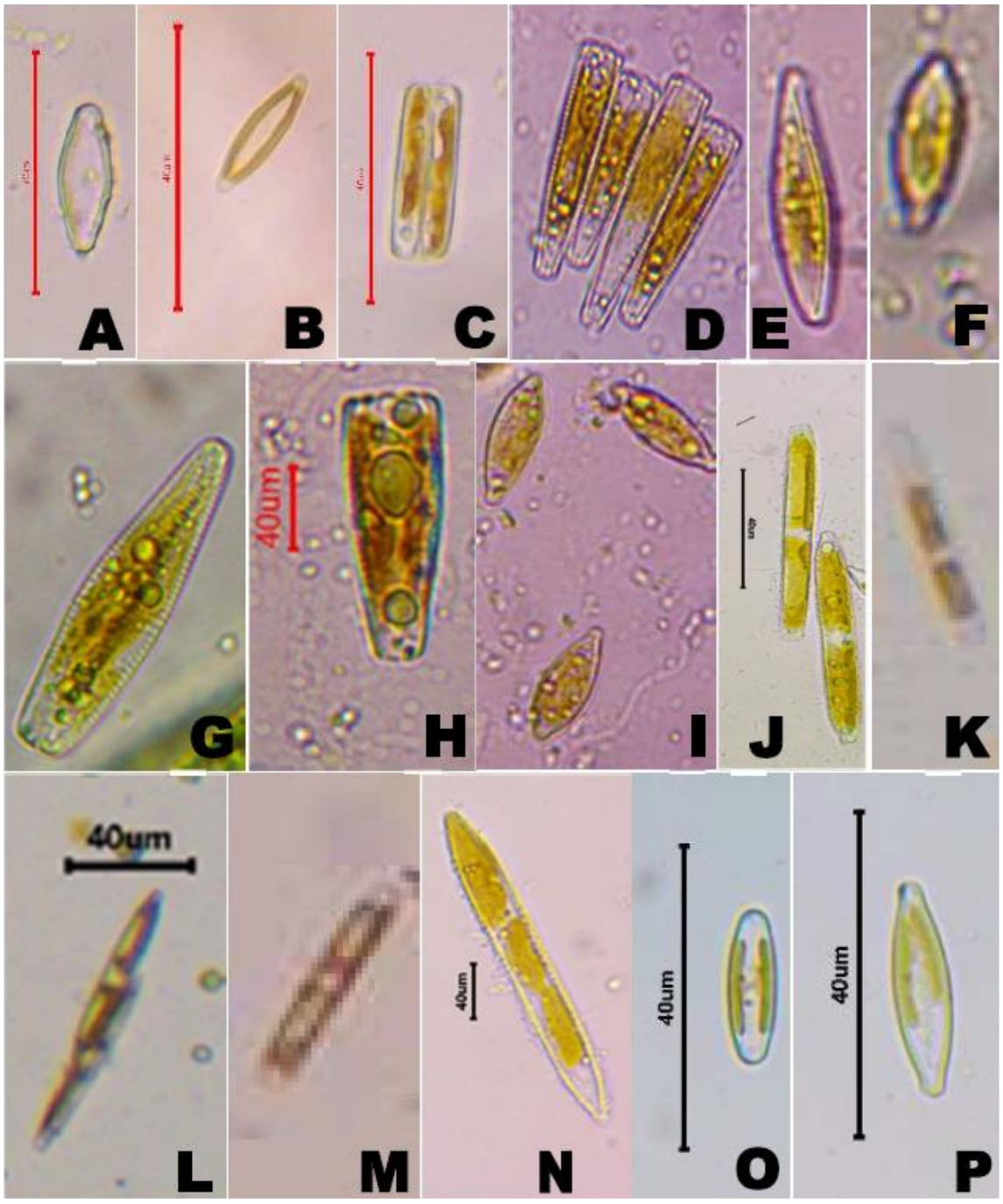

Fig. 5A-P. (A, B) *Achnanthidium exiguum*; **(C)** *Tabellaria japonica*; **(D)** *Gomphonema constrictum*; **(E)** *Navicula notha*; **(F)** *N. capitatoradiata*; **(G)** *Gomphonema abbreviatum*; **(H)** *G. truncatum*; **(I)** *Navicula zanonii*; **(J-M)** *Nitzschia palea*; **(N)** *N. linearis*; **(O)** *Pinnularia dariana*; **(P)** *Achnanthidium subatomus*

DISCUSSION

In India, countless phycologists **(Tiwari *et al.*, 2007, 2009, 2013; Kant, 2011, 2012; Tandon *et al.*, 2014a, b; Kant *et al.*, 2020; 2021a, b)** have explored the different

groups of the algae; however, most of the them either could not cover the adjoining area of Meerut, an important historical ancient city of western Uttar Pradesh, Bharat and could not explore the area for the occurrence of the algae. Although, few phycologists **(Kumar, 1970; Bendre & Kumar, 1975)** tried to explore the area but their work was carried five decades ago during 1970-1975 and they focused mainly on cyanophytes. After that Meerut and its adjoining area have witnessed tremendous growth in the human population as well as different kinds of pollution due to heavy industrialization in the area which has dramatically changed the physico-chemical properties of the water, soil and air **(Singh, 2022)**. Although a few phycologists **(Neha *et al*., 2021; Singh *et al*., 2021a, b, 2022a, b, 2023a, b; Doli *et al*., 2023; Kumar & Kant, 2023)** have studied on blue-green algae in Meerut and surrounding areas, but they confined their work up to physiological characterization and allelopathic interaction and ignored the other group of algae in this region. As the algae are considered as the ecological indicator the exploration of the water bodies is of great concern in relation to the pollution.

There are 429 genera and 14684 species of diatoms (Bacillariophyceae) reported from all over the globe **(Guiry, 2024)**, out of which total 5249 taxa (including 3816 species, 12 subspecies, 1107 varieties and 314 forma) are accepted taxonomically and belong to the these twelve genera including *Achnanthidium*, *Craticula*, *Ctenophora*, *Fragilaria*, *Frustulia*, *Gomphonema*, *Navicula*, *Nitzschia*, *Pinnularia*, *Tabellaria*, *Tryblionella* and *Trachyneis* which share approximately 36% of the total kwon diatoms and which are more than 1/3 percent of the total know taxa. The details of globally accepted taxa of these twelve reported genera of the present study are given in Table (3).

Table 3. The globally known taxonomically accepted taxa of twelve genera of diatoms

Sl. No.	Genera	Species	Subspecies	Varieties	Forma	Reference
1.	*Achanthidium*	150	-	9	-	Guiry and Guiry, 2022
2.	*Craticula*	60	-	10	1	Guiry and Guiry, 2018
3.	*Ctenophora*	5	-	2	-	Guiry and Guiry, 2023
4.	*Fragilaria*	216	2	114	29	Guiry and Guiry, 2021
5.	*Frustulia*	122	2	11	8	Guiry and Guiry, 2015
6.	*Gomphonema*	603	5	178	54	Guiry and Guiry, 2017
7.	*Navicula*	1659	3	505	164	Guiry and Guiry, 2019
8.	*Nitzschia*	875	-	235	52	Guiry and Guiry, 2021
9.	*Pinnularia*	893	-	500	129	Guiry and Guiry, 2015
10.	*Tabellaria*	20	-	8	-	Guiry and Guiry, 2017
11.	*Trachyneis*	16	-	17	-	Guiry and Guiry, 2011
12.	*Tryblionella*	70	-	10	6	Guiry and Guiry, 2021

The diatoms of India have been investigated by a large number of algologists from different states of the country **(Ehrenberg, 1851; Venkataraman, 1939; Desikachary & Maheswari, 1958; Gandhi, 1960; Prasad, 1984; Sarode & Kamat, 1984; Venkateswarlu *et al*., 1987; Padhi & Padhi, 2001; Sharma & Lyngskor, 2003; Tomy, 2003; Kumawat & Jawale, 2005; Jena *et al*., 2006; Mahajan, 2012; Mishra & Balasubramanian, 2012; Sirmour *et al*., 2012; Nautiyal, 2014; Humane *et al*., 2015; Jyotsna *et al*., 2015; Roy & Kesari, 2015; Venkataraman & Raghunathan, 2015; Rajeshwari & Krishnamurthy, 2016; Meeravali *et al*., 2017; Mishra & Pandey, 2017; Prabavathy & Pillai, 2017; Prasad *et al*., 2018; Arulmurugan *et al*., 2019; Bharati *et al*., 2019; Mishra *et al*., 2019; Narchonai *et al*., 2019; Behera *et al*., 2020; Dubey *et al*., 2020; Ramanujam *et al*., 2020; Awasthi, 2021; Hajong *et al*., 2021; Raju & Aruna, 2021; Tripathi, 2021; Satpati *et al*., 2021; Saxena *et al*., 2021; Susmitha & Mahesh, 2021; Achankunju & Panikkar, 2022; Das *et al*., 2022; Hooda *et al*., 2022; Kumar & Kaur, 2022; Parihar *et al*., 2022; Radhakrishnan *et al*., 2022; Sharma & Sharma, 2022; Thacker & Karthick, 2022; Arumugham *et al*., 2023; Karthick *et al*., 2023; Kere *et al*., 2023; Pardhi *et al*., 2023; Rao & Rao, 2023; Singh *et al*., 2023; Tandon *et al*., 2023; Tiwari *et al*., 2023; Venkatachalapathy *et al*., 2023; Keshari, 2024; Reddy, 2024; Thacker *et al*., 2024; Thippeswamy, 2024, Thrupthi & Prasad, 2024)**.

The diatom flora of Uttar Pradesh, India has been studied by many algologists **(Singh, 1961, 1962, 1963; Habib & Chaturvedi, 1991; Prasad & Singh, 1996; Verma *et al*., 1996; Sussela & Dwivedi, 2002; Mishra *et al*., 2008; Tripathi *et al*., 2012; Nautiyal *et al*., 2013; Singh, 2015; Suseela *et al*., 2016; Verma & Nautiyal, 2016; Dasgupta *et al*., 2017; Grover *et al*., 2017; Saini *et al*., 2022; Kumar & Nautiyal, 2023; Tiwari *et al*., 2023)** but most of them could not explore the area of western Uttar Pradesh, particularly Meerut and its surrounding area including Hastinapur and thus present studied area have been totally neglected for the study of the diatoms near about half century (1975-2024). From our present study on diatom flora of four different biotopes of Meerut and Hastinapur, we are reporting 33 species of diatoms belonging to 6 orders, 9 families and 12 genera *viz. Achnanthidium exiguum*, *A. subatomus*, *Craticula ambigua*, *C.cuspidata*, *Frustulia rhomboides* var. *crassinervia*, *Navicula capitatoradiata*, *N. cryptotenella*, *N. notha*, *N. pupula*, *N. zanonii*, *Trachyneis aspera*, *Pinnularia dariana*, *P. subcapita*, *P. viridis*, *Ctenophora pulchella*, *Fragilaria capucina*, *F. capucina* var. *rumpens*, *F. intermedia*, *Nitzschia reversa*, *N. acicularis*, *N. baculum*, *N. capitellata*, *N. filiformis*, *N. fruticosa*, *N. linearis*, *N. palea*, *N. constricta*, *Tryblionella hungarica*, *Gomphonema abbreviatum*, *G. constrictum*, *G. truncatum* and *Tabellaria japonica*.

CONCLUSION

The results indicate that all four biotopes were previously unexplored and are rich in diatom flora. Based on field observations and morphological analyses, it can be

concluded that the Meerut and Hastinapur regions of western Uttar Pradesh, India, harbor a significant diversity of diatoms. Given that this is the first study on the diatom flora of the area, further investigation is needed to explore the diversity of these organisms more thoroughly. Additionally, it can be concluded that the occurrence of diatoms is comparatively low in both regions, highlighting the need for more extensive study and documentation.

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