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RESEARCH ARTICLE

The genus *Oscillatoria* Vaucher ex Gom. (Cyanoprokaryote) from polluted biotopes of Meerut, Uttar Pradesh, India

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Abstract Water is an essential component of life and required for the survival and development of every organism, but globally many countries are facing water pollution problems. Present investigation deals with the diversity and distribution pattern of different species of genus *Oscillatoria* in five different polluted biotopes of Meerut, Uttar Pradesh, India. In this study, total twenty eight species of the genus *Oscillatoria* namely *Oscillatoria agardhii, O. annae, O. corakiana*, *O. curviceps*, *O. fracta*, *O. jenensis, O. leavittae*, *O. leonardii*, *O. limosa*, *O. lutea*, *O. luteola, O. mitrae*, *O. nigro-viridis, O. princeps, O. proboscidea*, *O. proteus*, *O. pseudocurviceps*, *O. rupicola*, *O. salina, O. sancta, O. simplicissima, O. subbrevis*, *O. subsalsa*, *O. subuliformis*, *O. tenuis*, *O. ucrainica*, *O. vizagapatensis* and *O. yamadae* are reported from Meerut, Uttar Pradesh, India after a gap of more than last five decades. Present study also revealed that the occurrence of the individual taxa is seriously influenced by various factors and these factors play very significant role in occurrence and distribution pattern of *Oscillatoria* in different polluted biotopes.

Key words: Biodiversity, Biotopes, Cyanoprokaryotes, Pollution, Meerut

Introduction

Water is an precious natural resource and essentially required for the growth and development of almost all types of organisms including microbes, plants, animals and human beings. Because of this most of the civilizations of the world flourished near many major rivers including river Sindhu during ancient periods due to easily availability of natural water resources. But recently most of the natural water resources all over the world have become contaminated by large numbers of pollutants and the water of most of them is not safe for drinking (Mensah *et al*. 2013, Zakir *et al*. 2016). In India, many majors rivers of the country including Ganga, Gomati, Hindon, Krishna, Krishni, Yamuna and their tributaries are highly polluted by toxic chemicals (Lewis 2007, Sharma *et al*. 2014, Mohanty and Nayak 2017, Jangwan *et al*. 2019, Kumar *et al*. 2019, Rizvi and Mohammed-Aslam 2019, Bharti *et al*. 2020; Sharma *et al*. 2020).

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In western Uttar Pradesh of India, the Meerut has been a famous ancient city and presently considered as one of the densely populated city of western U.P. The population of human beings in Meerut city has increased 6-7 folds during last five decades (1972-2021). Meerut city and adjoining areas have also witnessed huge increase in industries. The Meerut city is located near Kali river, a tributary of Hindon river. Kali river flows through the Meerut city. Presently water of the Kali river is not safe for human beings due to presence of high level of both organic and inorganic toxic pollutants (Singh *et al*. 2020) and different types of microbes (Singh *et al*. 2021). The toxic chemicals released by various industries including dairy, sugarcane, pesticides, fertilizers, slaughter houses, meat processing units and municipal corporations reach directly or indirectly to Kali river and cause pollution. These released chemicals promote the growth of a large number of beneficial and harmful microbes including cyanoprokaryotes (Singh *et al*. 2021).

The cyanoprokaryotes are very important and interesting group of autotrophic oxygenic

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photosynthetic microbes with some of these having nitrogen fixing potential. They are also known as blue-green algae / cyanophytes / cyanobacteria and they evolved on the planet Earth approximately 3.5 billion years ago (Schopf and Packer 1987, Blank, 2013). They play very important role in the ecosystem as primary colonizer (Schwabe 1974) and also act as ecological indicator and they have tremendous potential to adapt to very harsh environmental conditions and can grow in a wide range of biotopes including polluted water reservoirs.

Based on morphological features and thallus structures, traditionally cyanoprokaryotes have been arranged into three groups namely unicellular, non-heterocystous filamentous and heterocystous forms (Desikachary 1959, Komárek and Anagnostidis 1998, 2005, Komárek 2013) but recently their taxonomy has been revised thoroughly and this group of organisms has been rearranged under nine orders following polyphasic approach (Komárek *et al*. 2014). All the filamentous genera without heterocysts and akinetes have been classified under the order Oscillatoriales (Komárek and Anagnostidis 2005), with five families including Oscillatoriaceae. The genera of the family Oscillatoriaceae have very typical round end trichomes in the cross section. Further, the family has been divided into two sub-families Oscillatorioideae and Homoeotrichoideae on the basis of trichome's polarity. The members of sub-family Oscillatorioideae have characteristic isopolar trichome with isomorphic ends in mature trichomes (Komárek and Anagnostidis 2005).

In nature, the growth of *Oscillatoria* may be seen in a wide range of biotopes ranging from fresh water to marine reservoirs including lakes, pond, pools, small ditches, seasonal water reservoirs, slow flowing rivers and rice fields (Figs.2A-H and 3A-F).

The present investigation is a part of the study of the Blue-green algal flora from five different polluted biotopes of Meerut, Uttar Pradesh, India under taken after a long gap of approximately five decades (1972-2021). In the present study twenty eight species of the genus *Oscillatoria* are reported from five different biotopes of Meerut, India.

Materials and methods

Study sites and sampling methods

Five sites (MST-1, MST-2, MST-3, MST-4 and MST-5) of Meerut city area were selected in the present investigation and total more than 1095 water samples alongwith visible growth of cyanoprokaryotes were collected randomly from these sites in 50 ml vials (Polylab) during May-2018 to April-2022. Details of the study area and sampling site are given in modified India maps (Fig.-1A; 1B), Burning compass map (1C) and Table-1.

Water sample analysis

Water samples collected from all the five selected sites (MST-1, MST-2, MST-3, MST-4 and MST-5) during two seasons Summer (May-June) and Winter (November-December) of each year of the study periods (May 2018-April 2022) were analyzed for physico-chemical parameters such as water colour, odour, temperature, pH, turbidity, electric conductivity (EC) and salinity with the help of Water analyzer (Systronics-371). Details of

Table-1 Showing characteristics of five different biotopes

Site Details	**Characteristics of Biotopes**				
Sampling site Code	MTS-1	MTS-2	MTS-3	MTS-4	MTS-5
Location	Maliyana, Meerut	Cantt, Meerut	Odian drain	Kali River	CCSU Campus
GPS Location	28°59’57.6”N; 77°38’51.7”E	29°00’12.2”N; 77°42’38.4”E	28°59'25.5"N 77°42'48.8"E	28°56’52.1”N; 77°45’53.4”E	28°58'03.5"N 77°44'30.6"E
Type of Water reservoir	Stagnant Water	Stagnant Water	Flowing Water	Flowing Water	Stagnant Water
Water source	House hold drains	Dairy waste drains	House hold drains	House hold drains	Water supply pipeline
Source Pollution	AW, HW, MW	AW, DW	AW,HW,IE,MW	AW,HW,IE,MW	PW
Pollutant types	O, I	O	O, I	O, I	O

AW-Animal Waste, DW-Dairy Waste, HW-Household Waste, IE-Industrial Effluents, MW-Municipal Waste, PW-Plant Waste, O-Organic, I-Inorganic

Table-2. Water characteristics of selected biotopes

Water Parameters	Water Characteristics of Biotopes									
Sampling sites Code	**MTS-1**		**MTS-2**		**MST-3**		**MTS-4**		**MTS-5**	
Sampling Seasons	**SS**	**WS**	**SS**	**WS**	**SS**	**WS**	**SS**	**WS**	**SS**	**WS**
Colour	LG	LG	DB1	DB1	DB2	DB2	DB2	DB2	CL	CL
Odour	Grassy	Grassy	Musty	Musty	Moldy	Moldy	Moldy	Moldy	Odourless	Odourless
pH	8.30	8.21	8.79	8.71	8.36	7.41	8.66	7.31	8.25	8.16
EC (µS/cm)	1.90	1.85	3.20	3.18	1.24	1.08	1.45	0.92	0.46	0.42
TDS (ppt)	1.45	1.34	2.14	2.11	1.10	0.69	1.10	0.61	0.25	0.23
Salinity (ppt)	1.55	1.50	2.45	2.40	0.95	0.60	0.90	0.60	0.31	0.29
Turbidity (NTU)	074	072	158	156	080	064	050	028	015	009
Temperature	23.5	21.9	23.3	22.9	23.1	22.6	23.3	22.6	22.1	21.9

LG=Light Green; DB1=Dusky Brown; DB2=Dark Brownish; CL=Colourless; Summer Season; Winter Season

result of water sample analysis are given in Table-2.

Enrichment culturing, isolation and purification

The samples collected from all the five different biotopes were mixed by magnetic stirrer (RQT-127A/D, Remi) and 5 ml from each samples were inoculated into the nitrogenous liquid BG-11 medium (Stanier *et al.*1971) for enrichment under controlled conditions (Temperature 28±2ºC, light-4-6K Lux, 14:10 h light: dark cycle) for seven days and their unialgal cultures were raised by repeated culturing and sub-culturing methods (Kaushik 1987, Kant *et al*. 2005).

Microscopic observations

For the study of morphological details, slides were prepared from the materials collected from nature, enriched cultures, unialgal cultures and were observed under the Research Microscope (Trinocular, Olympus, CH21i) fitted with Digital Camera (Magcam-DC10) and their morphological details were recorded.

Identification

From all the collected water samples, total 470 strains of 62 species belonging to 29 genera were isolated and identified upto the species level with the help of available monographs (Geitler 1932, Drouet 1968, Desikachary 1959, Komárek and Anagnostidis 1998, Komárek and Anagnostidis 2005, Komárek 2013) and out of which 74 strains belong to 28 species of *Oscillatoria* (Figs.4A-W and 5A-J). Identification and the morphological descriptions of all the twenty eight species of *Oscillatoria,* Oscillatoriales have been described following Komárek and Anagnostidis (2005).

Results

Results of water analysis of the samples collected from selected five biotopes of five different sampling sites are shown in Table-1 having pH range 7.31-8.71, electric conductivity range 0.42-3.18 µS/cm; Total dissolved solids were in the range of 0.23-2.11 ppt; salinity in the range of 0.2-2.4 ppt while Turbidity varied from 9 to 156 NTU; and the temperature recorded was between 21.9 and 23.5^{o}C (Table 1).

Table-3. Showing occurrence of *Oscillatoria* species in different biotopes:

Sl.No.	Species	MTS-1	MTS-2	MTS-3	MTS-4	MTS-5
1	*Oscillatoria agardhii*	-	-	+	+	-
2	*O. annae*	+	-	-	+	-
3	*O. corakiana*	+	-	-	-	-
4	*O. curviceps*	+	-	+	+	-
5	*O. fracta*	-	-	-	-	-
6	*O. jenensis*	+	-	+	+	-
7	*O. leavittae*	+	-	+	+	-
8	*O. leonardii*	+	-	-	-	-
9	*O. lutea*	+	-	+	+	-
10	*O. luteola*	+	+	-	+	-
11	*O. mitrae*	+	-	+	+	-
12	*O. limosa*	+	-	-	-	-
13	*O. nigro-viridis*	+	+	+	+	-
14	*O. princeps*	+	-	+	+	-
15	*O. proboscidea*	+	+	-	-	-
16	*O. proteus*	+	+	+	+	-
17	*O. pseudocurviceps*	-	+	-	-	-
18	*O. rupicola*	+	-	+	+	-
19	*O. salina*	+	+	-	-	-
20	*O. sancta*	+	-	-	-	+
21	*O. simplicissima*	+	-	+	+	-
22	*O. subbrevis*	+	-	-	-	+
23	*O. subsalsa*	+	+	-	-	-
24	*O. subuliformis*	+	-	+	+	-
25	*O. tenuis*	+	+	-	-	-
26	*O. ucrainica*	+	+	+	+	-
27	*O. vizagapatensis*	+	-	-	-	-
28	*O. yamadae*	+	-	+	+	-

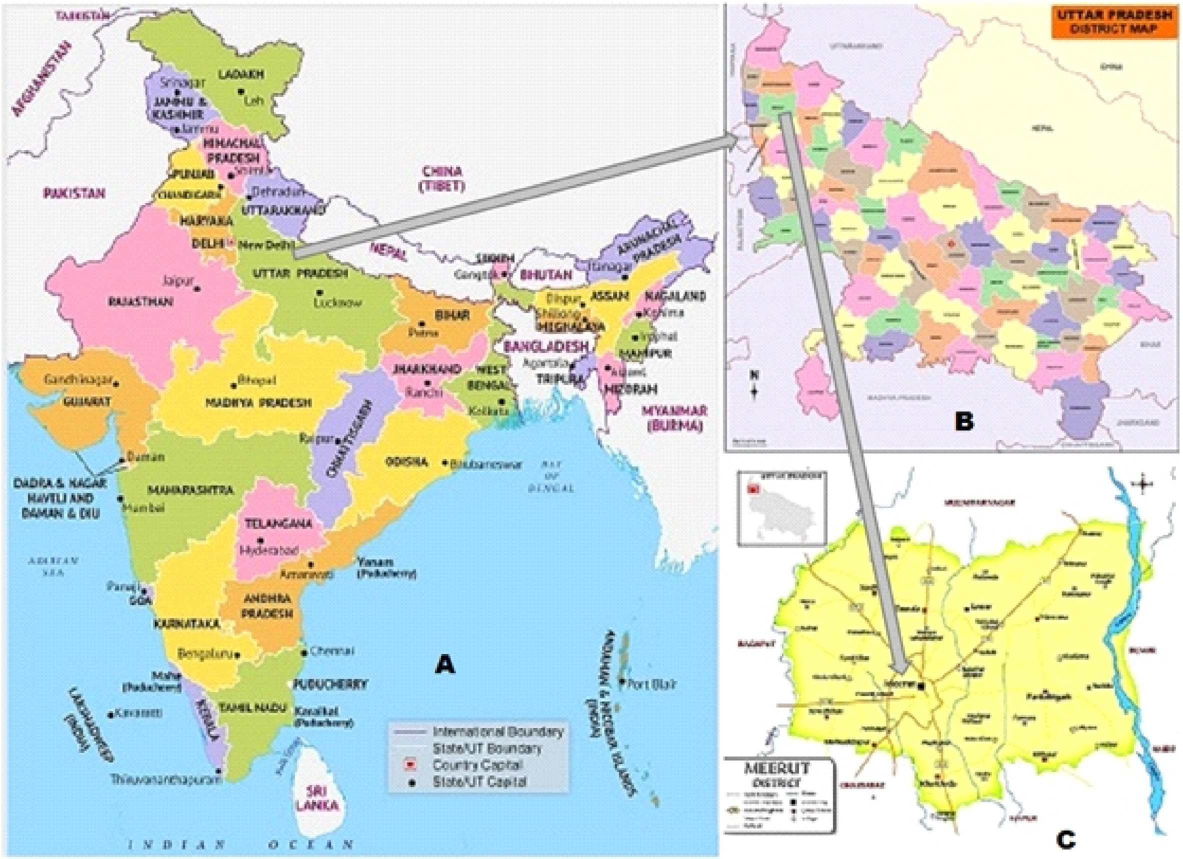

Figure-1 (A-C): Location maps. 1A-India, 1B-Uttar Pradesh; 1C-Meerut

Occurrence and distribution pattern of *Oscillatoria*

Results of microscopic analysis of collected water samples and enriched cultures revealed the occurrence of more than 470 strains of blue-green algae of three different groups *viz*., coccoid, non-heterocystous and heterocystous forms. Out of total 470 strains, 74 strains belong to twenty eight species *Oscillatoria.* Result also revealed that out of 28 species, maximum number of species (25 species) were recoreded from stagnant water reservoir (MST-1) located at Maliyana, Meerut, while minimum (02 species) were observed in the water reservoir MST-5, located near Botany Department, Chaudhary Charan Singh, University, Meerut and 16, 14, 9 speceis of *Oscillatoria* were observed in MST-4, MST-3, MST-2 reservoirs respectively. Details of occurence and distribution patterns of different species of *Oscillatoria* are shown in Table-3.

Morphological observations and taxonomic enumeration

Family: Oscillatoriaceae
Sub-family: Oscillatorioideae

1. *Oscillatoria agardhii* Gomont (Fig. 4G)
Oscillatoria agardhii Gomont; *O. agardhii* f. *aequicrassa* Elenkin; *O. agardhii* f. *moebiusii* Elenkin; *O. agardhii* f. *lemmermanii* Elenkin; *O. agardhii* f. *wislouchii* Elenkin; *O. agardhii* f. *gomontii* Elenkin

Thallus filamentous, trichomes free floating, forming a bundle or a leathery thallus, straight or somewhat curved, at the ends gradually tapering, 4-6 µm wide. Cells mostly shorter than long, quadrate, 2.5-4 µm long, granulated at the septa, with gas vacuoles. End cells convex, sometimes bluntly conical, more or less pointed, with a convex calyptra, capitate.

2. *O. annae* Van Goor (Figs. 4F & 5F)
Thallus filamentous, trichomes solitary, in fine mats or clusters, or free floating, dull blue-green 7-8 µm wide, straight, constricted at the granulated

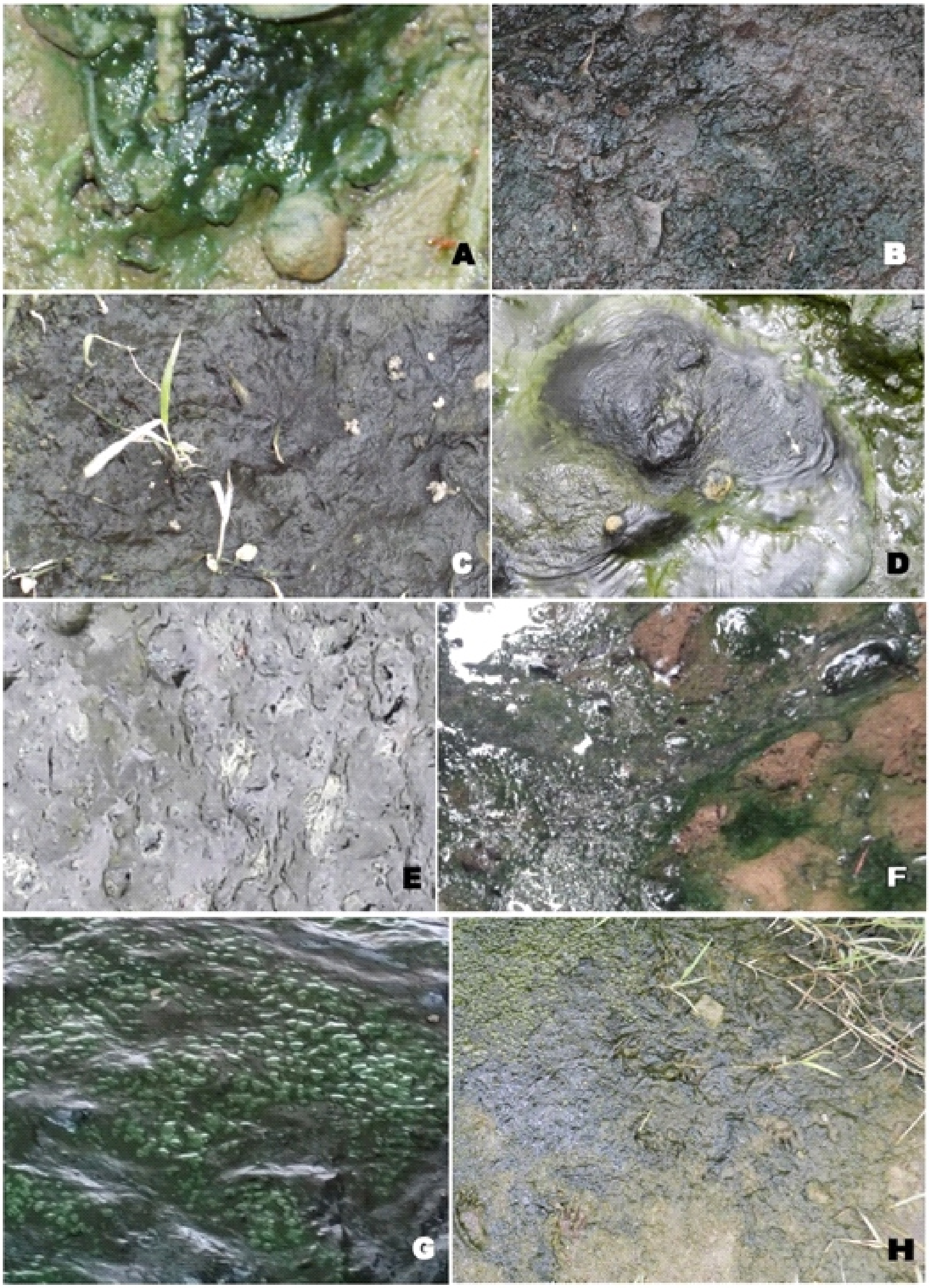

Figure-2 (A-H): Mixed **g**rowth of Blue-green algae with different species of *Oscillatoria* in nature at different polluted habitats of Meerut

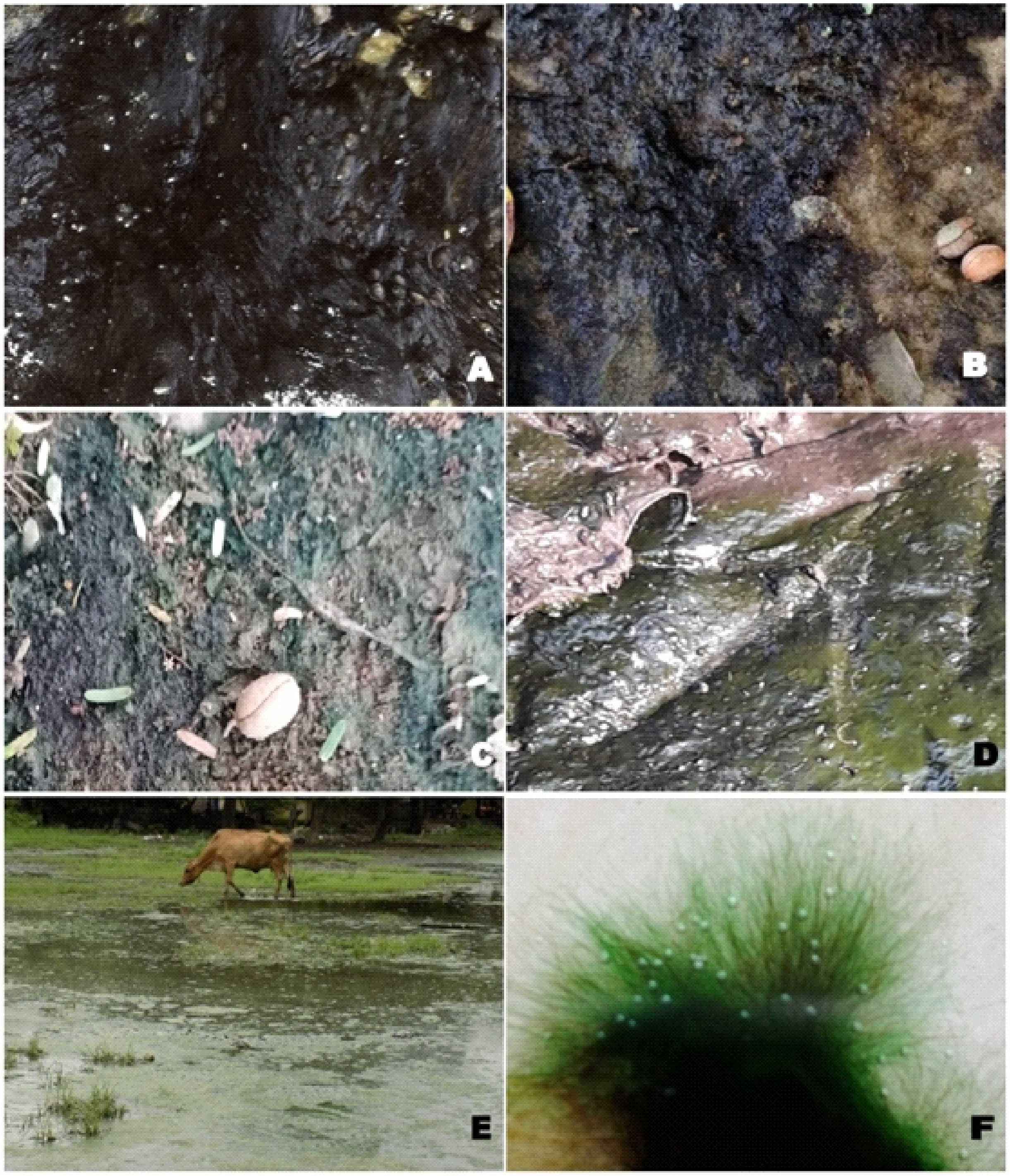

Figure-3 (A-E): Mixed **g**rowth of Blue-green algae with different species of *Oscillatoria* in nature in different polluted habitats of Meerut **A,B,C,D,E & F.** Growth and Trichomes of *O. subbrevis* in nature **G&H**

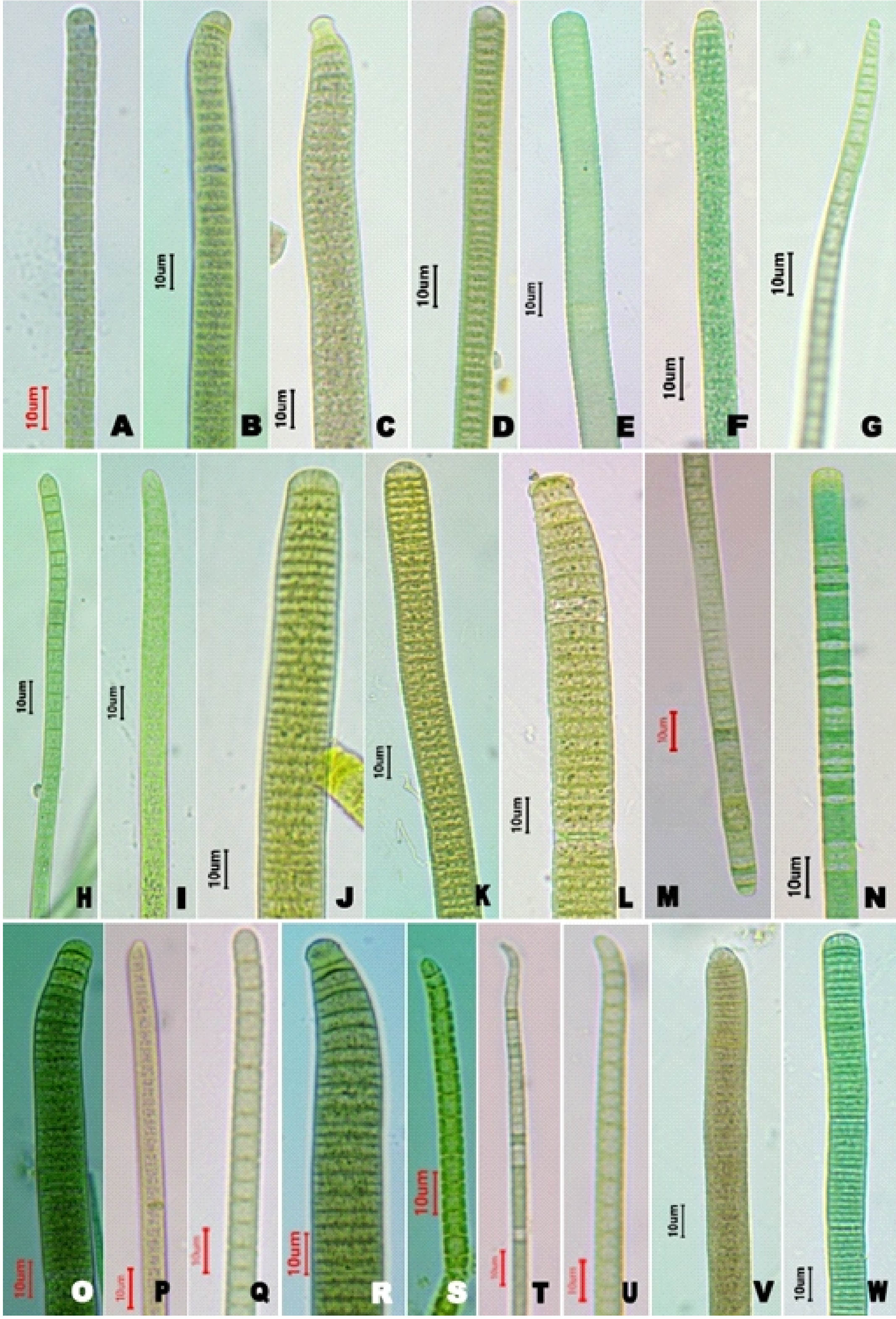

Figure-4 (A-W): Details of trichomes of different species of *Oscillatoria* **A.** *Oscillatoria tenuis* **B.** *O. leavittae* **C**.*O. proboscidea* **D**. *O. rupicola* **E.** *O. fracta* **F.** *O. annae* **G.** *O. agardhii* **H.** *O. subuliformis* **I**. *O. subsalsa* **J**. *O. limosa* **K.** *O. corakiana* **L**. *O. leonardii* **M.** *O. simplicissima* **N.** *O. subbrevis* **O**. *O. jenensis* **P**: *O. luteola* **Q.** *O. nigro-viridis* **R.** *O. princeps* **S**. *O. proteus* **T.** *O. salina* **U.** *O. ucrainica* **V.** *O. sancta* **W.** *O. curviceceps*

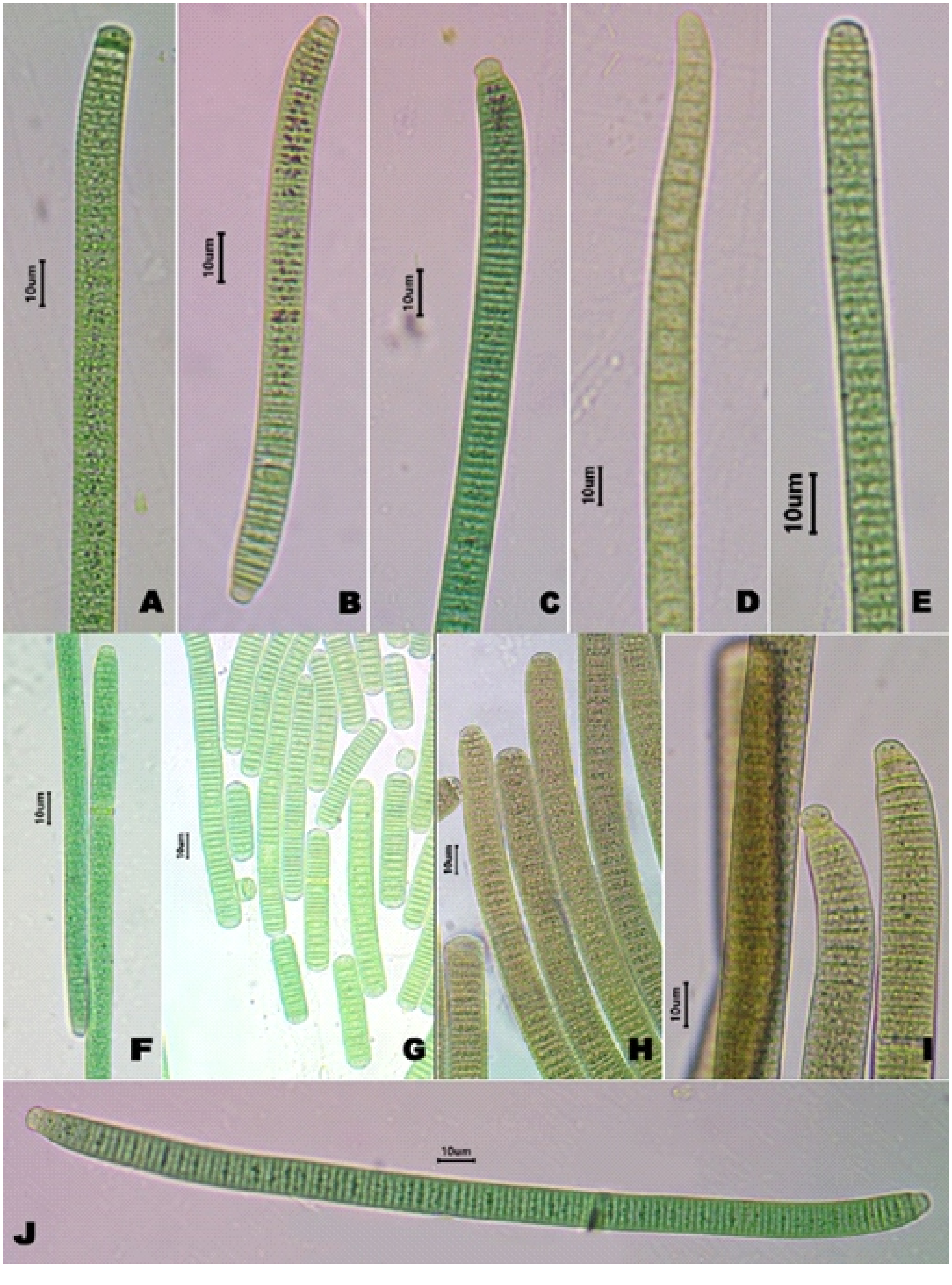

Figure-5 (A-J): Details of trichomes of different species of *Oscillatoria* **A.** *O. lutea* **B, J.** *O. yamadae* **C.** *O. mitrae* **D**. *O. pseudocurviceps* **E.** *O. vizagapatensis* **F.** *O. annae* **G**. *O. subbrevis* **H**. *O. sancta* **I.** *O. proboscidea* cross-walls, mostly slightly attenuated at the ends up to 7 µm wide and bent. Cells 7.5-8 µm wide, 1.5-3 µm long. Trichomes straight at the ends. Apical cells in well developed trichomes conically-narrowed, rounded.

3. ***O. corakiana*** Playfair (Fig. 4K)
Thallus filamentous, trichomes forming flat mats or crust, pale or greyish green, sometimes pinkish brown. Cells 11-12 µm wide, 2-4 µm long, not constricted or slightly constricted at the cross walls. Apical cells rounded.

4. ***O. curviceps*** Agardh ex Gomont (Fig. 4W)
Oscillaroria curviceps var. *angusta* Ghose
Thallus in the form of bright blue-green or blackish blue-green mats, steel-blue when dried. Trichomes blue-green, 10-17 µm wide straight, long, motile with left handed rotation. Cells 10-17 µm wide, 2-5 µm long. Apical cells flattened rounded.

5. ***O. fracta*** Carlson (Fig. 4E)
Oscillatoria simplicissima var. *antarctica* Fritsch
Trichomes straight or slightly curved, short, to 200 µm long, blue-green, not constricted at cross walls, 6-11.2 µm wide, cylindrical. Apical cells flattened-rounded.

6. ***O. leavittae*** Buell (Fig. 4B)
Colonies forming gelatinous mats or in clusters, black or red. Trichomes straight, gradually tapering towards end, greenish grey to violet, 7.5-11.5 µm wide, constricted at cross walls, with hooked or curved apex. Apical cell conical and flattened on the upper portion.

7. ***O. leonardii*** Compere (Fig. 4L)
Filamentous, trichomes solitary, 17-26 µm wide, somewhat attenuated towards ends, constricted at the cross-walls, apical cells flattened-rounded, with thickened outer cell-wall.

8. ***O. limosa*** Agardh ex Gomont (Fig. 4J)
Oscillatoria limosa f. *constricta* Biswas; *Lyngbya tenuis* var. *limosa* (Agardh) Kirchner ex Hansgirg
Thallus filamentous, light blue-green to olive-green, extended, thick, frequently layered, attached to the substrate. Trichomes solitary, free-floating forming tufts at the water level, dark to bright blue-green, brown-violet or olive-green, 10-22 µm wide, generally long up to 4 mm, straight, rarely weakly curved, remarkably with thin colourless sheaths, not constricted at the often granulated cross walls, motile with slow gliding and oscillation, with left handed rotation. Cells 10-22 µm wide and 1.5-6 µm long, cell content mostly finely granular. Apical cells flat-rounded or obtuse rounded, convex, mostly with slightly thickened outer cell wall.

9. ***O. lutea*** Agardh ex Gomont (Fig. 5A)
Thallus filamentous, trichomes in small clusters mixed with other algae, yellowish blue-green, 6-9 µm wide, constricted and not granulated at cross-walls, not tapered towards ends. Cells frequently much wider than long; apical cells flattened-rounded, with outer cell walls slightly thickened.

10. ***O. luteola*** Drouet (Fig. 4P)
Thallus thin, membranaceous, sheath absent, trichomes yellow-green, straight, 3-5 µm wide, constricted at cross-walls. Cells 1.5-5.5 µm long, isodiametric or shorter than wide, apical cells obtuse-conical, sometimes slightly asymmetrical, and rounded.

11. ***O. jenensis*** Schmid (Fig. 4O)
Oscillatoria curviceps var. *violascens* Schmid
Thallus forming dark brown or dirty blue-green mats. Trichomes without sheaths grey-brown, olive-green to greyish blue-green 14-33µm wide, 3-7µm long, straight, motile with right handed rotation, shortly attenuated at the ends with hook like bent, 7-14 µm wide near the ends. Apical cells convex, widely-rounded or somewhat conical-rounded.

12. ***O. mitrae*** Kamat (Fig. 5C)
Thallus forming olive green, gelatinous mats. Trichomes long, tapering towards ends and slightly curved. Cells 12-20 µm wide, not constricted at cross walls. Apical cell capitate without calyptra.

13. ***O. nigro-viridis*** Thwaites in Harvey (Fig. 4Q)
Thallus filamentous, olive-green to bright blue-green, prostrate. Trichomes olive green, slightly wavy, constricted and granular at cross- walls, 7-13 µm wide, somewhat narrowed at the ends. Cells shorter than wide, 2-6 µm long with granular content. Apical cells conical-rounded, without calyptras, with slightly thickened outer cell walls.

14. ***O. princeps*** Vaucher ex Gomont (Fig. 4R)
Oscillatoria princeps var. *pseudolimosa* Ghose; *O. princeps* f. *violacea* Frémy; *O. princeps* var. *pallida*

Copeland; *O. princeps* var. *tenella* Copeland; *O. princeps* f. *recta* Elenkin; *Lyngbya princeps* (Vaucher) ex Hansgirg

Thallus filamentous, dark blue-green, thin, expanded, attached, forming layered mats or small clusters of filaments or free-floating. Trichomes olive-green, 18-50 µm wide, predominantly straight or slightly curved, firm, very long, motile with left-handed rotation and simultaneous fast gliding, not constricted at the ungranulated cross-walls, slightly attenuated at the ends, bent and nearly truncate, subcapitate. Cells discoid, short, 18-50 µm wide, 2-8.7µm long; cell content mostly finely granular. Apical cells rounded, hemispherical, depressed-hemispherical or truncate, with slightly thickened cell wall, without calyptra.

15. *O. proboscidea* Gomont ex Gomont (Figs. 4C & 5I)
Oscillatoria proboscidea var. *westii* Forti; *O. proboscidea* f. *westii* Poljanskij; *O. proboscidea* f. *fusca* Schwabe; *O. proboscidea* f. *taiwanensis* Schwabe; *O. proboscidea* f. *hoshiarpurensis* Vasishta
Thallus filamentous, membranaceous, thin to thick, elastic, dark-green to blackish blue-green, trichomes solitary or mixed with other cyanoprokaryotes. Trichomes bright blue-green, rarely olive-green to violet-brown, 9-23 µm wide, straight, often irregularly screw-like coiled, rarely with thin, colourless sheaths, motile, with left handed rotation, distinctly attenuated, slightly curved or sometimes screw-like coiled at the ends, capitate. Cells 9-23 µm wide, 2-4 µm long. Apical cells flat, rounded hemispherical, with slightly thickened outer cell wall.

16. *O. proteus* Skuja sensu Senna (Fig. 4S)
Filaments solitary, among other algae, straight, trichomes mostly short, pale olive-green or blue-green, 5-7.5 µm wide, constricted at cross-walls, briefly attenuated and slightly bent at the ends, apical cell hemispherical to conical-rounded, without thickened cell wall. Cells 2.5-4 µm long.

17. *O. pseudocurviceps* Welsh (Fig.5D)
Thallus dark blue-green or olive green forming gelatinous fine mats. Trichomes solitary, straight, 12-15 µm wide, not constricted at cross walls, slightly attenuated towards ends. Apical cells conical rounded.

18. *O. rupicola* Hansgirg (Fig. 4D)
Lyngbya rupicola Hansgirg; *Oscillatoria rupicola* var. *phormidioides* (Hansgirg) Hansgirg ex Forti
Thallus in small clusters, mats or fasciculate. Trichomes solitary, 4-9 µm wide, olive-green or blue-green rarely with fine sheaths. Trichomes straight or slightly curved with straightened ends. Cells shorter than wide 1.2-3 µm long. Apical cells widely rounded.

19. *O. salina* Biswas (Fig. 4T)
Thallus membranaceous, blue-green, trichomes straight, 3-5 µm wide, not constricted at cross-walls, cells up to 2µm long; trichomes ends attenuated, apical cells elongated, hyaline, arcuated and pointed.

20. *O. sancta* Kutzing ex Gomont (Figs. 4V and 5H)
Lyngbya sancta (Kützing) ex Hansgirg
Thallus filamentous, brownish blue-green, thin, glowing, mucilaginous. Trichomes brownish blue green, 9–12 µm wide, very long straight or slightly curved, sometimes (rarely) with thin sheaths, usually distinctly, sometimes somewhat constricted at the granulated cross-walls, not attenuated or little attenuated at the ends, motile, with left-handed rotation. Cells discoid, 9–12µm wide, 1.5–6µm long. Apical cells hemispherical or flattened, slightly capitates to wart-like with thickened calyptroid outer cell wall.

21. *O. simplicissima* Gomont (Fig. 4M)
Thallus in form of flat mats, blackish blue-green. Trichomes straight, yellowish blue-green, grey-green to intense blue-green, not constricted at cross-walls, cylindrical, 7-9µm wide. Trichome ends straight, not attenuated. Cells 2-4µm long, finely homogeneously granulated, without prominent granulation at cross-walls. Terminal cells rounded.

22. *O. subbrevis* Schmidle (Figs. 4N and 5G)
Oscillatoria subbrevis f. *major* G. S. West
Trichomes solitary, yellow-grey to green yellowish. Filaments 3.9-12µm wide, usually straight, occasionally arched, sometimes constricted at ungranulated cross walls, Cells shorter than wide, discoid, 1-2.5µm long. Apical cells rounded, without calyptra.

23. *O. subsalsa* Agardh ex Forti (Fig. 4I)
Thallus dark blue-green; trichomes straight or lightly or irregularly spirally coiled, slightly constricted at the constricted at the cross-walls, attenuated at the apex, and somewhat bent, 8-13 µm broad, blue-green; cells 8-13 µm, rarely as long as broad, 3.6-8 µm long, septa not granulated, end cells obtuse, not capitates, without calyptra.

24. *O. subuliformis* Kützing ex Gomont (Fig. 2H)
Thallus filamentous, light blue-green, trichomes yellow-green, very long, flexuous and bent, 4.7-6.5 µm wide, gradually attenuated at the ends and bent. Cells nearly quadrate, 4.7-6.5 µm long, at the ends up to 10 µm long, obtuse.

25. *O. tenuis* Agardh ex Gomont (Fig. 4A)
Oscillatoria tenuis var. *natans* Gomont; *O. tenuis* var. *asiatica* Wille; *O. tenuis* var. *levis* Gardner
Thallus filamentous, flat, forming mats or clusters, blue-green or olive green, usually thin, mucilaginous. Trichomes straight or somewhat irregularly curved, blue-green or greyish violet 4-11 µm wide, cylindrical, not attenuated, rarely slightly curved at the ends. Cells wider than long, 2-4.8 µm long, rarely with scattered solitary granules. Apical cells rounded, not capitate, with slightly thickened outer cell wall in well developed trichomes.

26. *O. ucrainica* Vladimirova (Fig. 4U)
Trichomes solitary, straight or curved, indistinctly constricted at cross-walls; sometimes hooked at the ends, 75-1200µm long. Cells 3-5.5µm wide, slightly attenuated at the ends, cells longer than wide, 4.5-9 µm long, apical cells conical-rounded, sometimes very narrowed and elongated.

27. *O. vizagapatensis* Rao (Fig.5E)
Thallus stratified, forming blue-green flat mats. Trichomes pale blue-green, straight or bent. Cells 8-10 µm wide not constricted at cross walls. Apical cells hyaline, rounded with slightly thickened outer call wall or calyptra.

28.*O. yamadae* Kamat (Figs. 5B & 5J)
Thallus blue-green forming fine gelatinous mats. Trichomes long, 9.5-11 µm wide, not constricted at cross walls. Cells 2-4 µm long, with slight tapering towards ends. Apical cells capitate, without calyptra.

Discussion

The cyanoprokaryotes have become more interesting and fascinating group of microbes because of their nitrogen fixing ability and being source many biotechnology important molecules (Pearson 1926, De 1939, Stewart *et al.* 1968, Castenholz 1968, Baker and Bold 1970, Roger 1991, Roger and Kulasooria 1980, Spiller and Gunasekaran 1990, Yamaguchi 1997, Whitton and Potts 2000, Boone and Castenholz 2001, McGregor 2007, Bohunicka *et al*. 2011, Martins and Branco 2016, Muhlsteinova *et al*. 2018, Saraf *et al*. 2019, Zimba *et al*. 2017, 2020, 2021, Hauerová *et al*. 2021 Komárek 2020, Hauerová *et al*. 2021). Some potential species of few genera of blue-green algae namely *Aphanothece*, *Arthrospira*, *Spirulina*, *Aulosira, Nostoc* etc. are being cultivated at commercial level and contributing significantly in the economy of many countries (Chensong *et al*. 2018).

In India, the blue-green algae have been studied in quite detail by a large number of Indian phycologists including Mitra (1951), Desikachary (1959), Pandey and Mitra (1965), Vashishta (1965), Singh and Chaturvedi (1970), Kamat (1972), Tiwari (1972), Grover and Pandhol (1975), Sinha and Mukharjee (1975), Tiwari and Pandey (1976), Dabral *et al*. (1978), Singh and Bisoyi (1989), Prasad and Mehrotra (1980), Pandey and Chaturvedi (1979), Prasad and Srivastava (1985), Pandey and Tripathi (1988), Anand (1989), Santra and Pal (1991), Prasad and Misra (1992), Santra (1993), Tiwari *et al*. (2000), Hazarika *et al*. (2002), Kant *et al.* (2006), Mishra and Srivastava (2005), Dhingra and Ahluwalia (2007), Tiwari *et al*. (2013), Mishra *et al*. (2008), Kant *et al*. (2020a-b; 2021) and Sarma *et al*. (2020), but cyanobacterial flora of Meerut has not been studied although reports of Kumar (1970) and Bendre and Kumar (1975) are available.

The genus *Oscillatoria* Vaucher *ex* Gomont (Gomont 1892) is a very common filamentous cyanoprokaryote without heterocysts. The trichomes of *Oscillatoria* are straight and slightly irregularly undulating, cylindrical with a very big range of cells size particularly width ranging 5 -70 µm. The trichomes of the genus *Oscillatoria* exhibit oscillatory movement (Halfen and Castenholz 2008). The movement of trichomes of

Oscillatoria may be influence by the environmental factors including light, temperature, water and nutrients (Gupta and Agrawal 2006). The cells of the genus *Oscillatoria* are always shorter than width and similar to disc like structures. Sheath normally absent, but it may be observed occasionally under stress conditions (Komárek and Anagnostidis 2005). The cells divide quickly and transverse to the axis of trichomes. Trichomes fragmentation is the very common method of reproduction and as a result 2-6 celled, short, motile hormogonia are produced. The genus *Oscillatoria* is represented by taxonomically recognized total 306 species globally in Aglaebase (Guiry and Guiry 2021)

The growth of *Oscillatoria* can be frequently encountered in nature after 3-4 days of heavy rain during rainy seasons in almost all types of biotopes but for rest of seasons their growth may be restricted to pools, ponds, lakes, slow flowing rivers, drains and irrigation water channels. Although in India, the genus *Oscillatoria* has been explored by many phycologists (Kesarwani *et al.* 2015a-b, Sikdar and Keshri 2014, Halder 2017, Kant *et al*. 2021) from a quite large number of habitats covering different parts of the country but most of them did not correlate with the occurrence of different species of *Oscillatoria* in a particular niche with factors responsible for their growth in specific biotopes.

In India, the genus *Oscillatoria* is represented by 208 taxa (Tiwari *et al*. 2007). In addition, some of the surveyed states of India including Assam (Deka and Sarma, 2011), Arunachal Pradesh (Mikter *et al*. 2006), Bihar (Kumar and Choudhary 2009), Kerala (Senthil *et al*. 2012), Madhya Pradesh (Singh and Samdariya, 2006), Maharashtra (Kumawat and Jawale 2006, Bhosale *et al*. 2012), Manipur (Bharadwaja 1963), Orissa (Dash *et al*. 2011), Tamil Nadu (Subramaniyan *et al*. 2012), Tripura (Kant *et al*. 2021), Uttar Pradesh (Tiwari and Chauhan 2006, Kesarwani *et al.* 2015a-b), West Bengal (Sikdar and Keshri 2014) etc. but most of them did not make a comparative study of different biotopes and they only reported floristic diversity.

Tiwari *et al*. (2004), Kesarwani *et al*. (2015b) studied *Oscillatoria* in detail from U.P. but their study was restricted to few habitats of approximately one dozen districts of U.P. Kesarwani *et al.* (2015a-b) reported the occurrence of thirty species of *Oscillatoria* from U.P., India with ten species occurring in U.P., India. Tiwari and Chauhan (2006) made a comparative study on the occurrence of *Oscillatoria* from polluted ponds of Agra (U.P.) and reported the occurrence of thirty two species. Although, they correlated the various factors with the occurrence of different species of *Oscillatoria* but they studied only monotypic habitats, thus their study did not cover different types of biotopes for comparative account.

Sikdar and Keshri (2014) studied the blue-green algal flora of West Bengal and reported total sixteen taxa of *Oscillatoria* from W.B. and in their study. They also revealed that fives species namely *O. simplicissima, O. princeps, O. subbrevis, O. sancta* and *O. tenuis* are most common species of unpolluted habitats, while *O. limosa* is common in polluted habitats.

Kumar (1970) worked on blue-green algae of Sardhana and adjoining areas of Meerut (U.P.), India and reported total 106 species of 22 genera, out of which 26 taxa including 25 species and one variety was of *Oscillatoria*. Further, Bendre and Kumar (1975) did floristic survey and reported 131 taxa of blue-green algae from Meerut and adjoining areas, out of which 39 species were of *Oscillatoria* and with only two species i.e. *O. santa* and *O. subuliformis* reported from Kali river. But at present most of the species of *Oscillatoria* reported by Kumar (1970) and Bendre and Kumar (1975) have been shifted to other genera of the Oscillatoriales (Komárek and Anagnostidis 2005). In present investigation, we are reporting twenty eight species of *Oscillatoria* from five different types of polluted water reservoirs from Meerut, India.

On comparison of observations on occurrence and distribution pattern of different species of *Oscillatoria* in five different biotopes, it is observed that a number of factors like pH, EC, salinity etc. sevearly affect the occurence and distribution pattern of *Oscillatoria* in different biotops. Out of total 28 species, 25 species occured in stagnant water reservoir (MST-1) located at Maliyana, Meerut, while minimum 02 species were observed in the water reservoir (MST-5) located in Chaudhary Charan Singh, University, Meerut and speceis of *Oscillatoria* were observed 16, 14, 9 in MST-4, MST-3, MST-2 reservoirs respectively.

The occurence of more species of *Oscillatoria* in MST-1 may be to due to heavy load of pollutants as indicated by results of physico-chemical parameters of water samples analysis and occurence of less number of species of *Oscillatoria* in MST-5 may be because of small area of water reservoir in comparison to site MST-2. However, presence of 16th and 14th species of *Oscillatoria* in MST-4, and MST-3 respectively may be because of presence of high amount of toxic metals, inorganic and organic waste discharged by different industries and municipal corporation in flowing water streams (Singh *et al*. 2020) and while occurrence of 9 species in MST-2 may be because of high pH, salinity and turbidity of the stagnent water reservoir, as the source of water is waste released by domestic animals.

Conclusions

Although most of the part of the Indian sub continent have been explored thoroughly for the diversity of native Indian blue-green algae, but still there is an ample scope for phycologists to investigate and explore the diversity of useful blue-green algal strains from unexplored biotopes of India for their commercial exploitation for different purposes.

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