TAXONOMIC INVESTIGATION OF EUPLANKTONIC DIATOM COMMUNITIES AS INDICATOR OF COPPER IN THE BANK OF THE SUBARNAREKHA RIVER, GHATSHILA, JHARKHAND, INDIA

Gour Gopal Satpati*, Rahul Bose†, Ruma Pal‡

Address(es):*1 Department of Botany, Bangabasi Evening College, University of Calcutta, 19 Rajkumar Chakraborty Sarani, Kolkata 700009, West Bengal, India.
‡Phyology Laboratory, Department of Botany, University of Calcutta, 35 Ballygunge Circular Road, Kolkata 700019, West Bengal, India.

*Corresponding author: gour_satpati@yahoo.co.in

ABSTRACT

The aim of this study was to determine and evaluate the diatom communities in the copper infected areas readily associated with the Hindustan Copper Limited (HCL) at the bank of the Subarnarekha River. This study was based on three sampling sites commonly designated as high copper (>100 μg.L⁻¹), medium copper (≤100 μg.L⁻¹) and low copper (≤50 μg.L⁻¹) contaminated area. Results indicated the detailed taxonomic description of 31 species that are dominant or less dominant over these contaminated area. Among the identified taxa, 10 were recorded as new to the Jharkhand state. Water analysis has suggested the presence of 17 species in the high copper contaminated area adjacent to HCL. Nine species was less dominant in the outlet of HCL that belonged to the medium contaminated and only 5 species were dominant over the low copper contaminated area. Physico-chemical parameters like pH, air and water temperature, salinity, conductivity, light extinction coefficient, turbidity, dissolved inorganic salts, dissolved oxygen and carbon-di-oxide, biological oxygen demand and total hardness were also estimated in the surrounding aquatic habitats. Cu mining wastes flow directly into the river without any treatment, resulting in significant growth of diatom and other planktonic organisms. The sampling sites were chosen on the basis of high, medium and low Cu contamination. Diatom assemblages of these sites were identified and described in detail in relation to abundance. The dominant species from the three different sampling stations were marked on the basis of abundance. Physico-chemical parameters like nitrate, phosphate, silicate, sulphate, calcium, dissolved oxygen (DO), biological oxygen demand (BOD), conductivity, salinity and pH were also recorded in the present study.

The objective of this study was to determine the diversity of diatom flora as indicator of Cu in the adjoining water bodies of HCL and Subarnarekha River. In addition, the abundance of the diatom species in terms of low, medium and high Cu accumulation were also examined. The detailed taxonomic description suggests the proper identification of the euplanktonic diatoms as pollution indicator in aquatic ecosystems. The biochemical assessment of the water has also determined the water quality in the adjacent water bodies of HCL and Ghatshila.

INTRODUCTION

Bioaccumulation is a well-known method of phytoremediation, which binds the toxic chemicals or metals and accumulates it in their biological systems especially in cellular structures. The process is widely used to encourage the remediation of heavy metals from the aquatic ecosystems. It also has the potential towards wastewater treatment. Metal toxicity in aquatic ecosystems is commonly triggered by anthropogenic activities including domestic and industrial wastewater, agricultural runoff and dumping of toxic chemicals, e-waste and others (Satpati, 2021). The deposition of toxic elements or trace metals in the aquatic bodies resulting in severe environmental impacts including contamination of surface and ground water and increasing the rate of biomagnification (Sibli et al., 2014; Satpati, 2021). Trace metals like copper (Cu) is a well known aquatic pollutant for its adverse affects on phytoplanktons, especially diatoms (Absil, Kroon & Wolterbeek, 1994). The heavy presence of Cu in the aquatic food chains may be hazardous to the associated living organisms and to the environment (Nor, 1987). Aquatic living systems may scavenge the trace metals from the water column as well as from the bottom sediments or from both. Recently, algae have served as the most potential aquatic living system or bioindicator for accumulating toxic metals (Pandey et al., 2011). Diatoms belong to the group of Bacillariophyta (Guiry in Guiry & Guiry, 2021, AlgaeBase), which are frequently used as bioindicators for heavy metals in aquatic bodies. They are unicellular having silicified cell wall. The cell wall consists of two valves held together by a band of girdle. Most of the studies have been done so far on taxonomic documentation. In India, there are many reports on the freshwater diatom flora with detailed taxonomic account (Gandhi, 1959, 1967; Bhakta et al., 2011; Das & Adhikary, 2012; Dwivedi & Misra, 2015; Bhakta, Das & Adhikary, 2016; Bose, Bar & Pal, 2017). Only few reports on the metal toxicity in diatoms are available. Pandey et al. (2014) have studied the morphological changes of few diatoms exposed to Cu, lead (Pb) and zinc (Zn). Modification of raphe was found more frequent in Fragilaria capucina, Gomphonema parvulum, Nitzschia palea, Pinnavulara conica and Ulnaria ulna. As diatoms are planktonic, they remain in the open water systems rather in the sediment (Cattaneo et al., 2011). Diatoms are ecologically diverse from centric to pennate form and found in almost all microhabitats in the aquatic ecosystems (Arguelles, 2019). Diatom assemblages can be formed in the open water systems of rivers, lakes and canals (euplanktons), they may be associated with plants (epiphytic), they may be found in the sand (epipsammon), or mud (epipelon) and even in animals (epizoic). (Dixit et al., 1992; Satpati et al., 2017; Arguelles, 2020).

In the present research, the work has been carried out on the taxonomic investigation of some euplanktonic diatoms, which frequently dominate over the Cu mining area. Hindustan Copper Limited (HCL), situated at the bank of the Subarnarekha River of Ghatshila is the biggest source of Cu discharge in the surrounding aquatic habitats. Cu mining wastes flow directly into the river without any treatment, resulting in significant growth of diatoms and other planktonic organisms. The sampling sites were chosen on the basis of high, medium and low Cu contamination. Diatom assemblages of these sites were identified and described in detail in relation to abundance. The dominant species from the three different sampling stations were marked on the basis of abundance. Physico-chemical parameters like nitrate, phosphate, silicate, sulphate, calcium, dissolved oxygen (DO), biological oxygen demand (BOD), conductivity, salinity and pH were also recorded in the present study.

The objective of this study was to determine the diversity of diatom flora as indicator of Cu in the adjoining water bodies of HCL and Subarnarekha River. In addition, the abundance of the diatom species in terms of low, medium and high Cu accumulation were also examined. The detailed taxonomic description suggests the proper identification of the euplanktonic diatoms as pollution indicator in aquatic ecosystems. The biochemical assessment of the water has also determined the water quality in the adjacent water bodies of HCL and Ghatshila.

MATERIAL AND METHODS

Sampling sites

For the collection of diatom and water samples, four sites were chosen: canal adjacent to HCL, outlets of HCL, poured into the Subarnarekha River and the
river itself commonly designated as Station 1 (22.5954° N, 86.4519° E), Station 2 (22.5962° N, 86.4522° E) and Station 3 (21.3325° N, 87.2341° E) respectively. All sampling stations are situated in Ghatshila, Jharkhand (Figure 1).

Figure 1 Google satellite image showing three sampling stations (https://www.google.com/maps/search/ghatshila, hindustan+copper+limited/@2.5911511,86.4454325,4927m/data=!3m1!1e3). (2014), station 3. Electrical conductivity and light extinction coefficient was significantly decreased in the order station 3>station 2>station 1. Highest conductivity recorded in Subarnarekha River was 560.33 μS.cm⁻¹. Total hardness varied from 260.33 in station 1 to 180.35 in station 3. Salinity was recorded highest (10 ppt) in station 1 and lowest (6 ppt) in station 3. Comparatively DO was highest in station 3 with 3.42 mg.L⁻¹ and lowest in station 1 with 2.21 mg.L⁻¹. However, station 1 recorded highest amount of dissolved CO₂ and BOD instead of station 2 and 3. Interestingly nitrate, sulphate and silicate level in the water was high in station 1, which was highly polluted and found adjacent to HCL. Phosphate level in the water of Subarnarekha River was recorded highest (0.84 mg.L⁻¹) and lowest (0.57 mg.L⁻¹) in the outlet of HCL poured directly into the river. Relatively the concentration of the calcium was high in station 3 and low in station 1. Accumulation of Cu in the water body was recorded highest in station 1 (400 μg.L⁻¹) and lowest in station 3 (47.87 μg.L⁻¹).

Diatom collection and preservation

The copper containing sites associated to Subarnarekha River was investigated in March 2018. The diatom sample was collected through the phytoplankton net of mesh size 25 μm (Satpati & Pal, 2017). After collection, the turbid sample was brought to the laboratory and centrifuged at 10000 rpm for 10 minutes. The pellet thus collected was preserved in 4% (v/v) formalin for the microscopic study. All the preserved materials were assigned to Calcutta University Herbarium (CUH) voucher specimens.

Water analyses

Water samples were collected in triplicates at the depth of 0.5 m. The physico-chemical parameters were determined with the help of the filtrate obtained from the water samples. All parameters like pH, temperature, electrical conductivity, total hardness, light extinction coefficient, BOD, salinity, nitrate, phosphate, silicate, sulphate and calcium were analyzed using the standard methods of APHA, (APHA, 1998). Salinity, pH and temperature were recorded immediately after sampling with ERMA Refractometer (ERMA, Tokyo), Beckman potentiometer zeromatic II and centigrade thermometer respectively. DO content in water sample was estimated in situ following Winkler’s iodometric titration method (Winkler, 1885).

Light Microscopy and Identification

For light microscopy study, slides were prepared with 20% glycerin (v/v) and photographs were taken under Carl Zeiss Axiostar Plus Microscope by Cannon Power Shot 500D Camera with a coupled micrometer eyepiece (et al. 2012, 2013; Satpati & Pal, 2016). The identification of the species was done using the literature of Hendey (1974), Aboal et al. (2003), Levkov (2009), Wang et al. (2014), Steppeak & Kociolkew (2018) etc. The classification system was based on the recent up gradation given in AlgaeBase (Guiry in Guiry & Guiry, 2021).

Copper accumulated in water samples were analyzed using an ICP 2070 Spektrophotometer (Baired, USA) and AAS using a Varian Spect AA10 apparatus with Graphite Tube Atomizer GTA-95 (Victoria, Australia). The measurement accuracy was checked by the reference of Chenglewski & Medved (2001).

RESULTS

Water analyses

Water analysis report is demonstrated in table 1. During the study, all the sampling stations showed a static air temperature but slightly varied in water temperature. Water temperature was recorded minimum in station 1 with 28.35°C whereas highest in Subarnarekha River (station 3) with 30.33°C. pH ranges from slightly acidic (below 7.0) to slightly alkaline (above 7.0). The water pH of the canal adjacent to HCL (station 1) was recorded 6.8. However pH was recorded highest (7.3) in Subarnarekha River. High turbid condition of the water was noticed in station 1 followed by station 2 and 3. Electrical conductivity and light extinction coefficient was significantly decreased in the order station 3>station 2>station 1. Highest conductivity recorded in Subarnarekha River was 560.33 μS.cm⁻¹. Total hardness varied from 260.33 in station 1 to 180.35 in station 3. Salinity was recorded highest (10 ppt) in station 1 and lowest (6 ppt) in station 3. Comparatively DO was highest in station 3 with 3.42 mg.L⁻¹ and lowest in station 1 with 2.21 mg.L⁻¹. However, station 1 recorded highest amount of dissolved CO₂ and BOD instead of station 2 and 3. Interestingly nitrate, sulphate and silicate level in the water was high in station 1, which was highly polluted and found adjacent to HCL. Phosphate level in the water of Subarnarekha River was recorded highest (0.84 mg.L⁻¹) and lowest (0.57 mg.L⁻¹) in the outlet of HCL poured directly into the river. Relatively the concentration of the calcium was high in station 3 and low in station 1. Accumulation of Cu in the water body was recorded highest in station 1 (400 μg.L⁻¹) and lowest in station 3 (47.87 μg.L⁻¹).

Table 1 Geophysical and physico-chemical parameters of the Cu contaminated sites

| Geophysical parameters | Station 1 (High Cu, (100 μg.L⁻¹)) | Station 2 (Medium Cu, (100 μg.L⁻¹)) | Station 3 (Low Cu, (50 μg.L⁻¹)) |
|------------------------|-----------------------------------|-----------------------------------|--------------------------------|
| Coordinates            | 22.5954° N, 86.4519° E           | 22.5962° N, 86.4522° E           | 21.3325° N, 87.2341° E        |
| pH                     | 6.8                              | 7.1                              | 7.3                            |
| Air temperature (°C)   | 32.33                            | 32.12                            | 32.32                          |
| Water temperature (°C) | 28.35                            | 29.16                            | 30.33                          |
| Turbidity (NTU)        | 32.22                            | 26.33                            | 24.21                          |
| Electrical conductivity (μS.cm⁻¹) | 485.31                        | 520.22                           | 560.33                         |
| Light extinction coefficient (m) | 1.39                            | 1.42                             | 1.46                           |
| Total hardness         | 260.33                           | 220.22                           | 180.35                         |
| Salinity (ppt)         | 10                               | 8                                | 6                              |
| Dissolved oxygen (mg.L⁻¹) | 2.21                            | 2.32                             | 3.42                           |
| Dissolved CO₂ (mg.L⁻¹) | 10.22                            | 8.73                             | 7.54                           |
| Biological oxygen demand (mg.L⁻¹) | 8.83                           | 7.43                             | 4.45                           |
| Nitrate (mg.L⁻¹)       | 1.83                             | 1.74                             | 0.89                           |
| Phosphate (mg.L⁻¹)     | 0.76                             | 0.57                             | 0.84                           |
| Sulphate (mg.L⁻¹)      | 62.32                            | 54.48                            | 45.22                          |
| Silicate (mg.L⁻¹)      | 74.44                            | 63.22                            | 51.51                          |
| Calcium (mg.L⁻¹)       | 10.42                            | 12.55                            | 14.75                          |
| Copper (μg.L⁻¹)        | 400                              | 94.62                            | 47.87                          |
Taxonomic description
Phylum: Bacillariophyta
Subphylum: Bacillariophytina
Class: Bacillariophyceae
Subclass: Bacillariophycidae
Order: Naviculales
Suborder: Neidinae
Family: Diadesmidaceae
Genus: Diadesmis

1. Diadesmis confervacea Kützing [Figures 2a-b]
   Aponte, Maidana & Lange-Bertalot, 2005; Slate & Stevenson, 2007; Misroe et al., 2016; Li & Qi, 2018
   Frustules are 2-4 times longer than broad, 10-30 μm long and 5-8 μm broad, rectangular in girdle view, frustules attached side by side to form ribbon shaped colony; striae not distinct under compound microscope.
   Voucher no.: CUH/PLANK/DIA-29/1
   Family: Neidinae
   Genus: Neidium

2. Neidium affine var. amphirhynchus (Ehrenberg) Cleve [Figure 2c]
   Hustedt, 1930; Patrick & Reimer, 1966; Eberle, 2008
   Navicula amphirhynchus Ehrenberg
   Valves 7-8 times longer than broad, 50-70 μm long and 7-10 μm broad, lanceolate with wide central area with rounded apices.
   Voucher no.: CUH/PLANK/DIA-29/2

Table 2: List of Cu indicating diatoms in three distinct sites (+++ Most dominant, >70% of the population; ++ Dominant, 40-70% of the population; + Less dominant, <40% of the population; - Absent, No species found)

| Name of the taxa                                      | Station 1-High Cu (>100 μg L⁻¹) | Station 2-Medium Cu (≤100 μg L⁻¹) | Station 3-Low Cu (≤50 μg L⁻¹) |
|------------------------------------------------------|---------------------------------|----------------------------------|-----------------------------|
| 1. Diadesmis confervacea Kützing                     | ++                              | +                                | -                           |
| 2. Neidium affine var. amphirhynchus (Ehrenberg) Cleve| ++                              | +                                | -                           |
| 3. Navicula viridula (Kützing) Ehrenberg             | ++                              | -                                | -                           |
| 4. Navicula viridula var. rostellata (Kützing) Cleve  | ++                              | +                                | -                           |
| 5. Halamphora coffeiformis (C. Agardh) Mereschkowsky  | +++                             | -                                | -                           |
| 6. Pinularia viridis (Nitzsch) Ehrenberg             | -                               | ++                               | -                           |
| 7. Pinularia viridis var. (Nitzsch) Ehrenberg        | -                               | ++                               | -                           |
| 8. Rhopalodia gibba (Ehrenberg) O. Müller            | ++                              | +                                | +                           |
| 9. Rhopalodia gibberula (Ehrenberg) O. Müller        | -                               | ++                               | -                           |
| 10. Rhopalodia opecula (C. Agardh) Hákanusson        | +                               | -                                | ++                          |
| 11. Achnanthes exigua Grunow                         | +                               | +                                | -                           |
| 12. Mastogloia smithii var. lacustris Grunow         | +                               | ++                               | -                           |
| 13. Nitzschia obtusa var. scalpelliformis (Grunow)   | +                               | ++                               | -                           |
| 14. Nitzschia nana Grunow                            | +                               | ++                               | -                           |
| 15. Nitzschia acicularis (Kützing) W. Smith          | -                               | +                                | +                           |
| 16. Amphora elliptica (C. Agardh) Kützing            | -                               | +                                | ++                          |
| 17. Amphora ovum Cleve                               | +                               | +                                | -                           |
| 18. Himantidium minus Kützing                         | -                               | +                                | ++                          |
| 19. Synedra ulna (Nitzsch) Ehrenberg                 | -                               | +                                | ++                          |
| 20. Synedra ulna var. amphirhynchus (Ehrenberg) Grunow| +                               | -                                | ++                          |
| 21. Fragilaria intermedia var. robusta G. S. Venkataraman | + | ++ | - |
| 22. Diatoma mesodon (Ehrenberg) Kützing              | ++                              | +                                | -                           |
| 23. Cymbella ehrenbergii Kützing                      | ++                              | +                                | -                           |
| 24. Cymbella affinis Kützing                          | ++                              | +                                | -                           |
| 25. Cymbella olifii Cholnoky                          | ++                              | +                                | -                           |
| 26. Cymbella cristula (Ehrenberg) O. Kirchner        | ++                              | -                                | +                           |
| 27. Cymbella turgidula Grunow                         | ++                              | -                                | -                           |
| 28. Cymbella tumida (Brüissin) Van Heurek            | ++                              | -                                | +                           |
| 29. Gomphonema lanceolatum Ehrenberg, nom. illeg.     | ++                              | -                                | +                           |
| 30. Grammatophora undulata Ehrenberg                 | ++                              | +                                | -                           |

Suborder: Naviculinae
Family: Naviculaceae
Genus: Navicula

3. Navicula viridula (Kützing) Ehrenberg [Figure 2d]
Hendey, 1974; Hofmann, Weum & Lange-Bertalot, 2013; John, 2018
Basionym: Frustulia viridula Kützing
Valves 9-10 times longer than broad, 55-65 μm long and 6-8 μm broad, linear to lanceolate with capitate ends with narrow axial area and wide central area. Striaions are not clear under compound microscope.
Voucher no.: CUH/PLANK/DIA-29/3

4. Navicula viridula var. rostellata (Kützing) Cleve [Figure 2e]
Patrick & Reimer, 1966; Hofmann, Weum & Lange-Bertalot, 2013
Basionym: Navicula rostellata Kützing
Valves narrow, elliptic, lanceolate with short narrowly produced rostrate ends, 4-5 times longer than broad, 38-45 μm long and 9-10 μm broad; axial area narrow and central area big, rounded; striaions delicate, radial, approximately 10-12 in 10 μm area.
Voucher no.: CUH/PLANK/DIA-29/4
Family: Amphipleuraceae
Genus: Halamphora

5. Halamphora coffeiformis (C. Agardh) Mereschkowsky [Figure 2f]
Levko, 2009; Wang et al., 2014; Stepanek & Kociolek, 2018
Basionym: Frustulia coffeiformis C. Agradh
9. Rhopalodia gibberula (Ehrenberg) O. Müller [Figures 2k-l]
Hustedt, 1930; Proschkina-Lavenenko, 1950; John, 2018
Basionym: Euonota gibberula Ehrenberg
Frustules long, elliptical with rounded ends, 1.5 times longer than broad, sometimes as long as broad, 30-42 μm long and 25-30 μm broad, dorsal side highly convex; costae 3-4 in 10 μm area.
Voucher no.: CUH/PLANK/DIA- 30/3

10. Rhopalodia operculata (C. Agardh) Hákanasson [Figure 2m]
Ruck et al., 2016; John, 2018
Basionym: Frustula operculata C. Agardh
Valve linear, solitary, lanceolate or elliptic with wide rounded apices, 3 times longer than broad, 55-60 μm long and 22-24 μm broad; striaæ transverse, wide apart from each other.
Voucher no.: CUH/PLANK/DIA- 30/4
Order: Mastogloiales
Family: Achnanthaceae
Genus: Achnanthus

11. Achnanthes exigua Grunow [Figure 2n]
Patrick & Reimer, 1966; Krammer & Lange-Bertalot, 2004; Hofmann, Werum & Lange-Bertalot, 2013
Frustules narrow, rectangular in girdle view, forming short chains; valves narrowly lanceolate with clearly convex margins and rostrate apices; valves 5-15 μm long and 3-5 μm broad; striaæ not clearly visible under compound microscope.
Voucher no.: CUH/PLANK/DIA- 30/5
Order: Bacillariaceae
Family: Achnanthaceae
Genus: Achnanthus

12. Mastogloia smithii var. lacustris Grunow [Figure 2o]
Proschkina-Lavenenko, 1950; Lee et al., 2014
Valve linear, elliptical and constricted, two narrow ends with central broad area, 4 times longer than broad, 31-32 μm long and 7.5-8.5 μm broad; striaæ are not clearly visible under compound microscope.
Voucher no.: CUH/PLANK/DIA- 30/6
Order: Bacillariaceae
Family: Mastogloiales
Genus: Mastogloia

6. Pinnularia acrosphaeria W. Smith [Figure 2g]
Hustedt, 1930; Proschkina-Lavenenko, 1950; Kulikovskiy et al., 2016
Valves linear, gibbous in the middle and at the ends, axial area broad linear and central area punctate, 4.5 to 5.5 times longer than broad, 38-62 μm long and 8-12 μm broad; striaæ parallel and slightly radial at the ends, striaæ 9-12 in 10 μm area.
Voucher no.: CUH/PLANK/DIA- 29/5
Suborder: Selliaphtoraceae
Family: Pinnulariaceae
Genus: Pinnularia

7. Pinnularia viridis (Nitzsch) Ehrenberg [Figure 2h]
Hustedt, 1930; Proschkina-Lavenenko, 1950; Kulikovskiy et al., 2016
Valves linear, gibbous in the middle and at the ends, axial area broad linear and central area punctate, 4.5 to 5.5 times longer than broad, 38-62 μm long and 8-12 μm broad; striaæ parallel and slightly radial at the ends, striaæ 9-12 in 10 μm area.
Voucher no.: CUH/PLANK/DIA- 29/6
Order: Rhopalodiales
Family: Rhopalodaceae
Genus: Rhopalodia

8. Rhopalodia gibba (Ehrenberg) O. Müller [Figures 2j-l]
Aboal et al., 2003; Jahn & Kusber, 2004; Cocquyt, Kusber & Jahn, 2018
Basionym: Navicula gibba Ehrenberg
Frustules linearly lanceolate with cuneate apices and inflated center, 7-12 times longer than broad, 45-140 μm long and 6-12 μm broad; striaæ distinct 12-18 in 10 μm.
Voucher no.: CUH/PLANK/DIA- 30/2

Figure 2 Light micrographs of (a-b) Diadesmis confervacea Kützing. (c) Neidum affine var. amphiphrychus (Ehrenberg) Cleve. (d) Navicula viridula (Kützing) Ehrenberg. (e) Navicula viridula var. rostellata (Kützing) Cleve. (f) Halanephora coffeiformis (C. Agardh) Mereschkowsky. (g) Pinnularia acrosphaeria W. Smith. (h) Pinnularia viridis (Nitzsch) Ehrenberg. (i-j) Rhopalodia gibba (Ehrenberg) O. Müller. (k-l) Rhopalodia gibberula (Ehrenberg) O. Müller. (m) Rhopalodia operculata (C. Agardh) Hákanasson. (n) Achnanthes exigua Grunow. (o) Mastogloia smithii var. lacustris Grunow. (p) Nitzschia obtusa var. scalpelliformis (Grunow) Grunow. (Scale bar a-e, g, 1-l, o-p: 10 μm; f, n: 5 μm; h, m: 20 μm)
Genus: *Fragilaria*  
Family: *Fragilariaceae*  
Order: *Fragilariales*

Frustules linear, broadened at the ends, 25-30 times longer than broad, 80-160 μm long and 3-7 μm broad; valves linear to lanceolate and gradually tapering towards the ends; central area rounded or rectangular; striae coarse, 10-12 in 10 μm area.

Voucher no.: CUH/PLANK/DIA-32/1

20. *Syndra ulna var. amphihrynchus* (Ehrenberg) Grunow  
(Figure 3g)  

Proschkina-Lavrenko, 1950; Aboal et al., 2003  

Basionym: *Syndra amphihrynchus* Ehrenberg  

Valve straight, linear and slender, narrow at the end and suddenly constricted to capitate end, 10-12 times longer than broad; 80-86 μm long and 7-8 μm broad; distinct and parallel striae present in both sides but not prominent in the middle, generally 9-15 in 10 μm area.  

Voucher no.: CUH/PLANK/DIA-32/2

Genus: *Fragilaria*  

21. *Fragilaria intermedia var. robusta* G. S. Venkataraman  
(Figure 3h)  

Venkataraman, 1939  

Frustules are linear, rectangular in girdle view, 14-18 times longer than broad, 70-140 μm long and 5-8 μm broad; valves linear with parallel sides and gradually tapering capitate ends; striae coarse and distinct, 11-12 in 10 μm area.  

Voucher no.: CUH/PLANK/DIA-32/3

Order: Tabellariales

Family: Tabellariaceae

Genus: *Diatoma*

22. *Diatoma mesodon* (Ehrenberg) Kützing  
(Figure 3i)  

Aboal et al., 2003; Hofmann, Werum & Lange-Bertalot, 2013; Lange-Bertalot et al., 2017  

Synonym: *Odontidium mesodon* (Kützing) Kützing  

Basionym: *Fragilaria mesodon* Ehrenberg  

Valves are rectangular arranged in chains, 10-20 μm long and 7-10 μm broad; striae are not clearly visible under compound microscope but usually 20 in 10 μm area.  

Voucher no.: CUH/PLANK/DIA-32/4

Order: Cymbellales

Family: Cymbellaceae

Genus: *Cymbella*

23. *Cymbella ehrenbergii* Kützing  
(Figure 3j)  

Proschkina-Lavrenko, 1950; Hu & Wei, 2006  

Asymmetrical, biraphid, lanceolate frustules with obtuse end, 2.5 to 3 times longer than broad, 35-36 μm long and 12.5-13 μm broad; transverse raphe located at the middle; central nodule present; distinct transverse striae present and radial towards the center, striae 5-10 in 10 μm area.  

Voucher no.: CUH/PLANK/DIA-32/5

24. *Cymbella affinis* Kützing  
(Figure 3k)  

Aboal et al., 2003; Hofmann, Werum & Lange-Bertalot, 2013  

Valves 5 times longer than broad, 20-30 μm long and 4-6 μm broad, strongly dorsiventral with rostrate apices; central stigma present; 8-12 striations in 10 μm area.  

Voucher no.: CUH/PLANK/DIA-32/6

25. *Cymbella oliffii* Cholnoky  
(Figure 3l)  

Cholnoky, 1956  

Frustules are oval to elliptical with large central chloroplast, 3-4 times longer than broad, 40-50 μm long and 12-14 μm broad; clear transverse striae present, 8-10 in 10 μm area.

Voucher no.: CUH/PLANK/DIA-33/1

26. *Cymbella cistula* (Ehrenberg) O. Kirchner  
(Figure 3m)  

Hustedt, 1930; Hu & Wei, 2006  

Basionym: *Bacillaria cistula* Ehrenberg  

Valve strongly dorsiventral with rounded apices, 3-5 times longer than broad, 35-80 μm long and 10-15 μm broad, ventral convex and median inflated; raphe central, proximal, straight; stigma present, 2-3; striae coarse, 8-12 in 10 μm area.  

Voucher no.: CUH/PLANK/DIA-33/2

27. *Cymbella turgidula* Grunow  
(Figure 3n)  

Aboal et al., 2003; Hu & Wei, 2006; John, 2018  

Valves dorsiventral, broadly lanceolate, 3 times longer than broad, 30-45 μm long and 10-15 μm broad, apices blunt, rostrate to truncate; proximal striae 10-12 and distal striae 12-15 in 10 μm area.

Voucher no.: CUH/PLANK/DIA-33/3

28. *Cymbella tumida* (Brébisson) Van Heurck  
(Figure 3o)  

Aboal et al., 2003; Hu & Wei, 2006; Hofmann, Werum & Lange-Bertalot, 2013  

Valves broadly lanceolate with obtuse ends, 3-5 times longer than broad, 50-70 μm long and 10-20 μm broad; dorsal and ventral margins of the valve bent in opposite direction; striae radial, 8-10 in 10 μm area.  

Voucher no.: CUH/PLANK/DIA-33/4

Order: *Gomphonematales*

Family: Gomphonomataceae

Genus: *Gomphonema*

29. *Gomphonema lanceolaturn* Ehrenberg, nom. illeg.  
(Figure 3p)  

Hustedt, 1930; Eberle, 2008  

Valves lanceolate to clavate in shape with distinctly rounded apex and base, 4-4.5 time longer than broad, 50-55 μm long and 12-14 μm broad; raphe slightly thick and straight; Striae radial and linate, 10 in 10 μm area.
Diatoms are widely used as environmental indicators in nano technology, oil exploration and forensic examinations (Dwivedi & Misra, 2015). Recently the emphasis has been made on the ecological problems such as eutrophication, acidification and climate change. Freshwater diatom flora in ecologically sensitive regions of Indian continent has been discussed with very few reports. Dwivedi & Misra (2015) has reported 31 diatom species from the Himalayan region of which Encyonema subalpinum and Gomphonema tovstate were found to be new to India. In our study we have also reported 31 species from Cu mining sites of Ghatsila of which 10 were newly recorded to the state. Pandey et al. (2014) have studied 19 periphytic diatom taxa from the river Ganges polluted with Cu, Pb and Zn.

Four types of abundance categories have been proposed in the present study: (i) most dominant, (ii) dominant, (iii) less dominant and (iv) absent, on the basis of the contaminated sites. This pattern of study is consistent with Cattaneo et al. (2011). Diatom diversity was highest in all three sampling stations that were affected by Cu contamination. It has also been reported that the high level of Cu, Cd and Zn can stimulate the growth of diatoms and increase their diversity (Shibl et al., 2014). Interestingly, the present study supported the point of view of Shibl et al. (2014). In station 1, 17 species were found to be dominant where Cu contamination was high. Among these, Halamphora coffeiformis was recorded as the most dominant species and not reported in station 2 and 3. These tolerant taxa did not only survive under high Cu contamination but also showed their absolute abundance. Five species were less dominant and 9 were completely absent in station 1, which shows their low abundance in high Cu contamination (400 μg.L−1).

In contrast to the remarkable Cu tolerance, only 9 species dominated in the medium Cu contaminated sites of station 2. Some of these species has confirmed their high Cu containing sites and one of them were completely absent in the area adjacent to HCL. It has been documented that some adate species like Achnanthes minutissima and Fragilaria Buchananii were found to be abundant in high Cu streams (Medley & Clements, 1998). The growths of coastal and oceanic diatoms were highly affected by Cu. Several coastal species like Chaetoceros decipiens, Thalassiosira weisflogii, Skeletonema costatum and many oceanic species like T. pseudonana, T. oceanica. S. menziesi were found to be rich in Cu contaminated areas (Annett et al., 2008). These results interpret that diatom tolerance to metals obviously has limits and their diversity fluctuates with the Cu level. Ecological characteristics such as optima and tolerance along with other environmental variables suggests diatom as ecological indicator (Dixit et al., 1992).

In station 3, only 5 species viz., Nitzschia acicularis, Amphora elliptica, Hinumtidium minus, Synedra ulna and S. ulna var. amphirhynchos showed their dominance over the less Cu contaminated area. These species were found as sensitive to high Cu (Table 2). Diatoms respond rapidly to any environmental changes. Changes in diatom assemblage in the present study sites correspond closely to shifts in other living communities such as picoplanktons, phytoplanktons, zooplanktons, fishes and hydro phytes (Dixit et al., 1992).

Limnological parameter greatly influences the assemblage of diatoms and results in water quality (Bigler & Hall, 2002). It has been suggested that the diatoms respond well to hardness, alkalinity, pH, salinity and nutrients (Greenaway et al., 2012). The appearance of low pH in water bodies indicates acidification. In our study we have observed the pH value in station 1 was 6.8, which is slightly acidic suggesting the starting point of acidification due to pollution (Pandey et al., 2014). High acidification also diminishes silica production in diatoms (Petrou et al., 2019). Minimum value of calcium in station 1 suggests the low pH. Total hardness and turbidity values in all stations suggest mineralization and eutrophic condition of the water bodies. Direct pouring of mining wastewater into the canals, outlets and in the River of Ghatsila results in significant changes to nitrate, phosphate, sulphate and silicate levels. High nitrate and sulphate values indicate the eutrophic condition of the water bodies of the sampling area. It is either due to anthropogenic activities or industrial pollution (Bella et al., 2007). Diatom communities play a significant role in maintaining the water quality in some areas. Some workers have concluded that diatoms can serve as indicator of organic and anthropogenic pollution (Choudhury & Pal, 2010). The photosynthetic activity of the diatoms is directly associated with DO of the water. The productivity in relation to gross primary productivity (GPP) and net primary productivity (NPP) is directly correlated with DO. Rise in DO level in water results in high GPP, whereas rise in BOD is a measure of drop in NPP in the concerned water bodies. In our study DO value sharply increased in the order: station 1 > station 2 > station 3, indicating the pollution level in the water. Similarly BOD level decreased in the order: station 1 < station 2 < station 3. As diatoms are primary producer they respond quickly to the ecological perturbations such as changing n physico-chemical parameters due to pollution (Adon, Quattara & Gourene, 2012). High value of dissolved CO₂ in station 1 adjacent to HCL indicates the competition of zooplanktons and other aquatic animals with the diatom communities for respiration. Poor water quality of station 1 due to contamination of Cu suggests diatom shift to the neighboring area of station 2 and 3. At some places diatoms can tolerate high metals whereas it drastically changes species composition in other places (Cattaneo et al., 2011). The conversion of oligotrophic to mesotrophic environment results in changing of species composition and species richness (Cumming et al., 1995). In our present study, Cu was sharply observed and the dominant taxa were found to be rich completely in station 1, which was highly polluted with Cu (Table 2). Similarly, species of highly Cu infected area were not observed in the less polluted area (station 3). Hence our study mainly focused on taxonomic implications of diatoms in Cu infected area with changing water quality.

CONCLUSION

Study of euplanktonic diatom communities in Cu mining sites is scarce. The present study was undertaken as first documentation of diatom communities in Bankhand, India. The site is rich in Cu as it is situated adjacent to HCL on the bank of Subarnarekha River. A total number of 31 diatom species were documented from three sampling stations distinguished by high, medium and low Cu contamination. Maximum species dominated in station 1, which is closely associated to HCL. The taxonomic shifts were sharply noticed in three sampling stations. Physicochemical parameters show the condition of the water bodies due to Cu contamination. From the study it can be concluded that the diatom assemblages of Ghatsila can serve as best bioindicator of Cu.

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