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Research Article

Algal diversity in coalfield areas of Talcher with response to physico-chemical parameters

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Abstract: The Talcher coalfield region in Angul district, Odisha, India, offers a unique ecological setting shaped by intensive coal mining activities, making it an important site for studying algal diversity. Spanning approximately 1,800 square kilometers, the area exhibits a range of physico-chemical parameters that significantly influence its aquatic ecosystems. This study investigates the algal diversity in the coalfield and examines its relationship with key physico-chemical factors. A total of 35 algal species were recorded, encompassing 21 genera, 18 families, and 15 orders across five major algal divisions. The division Bacillariophyta (diatoms) was the most dominant, with 19 species, followed by Charophyta (6 species), Cyanophyta (4 species), Chlorophyta (3 species), and Euglenophyta (3 species). The results revealed that temperature, pH, and dissolved oxygen (DO) are the primary environmental factors influencing algal diversity in the Talcher coalfield. Moreover, Canonical Correspondence Analysis (CCA) revealed that temperature, pH, and dissolved oxygen are key environmental drivers influencing algal diversity in the Talcher coalfield area. The study concludes that coal mining environments, provide favourable microhabitats for diverse algal communities despite of anthropogenic activity. The observed algal diversity reflects a complex interaction between natural conditions and mining-induced changes. These findings emphasize the need for sustained ecological monitoring and mitigation strategies to manage the environmental impacts of coal mining. The dataset of our study provides a valuable baseline snapshot of algal diversity in mining-impacted habitats of coalfield areas of Talcher.

Keywords: Algal diversity; Coal mining; Talcher coalfield; Physico-chemical parameters; Water quality

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1. INTRODUCTION

A coalfield is a region where coal is extracted and typically exhibits consistent geographical, geological, and cultural characteristics (Sen et al., 2012; Saini et al., 2016). While nature has generously endowed the Earth with resources, unsustainable human activities, particularly large-scale coal mining, have led to significant environmental challenges. Though the adverse impacts of mining are largely inevitable, they can be mitigated by understanding how these activities interact with natural resources and local ecological systems. Algae, although primarily associated with marine and freshwater habitats, are also known to inhabit terrestrial and semi-aquatic environments, including coal mining areas (Kumar, 2014). Their ability to grow under a wide range of environmental conditions makes them valuable indicators of ecological health. Different algal species respond to specific atmospheric and physico-chemical conditions, which allows them to reflect pollution levels in various ecosystems. This ecological sensitivity makes algae ideal biological tools for monitoring environmental quality in disturbed habitats such as coalfields. Coal mining areas offer favorable conditions for algal growth due to open landscapes with ample sunlight and elevated carbon dioxide levels (Singh & Nikhil, 2014). Algae are excellent indicators of pollution because of their wide temporal and spatial distribution and their rapid response to environmental changes (Agrawal & Nikhil, 2013). In addition to serving as indicators, algae can also help improve mine water quality by modulating parameters such as pH, temperature, nitrate, iron, chloride, and fluoride concentrations (Kumar, 2014). Algae also play an important role in bioremediation, the process of using live organisms to remove or neutralize contaminants from soil or water. Their ability to absorb and transform pollutants, including heavy metals, makes them effective agents for ecological restoration (Kumar et al., 2011). The presence of plant roots can further accelerate bioremediation by creating a supportive rhizosphere that enhances microbial activity (Kumar et al., 2018; Olson et al., 2003; Saeed et al., 2021). As such, bioremediation is increasingly recognized as a cost-effective, on-site, and environmentally safe alternative to traditional remediation methods. Algae are nucleus-bearing, photosynthetic organisms that lack true roots, stems, leaves, or reproductive organs found in higher plants (Kumar, 2014). They can be found in diverse water bodies, including freshwater, marine, and brackish environments. While commonly green due to chlorophyll, some algae exhibit other pigments; for example, snow algae contain carotenoids, giving the snow a distinctive red hue (Holzinger et al., 2016). Algal diversity is typically assessed in terms of species richness, habitat range, and their functional roles in ecosystems (Norton et al., 1996; Sharma et al., 2009). Their ecological and economic importance stems from their ability to produce a wide range of bioactive compounds and secondary metabolites, many of which have applications in food, pharmaceuticals, and environmental management (Soria-Mercado et al., 2012; Singh et al., 2020). In aquatic ecosystems, algae act as primary producers, forming the base of the food web and playing essential roles in oxygen production, carbon dioxide absorption, sediment stabilization, and pollutant removal (Schindler & Scheuerell, 2002; Chapman, 2013; Priya et al., 2022). Some algal species are particularly useful in detecting industrial pollutants and are employed in water quality assessment (Kanu & Achi, 2011). Mines are excavated sites for extracting coal or minerals (Bilgin et al., 2013), and Odisha is home to several such mines, including the Talcher coalfield. Although numerous studies have documented algal diversity in freshwater, marine, and subaerial habitats (Maharana et al., 2019; Behera et al., 2020; Dash et al., 2020; Behera et al., 2021a, 2021b; Dash et al., 2021; Bhuyan et al., 2022; Karjee et al., 2022; Pradhan et al., 2022; Bhuyan et al., 2023), there is absolutely no literature available on algal diversity specific to coalfield mining regions of Talcher, especially in relation to physico-chemical parameters. Hence, the present study was undertaken to document and analyze the algal diversity in the coalfield region of Talcher, Angul district, Odisha, and to examine its correlation with the prevailing physico-chemical characteristics of the environment.

2. MATERIAL AND METHOD

2.1. Study Area

The Talcher coalfield is recognized as the largest repository of power-grade coal in India. It occupies a basin in the southeastern part of the Mahanadi Valley belt of the Gondwana Basin, covering approximately 500 km² (190 sq mi), primarily located within the Angul district of Odisha. Geographically, the coalfield is bounded between latitudes 23°53′N to 21°12′N and longitudes 84°20′E to 85°23′E (Mishra & Das, 2017).

Talcher coalfield consists of eight opencast and three underground coal mines, including Ananta, Balram, Bharatpur, Bhubaneswari, Chhendipada, Hingula, Kaniha, Nandira, and Lingaraj Open Cast Project (OCP). For the present investigation, four selected sites within the Lingaraj OCP were chosen for algal diversity assessment. The Lingaraj coal mine, operated on an annual basis, is a major operational unit within the Talcher coalfield. Figure 1 shows the map of the study area and the sample collection sites within the coal mining zones. Figure 2 presents field photographs of the selected sites from the Lingaraj OCP during sample collection.

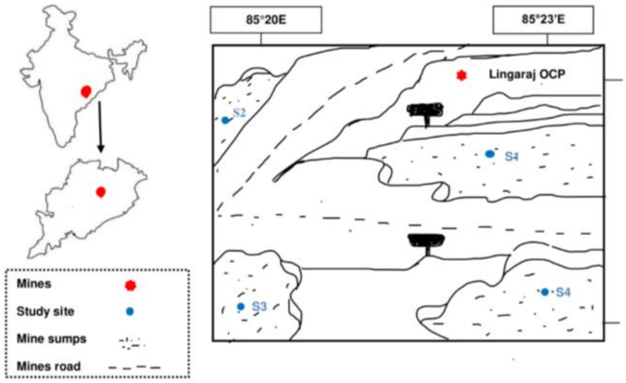

Figure 1. Map showing the location of sample collection sites of Lingaraj OCP. S1 & S4: mine sumps, S2 & S3: mine road site.

2.2. Sample Collection & Preservation

Algal samples were collected from four selected sites (S1–S4) within the Lingaraj Open Cast Project (OCP) of Talcher coalfield during March 2023. At each site, the algal specimens were pooled into sterilized Falcon tubes. The samples were immediately preserved using 4% formalin to prevent decomposition. Each sample was assigned a collection number and deposited in the laboratory of AIPH University, Odisha, for further analysis. Physico-chemical parameters of water, including pH, temperature, and dissolved oxygen (DO), were measured on-site using portable water quality testing instruments. The preserved algal samples were stored at low temperature and later examined microscopically for identification and diversity assessment.

Figure 2. Figure showing the photographs of sample collection sites of Lingaraj OCP.

2.3. Microscopy and Morphological Identification Algal Species

The preserved samples were observed under a Leica dm750 microscope. The morphological characteristics of each algal species were identified with the assistance of monographs, published literature, and algal databases.

2.4. Statistical Analysis

Statistical analysis was carried out to evaluate algal diversity and its relationship with environmental variables. Species richness was calculated using the Margalef's Index. To assess the relationship between physico-chemical parameters and algal diversity, Canonical Correspondence Analysis (CCA) was performed using the software PAST version 4.03. The Margalef's index is calculated as follows

$$(D_{mg}) = \frac{(S-1)}{ln\,(N)}$$

(where S= number of species (species richness), and N= total number of individuals and ln= natural logarithm)

3. RESULTS

3.1. Physicochemical Parameters

Physico-chemical parameters of water such as temperature, pH, conductivity, and dissolved oxygen are commonly used to assess water quality in aquatic environments. In the present study, the water temperature in the Lingaraj OCP sites ranged from 30.5°C to 30.7°C during the sampling period. The pH of the water was found to be slightly acidic, ranging from 4.78 at site S1 to 5.23 at site S2. Dissolved oxygen (DO) concentration varied significantly across the sites, with a minimum of 130.1 ppm recorded at site S1 and a maximum of 279.8 ppm at site S4 (Table 1).

Table 1: Physico-chemical parameters of four collection sites of Lingaraj OCP, Talcher, Odisha

Sample No.	Temperature (°C)	pH	DO (ppm)
S1	30.5	4.78	130.1
S2	30.7	5.23	206.1
S3	30.3	4.35	230.4
S4	30.6	4.12	279.8

3.2. Distribution of Algal Taxa

A total of 35 algal species belonging to 21 genera, 18 families, and 15 orders were identified from the mining area of Lingaraj OCP, Talcher, Odisha (Table 2). These species were distributed across five major algal divisions viz. Cyanophyta (4 species), Chlorophyta (3 species), Bacillariophyta (19 species), Charophyta (6 species), and Euglenophyta (3 species). Among the recorded divisions, Bacillariophyta was the most dominant division, representing 54% of the total diversity, followed by Charophyta (17%) and Cyanophyta (11%), and Chlorophyta (9%) and Euglenophyta (9%) (Figure 3).

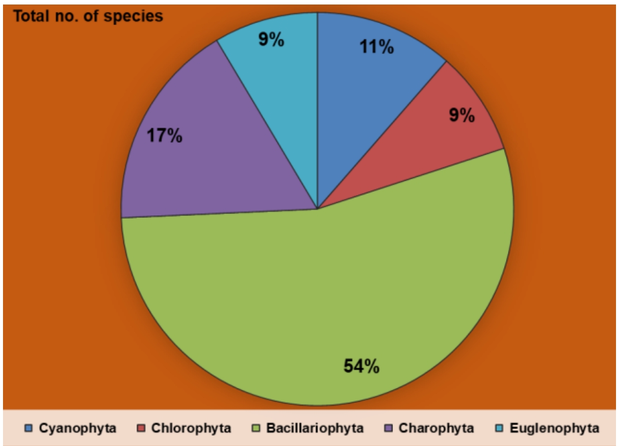

Figure 3. Total algal species of five divisions of OCP.

Table 2: List of algal species recorded from four different sites of Lingaraj OCP, Talcher, Odisha.

Sl. No.	Algal Taxa	S1 Mine area (sump)	S2 Mine road site	S3 Mine road site	S4 Mine area (sump)
	Cyanobacteria				
1	*Chroococcus limneticus* Lemmermann	-	-	-	+
2	*Chroococcus turgidus* (Kützing) Nägeli	-	-	-	+
3	*Lyngbya major* Meneghini ex Gomont	-	+	-	-
4	*Oscillatoria limosa*Agardh ex Gomont	+	-	-	-
	Chlorophyta				
5	*Oocystis lacustris* Chodat	-	-	+	-
6	*Scenedesmus bijugatus* Kützing, nom. illeg.	+	-	-	-
7	*Tetraspora gelatinosa* (Vaucher) Desvaux	-	-	-	+
	Bacillariophyta				
8	*Amphora ellipticaw*Kützing	+	-	-	-
9	*Bacillaria paradoxa* J.F. Gmelin,	+	-	-	-
10	*Cymbella aspera* (Ehrenberg) Cleve	-	+	-	-
11	*Clevamphora ovalis* (Kützing) Mereschkowsky	-	+	-	-
12	*Gyrosigma scalproides* var. *eximium* (Thwaites) Cleve	-	-	+	-
13	*Navicula amphirhynchus* Ehrenberg	-	-	+	-
14	*Navicula bacillum* Ehrenberg	-	-	+	-
15	*Navicula halophila* (Grunow) Cleve	-	-	+	-
16	*Navicula menisculus* Schumann	-	-	-	+
17	*Navicula viridis* (Nitzsch) Ehrenberg	-	-	+	-
18	*Neidium affine* var. *amphirhynchus* (Ehrenberg) Cleve	-	-	-	+
19	*Nitzschia filiformis* (W. Smith) Van Heurck	+	-	-	-
20	*Nitzschia obtuse* W. Smith	+	-	-	-
21	*Nitzschia palea* (Kützing) W. Smith	-	-	-	+
22	*Pinnularia saprophila* Lange-Bertalot, Kobayasi& Krammer	-	-	+	-
23	*Rhopalodia gibba* (Ehrenberg) O. Müller	+	-	-	-
24	*Synedra affinis* Kützing	-	+	-	-
25	*Synedra ulna* (Nitzsch) Ehrenberg	-	+	-	-
26	*Ulnaria ulna* (Nitzsch) Compère	-	+	-	-
	Charophyta				
27	*Cosmarium angulosum* Brébisson	-	+	-	-
28	*Cosmarium decoratum* West & G.S. West	-	-	+	-
29	*Cosmarium miscellum* Skuja 1964	-	-	+	-
30	*Cosmarium punctulatum* Brébisson	-	-	+	-
31	*Cosmarium subimpressulum* Borge	-	-	+	-
32	*Spirogyra condensata* (Vaucher) Dumortier	-	-	+	-
	Euglenophyta				
33	*Trachelomonas armata* f. *punctata* (Svirenko) Deflandre	-	-	+	-
34	*Trachelomonas volvocina* (Ehrenberg) Ehrenberg	+	-	-	-
35	*Trachelomonas volvocina* var. *punctata* Playfair	-	-	-	+

A total of 35 algal species were identified from the four sampling sites in the Lingaraj opencast mine area (Figure 4). Among these, Site S1 accounted for 8 species (23%) including *Oscillatoria limosa*, *Scenedesmus bijugatus*, *Amphora elliptica*, *Bacillaria paradoxa*, *Nitzschia filiformis*, *Nitzschia obtusa*, *Rhopalodia gibba*, and *Trachelomonas volvocina*. Site S2 recorded 7 species (20%) such as *Lyngbya major*, *Cymbella aspera*, *Clevamphora ovalis*, *Synedra affinis*, *Synedra ulna*, *Ulnaria ulna*, and *Cosmarium angulosum*. Site S3 exhibited the highest diversity with 13 species (37%) including *Oocystis lacustris*, *Gyrosigma scalproides*, *Navicula amphirhynchus*, *Navicula bacillum*, *Navicula halophila*, *Navicula viridis*, *Pinnularia saprophila*, *Cosmarium decoratum*, *Cosmarium miscellum*, *Cosmarium punctulatum*, *Cosmarium subimpressulum*, *Spirogyra condensata*, and *Trachelomonas armata*. Moreover, the Site S4 had 7 species (20%) such as *Chroococcus limneticus*, *Chroococcus turgidus*, *Tetraspora gelatinosa*, *Navicula menisculus*, *Neidium affine* var. *amphirhynchus*, *Nitzschia palea*, and *Trachelomonas volvocina*. The variation in algal composition across sites may reflect the influence of local physicochemical conditions and microhabitat characteristics within the coalfield environment of OCP.

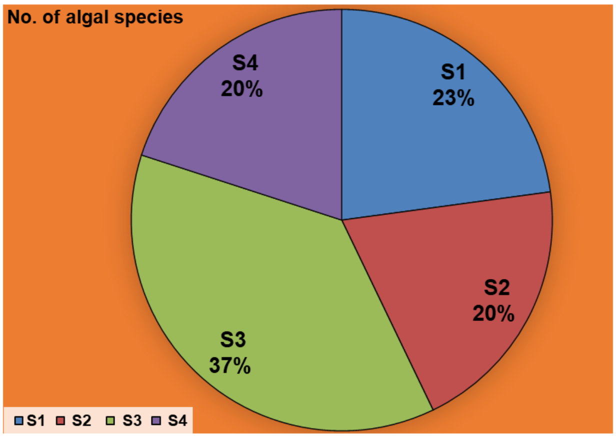

Figure 4. Total no. of algal species in four collection sites of OCP.

3.3. Diversity Indices

An ecological indicator of species richness is known as Margalef's index. It is calculated by dividing the total number of site participants by the logarithm of total number of taxa. A whole integer is used to represent the outcome. The Margalef's index of the collection site of Coalfield Areas of Talcher was calculated to be 1.97, 1.69, 3.38 and 1.69 of all the sites SI, S2, S3, and S4 respectively. The diversity indices revealed that site S3 exhibited the highest species richness, indicating a greater diversity of algal species compared to the other sites. This elevated diversity at S3 can be attributed to favourable physicochemical conditions, particularly its acidic water nature, which may support the proliferation of a wider range of algal taxa. In contrast, sites S2 and S4 showed lower algal diversity, suggesting that local environmental factors at these sites may not be as conducive to algal growth. Figure 5 illustrates the species richness index (Margalef's index) for each of the four collection sites, highlighting the variation in algal diversity across the study area.

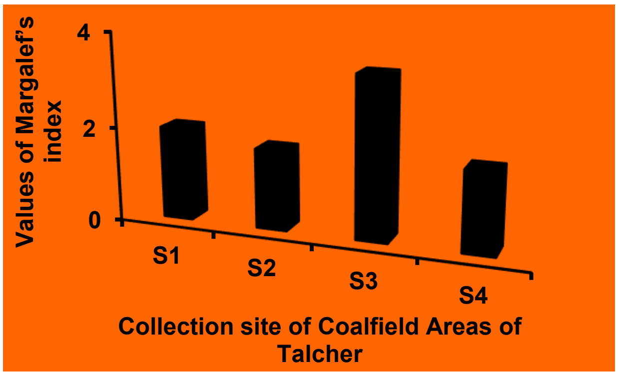

Figure 5. Species richness index / Margalef's index of OCP

3.4. Relationship between physicochemical parameters and algal diversity

To explore the relationship between physicochemical parameters and algal diversity, Canonical Correspondence Analysis (CCA) was employed. This multivariate statistical tool is widely used in ecological studies to identify the major environmental drivers influencing community composition. The results of the CCA revealed that Cyanobacteria showed a positive correlation with temperature, Bacillariophyta were associated with pH, and Euglenophyta correlated with dissolved oxygen. In contrast, Chlorophyta and Charophyta did not exhibit any clear relationship with the measured environmental variables (Figure 6).

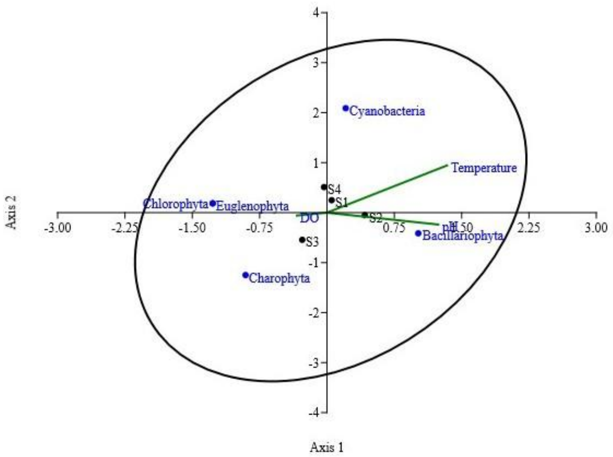

Figure 6. Relationship between major algal groups and physicochemical parameters of OCP

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Further, the relationship between the selected sites based on algal diversity and physicochemical parameters was analyzed using Hierarchical Cluster Analysis. The results indicated that sites S2 and S4 formed a close cluster, while site S1 clustered moderately with both S2 and S4. In contrast, site S3 formed a distinct and separate cluster from the others, suggesting a unique ecological profile (Figure 7).

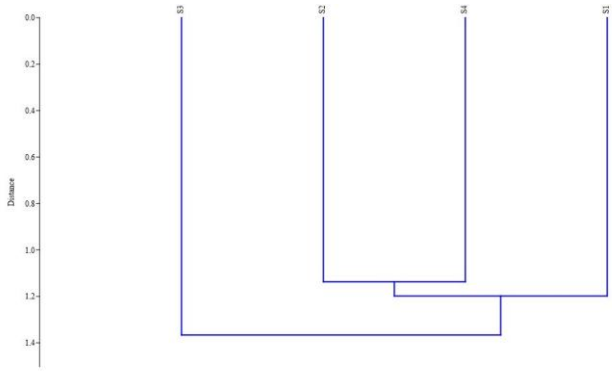

Figure 7. Relationship between selected sites on the basis of algal diversity and physicochemical parameters of OCP

4. DISCUSSION AND CONCLUSION

A total of 35 algal species representing Cyanophyta, Chlorophyta, Bacillariophyta, Charophyta, and Euglenophyta were recorded from the Lingaraj OCP, Talcher, Odisha. Among these, Bacillariophyta was the dominant division, followed by Cyanophyta, Charophyta, Chlorophyta, and Euglenophyta. Bacillariophyta, commonly known as diatoms or brown-pigmented algae, are also recognized as pollution indicators. The dominance of Bacillariophyta has been corroborated by previous studies (Bellinger & Sigee, 2015; Aguilar et al., 2023).

Physico-chemical parameters play a critical role in determining the density, diversity, and occurrence of phytoplankton (George et al., 2012; Goswami et al., 2018; Sharma et al., 2016). For standard water quality, the essential physico-chemical characteristics such as pH, temperature, conductivity, dissolved oxygen, and turbidity are frequently assessed (Igbinosa & Okoh, 2009; Gorde & Jadhav, 2013; Sila, 2019). These parameters are vital for aquatic ecosystems, and any fluctuation can affect aquatic flora and fauna. The values of selected physico-chemical parameters recorded from the four collection sites are presented in Table 1.

pH is a fundamental measure of the acidity or alkalinity of water, expressed as the negative logarithm of hydrogen ion concentration. It ranges from 0 to 14 on a logarithmic scale. Each unit change corresponds to a tenfold shift in hydrogen ion concentration. Algal diversity influence on pH varies depending on algal biomass, species, photosynthetic rate, and buffering capacity of the water (Gorde & Jadhav, 2013; Smith et al., 2013). In some cases, algal blooms significantly alter the pH, leading to increased alkalinity (O'Neil et al., 2012; Bhateria & Jain, 2016). Algae typically flourish in pH ranges of 8.2 to 8.7 (Vadlamani et al., 2017), but in coalfield-affected waters, which are often acidic, algae are found to survive at much lower pH levels. In the present study, algal species were observed thriving in acidic conditions, with a pH range around 4.12, a finding supported by earlier research (Tiwary, 2001; Siddharth et al., 2002).

Temperature, measured in degrees Celsius, is a key factor affecting water chemistry and aquatic biology. It influences dissolved oxygen levels, metabolic rates, and photosynthetic activity (Hosmani, 2013). Most algal species survive in temperatures between 20–30 ºC, with some tolerating up to 35 ºC or as low as 16 ºC (Butterwick et al., 2005; Ras et al., 2013). In this study, algal presence was consistent with temperatures ranging from 25 to 35 ºC. Our study results correspond with the previous study (Butterwick et al., 2005).

Dissolved oxygen (DO) is vital for the survival of aquatic organisms. Algal blooms, particularly those driven by phosphorus and nitrogen enrichment, can influence DO levels (Chen et al., 2011). Interestingly, higher levels of DO are often associated with increased algal growth in nutrient-rich or polluted waters. In this study, algal species were recorded at DO concentrations ranging from 130 to 279 ppm, supporting findings from Bhateria and Jain (2016) (Bhateria & Jain, 2016).

The Site-wise analysis revealed that the highest algal diversity occurred at site S3 (mines roadside), while lower diversity was recorded at sites S2 and S4. Although no previous studies exist specifically on algal diversity in coalfield areas, however, studies on lakes, ponds, and rivers across India showed minimal similarity to the current findings (Dash et al., 2020; Dash et al., 2021). Notably, seven algal species were recorded for the first time from Odisha namely, *Tetraspora gelatinosa*, *Navicula bacillum*, *Nitzschia filiformis*, *Navicula halophila*, *Pinnularia saprophila*, *Synedra affinis,* and *Lyngbya major*. In terms of composition, Bacillariophyta constituted the majority (54%), followed by Charophyta (17%), Cyanophyta (11%), and both Chlorophyta and Euglenophyta at 9% each. Bacillariophyta reported as the pollution indicator and our study exhibited the highest diversity of it as compared to others, which is consistent with earlier reports (Begum et al., 2010).

Statistical analyses using CCA revealed that temperature, pH, and dissolved oxygen are key environmental drivers influencing algal diversity in the Talcher coalfield area. These findings align with earlier studies highlighting the impact of water quality parameters on algal communities (Ebrahimzadeh et al., 2021; Akter et al., 2022). Moreover, Margalef's index is a biodiversity metric that emphasizes species richness (the number of species present) relative to the total number of individuals in the site (Sina & Zulkarnaen, 2019). In Talcher coal field, this index can highlight the ecological impact of abiotic stressors like temperature, pH, and dissolved oxygen.

Algae offer promising solutions to emerging environmental challenges, especially in bioremediation. Bioremediation involves the use of living organisms to degrade or transform environmental contaminants, particularly heavy metals and organic pollutants (Kumar et al., 2011; Sharma, 2020; Das et al., 2022). Algae enhance this process through metabolic activity and interaction with their environment, often via biosorption or bioaccumulation mechanisms. These methods are eco-friendly, cost-effective, and feasible for in-situ applications (Kensa, 2011). Diatoms, which contribute significantly to global primary productivity, have shown high potential for heavy metal remediation (Chasapis et al., 2022). Cyanobacteria (Cyanophyta), in particular, have demonstrated strong bioremediation capabilities by altering metabolic pathways and secreting bioactive compounds (Kaur & Bhatnagar, 2002; Singh et al., 2005; Sood et al., 2015). Their ability to degrade various contaminants suggests that algae-based bioremediation holds substantial promise for future environmental management strategies (Touliabah et al., 2022). Our results are also agreeing with the above results.

The present study highlights the algal diversity of the coalfield region of Talcher, Angul, Odisha, with a particular focus on its response to varying physico-chemical parameters. A total of 35 algal species, spanning and Bacillariophyta (diatoms) emerged as the dominant group, indicating their tolerance and adaptability to polluted environments, and reaffirming their role as bioindicators of environmental quality managements. Statistical analyses such as CCA revealed strong correlations between algal diversity and key water quality parameters, particularly pH, temperature, and dissolved oxygen. Moreover, the sites with acidic water and higher DO levels supported greater algal diversity, especially in terms of Bacillariophyta and Euglenophyta. Furthermore, the study provides evidence that several algal taxa recorded from this coalfield ecosystem possess notable bioremediation potential. These algae can naturally mitigate pollution through mechanisms such as biosorption and bioaccumulation, offering a sustainable and eco-friendly approach for managing coalfield-associated water contamination. Overall, this research underscores the ecological relevance of algal communities in disturbed mining landscapes and emphasizes their dual role as both indicators of environmental stress and agents of ecological restoration in industrially impacted regions like Talcher.

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Authors' Contributions:
PPB: Manuscript design, Writing, Draft checking.
SN: Field sampling, Laboratory experiments, Statistical analyses.
GSR: Draft checking, Formal analysis, Statistical analyses.
BP: Manuscript design, Draft checking, Writing, Reading, Editing.
All authors read and approved the final manuscript.

Conflict of Interest: The authors declare that there is no conflict of interest.

Statement on the Welfare of Animals
Ethical approval: For this type of study, formal consent is not required.

Statement of Human Rights
Ethical approval: For this type of study, formal consent is not required.

Data Availability Statements
The authors confirm that the data supporting the findings of this study are available within the article.

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