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Diversity of Freshwater Diatoms (Bacillariophyceae): A Review

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Abstract

Diatoms (Class Bacillariophyceae) are unicellular, siliceous-walled algae that occupy nearly every illuminated freshwater and marine habitat and are widely recognised as one of the most reliable biological tools for assessing aquatic ecosystem health. Because their community composition responds rapidly and predictably to physico-chemical change, diatoms are used across a broad span of applications, ranging from routine water-quality biomonitoring under frameworks such as the European Water Framework Directive, to the reconstruction of drowning sites in forensic medicine, and the description of regional freshwater biodiversity in previously unsurveyed river systems. This review synthesises findings from six recent primary studies and reviews conducted across peninsular India, central India, and a Mediterranean-climate river system in South Africa, together with a global systematic review of diatom research in ephemeral freshwaters, in order to (i) compare the taxonomic diversity and dominant genera reported across contrasting freshwater habitats, (ii) evaluate the abiotic and biotic drivers most consistently linked to diatom community structure, (iii) summarise the sampling and identification methodologies presently in use, and (iv) outline the forensic relevance of diatom analysis in medico-legal drowning investigations. Genera such as Navicula, Gomphonema, Amphora, Cyclotella and Fragilaria recur as dominant or tolerant taxa across geographically distant water bodies, while electrical conductivity, pH, temperature, nitrogen and phosphorus species, and selected trace metals emerge repeatedly as the principal structuring variables. The review closes by identifying a clear regional knowledge gap: although diatom surveys now exist for several districts of Maharashtra, including Dhule and Akola, no dedicated diatom diversity or bioindication study has yet been published for Washim district, despite its location within the same Purna–Tapti river system already shown to support a rich diatom flora. This gap is proposed as a concrete and methodologically well-precedented direction for future regional research.

Keywords

Bacillariophyceae; diatom diversity; freshwater bioindicators; water quality assessment; forensic diatomology; ephemeral freshwater ecosystems; Maharashtra; Washim district

1. Introduction

Diatoms are single-celled, eukaryotic, photosynthetic algae distinguished by a hard, glass-like cell wall termed the frustule, which is composed of amorphous silica and divided into two overlapping halves known as the epitheca and hypotheca. On the basis of frustule symmetry, diatoms are conventionally separated into two broad groups: the radially symmetric centric forms and the bilaterally symmetric pennate forms, the latter often bearing a longitudinal slit, the raphe, that permits limited gliding motility. Diatoms are represented by an estimated 100,000 to 200,000 extant forms distributed across marine, brackish and freshwater habitats, as well as soils, mosses and other moist terrestrial surfaces, and they are credited with fixing a substantial proportion of global primary productivity, underscoring their significance to both aquatic food webs and the global carbon cycle.

Because individual diatom taxa exhibit well-defined ecological preferences and comparatively short generation times, diatom assemblages respond swiftly to changes in nutrient concentration, ionic composition, pH, temperature and other physico-chemical variables, making them one of the most widely used biological quality elements in freshwater monitoring programmes. This sensitivity, combined with their ubiquity, ease of sampling and resistance to degradation owing to their siliceous composition, has additionally established diatom analysis as a recognised tool in forensic science, where diatoms recovered from the tissues of a body found in water can help distinguish ante-mortem from post-mortem drowning and can, in principle, indicate the specific water body of drowning through comparison with local reference diatom floras.

Despite this broad utility, the depth of diatom documentation remains highly uneven across regions. Well-studied river basins in parts of Europe, and a growing number of districts across India, now possess reasonably detailed diatom inventories, while many other freshwater systems, including several river stretches of central India, remain entirely undocumented. This review draws together recent primary research and a global systematic review to characterise (i) the taxonomic diversity reported from a range of contrasting freshwater habitats, (ii) the environmental variables most consistently shown to structure diatom communities, (iii) current sampling and identification methodologies, and (iv) the forensic applications of diatom analysis, before identifying a specific, methodologically grounded research gap in the Purna–Tapti river system of Maharashtra.

2. Comparative Taxonomic Diversity Across Freshwater Habitats

Table 1 summarises the diatom richness, dominant genera and principal research focus reported across the primary studies reviewed here. Although these studies span markedly different geographic and ecological settings, several patterns of convergence are evident.

Study area / water body	Diatom richness reported	Dominant genera	Primary research focus
Sulwade Barrage, river Tapti, Dhule, Maharashtra (Patil, 2019)	22 taxa across 5 genera	Amphora, Fragilaria, Gyrosigma, Pinnularia, Synedra	Seasonal taxonomic documentation and morphometric description
Lakes and ponds, Jabalpur, Madhya Pradesh (Garg et al., 2026)	22 genera across 16 water bodies	Navicula, Cyclotella, Cocconeis, Gomphonema, Amphora	Forensic diatomology; drowning-site identification via light microscopy after centrifugation
Six freshwater ponds, Kanyakumari district, Tamil Nadu (Arumugham et al., 2023)	27 taxa across 17 genera	Gomphonema montanum, Melosira granulata, Cyclotella meneghiniana	Diatom density correlated with physico-chemical parameters and pollution status (CCA)
Krom River system, Western Cape, South Africa (Dalu et al., 2022)	110 species pooled across two sampling events	30 taxa each >2% relative abundance; community shaped by sediment metals	Boosted regression tree modelling of sediment/water chemistry and fish-zone effects on community structure
Purna River, Akola district, Maharashtra (Badgujar, 2025)	4 genera identified	Fragilaria (~93% relative dominance), Tubularia, Amphipleura, Craticula	Seasonal diversity survey with taxonomic and morpho-anatomical description
Global synthesis of ephemeral freshwaters (Taurozzi et al., 2024)	48 primary studies screened under PRISMA protocol	Epilithic diatoms most frequently sampled (52% of studies)	Systematic review of diatom-based bioindication in intermittent rivers, temporary wetlands and small waters

Table 1. Comparative summary of diatom diversity and dominant genera reported in the reviewed literature.

2.1 Riverine and reservoir systems of Maharashtra

A survey of the Sulwade Barrage on the river Tapti in Dhule district recorded twenty-two taxa distributed across five genera, namely Amphora, Fragilaria, Gyrosigma, Pinnularia and Synedra, with peak abundance recorded during the winter season. Specimens were cleaned using Brun's method and examined under high-power light microscopy, with taxonomic assignment based on established regional monographs. A separate survey of the Purna River in the adjoining Akola district, conducted across the summer months, recorded a comparatively narrower set of four genera, Tubularia, Amphipleura, Craticula and Fragilaria, with Fragilaria alone accounting for the substantial majority of specimens observed. Both studies relied on Lugol's iodine or equivalent fixation, light microscopy at magnifications sufficient to resolve valve striae, and comparison against classical taxonomic monographs for genus- and species-level identification.

Notably, both Maharashtra studies fall within the wider Tapti–Purna drainage system, and both report Fragilaria and Amphora among the genera present, suggesting a degree of taxonomic continuity along this river system that has not yet been tested through a dedicated survey of the intervening or adjoining Washim district reach.

2.2 Pond ecosystems of southern India

A study of six freshwater ponds in Kanyakumari district, Tamil Nadu, identified twenty-seven taxa across seventeen genera, with Gomphonema montanum recorded as the predominant species at nearly every sampling station. Canonical correspondence analysis linked the occurrence of pollution-tolerant genera such as Nitzschia, Navicula, Cyclotella and Stauroneis to elevated nitrate, phosphate and lead concentrations, while genera such as Cymbella and Rhopalodia were more closely associated with calcium, chloride, alkalinity and silica. On this basis, the study classified three of the six ponds as heavily polluted and three as comparatively less impacted, illustrating how diatom assemblage composition alone can support a first-order water-quality classification even in the absence of continuous chemical monitoring.

2.3 Forensic diatom survey of Jabalpur water bodies

A recent study conducted at NIMS University, Rajasthan, examined sixteen lakes and ponds in the western part of Jabalpur district, Madhya Pradesh, several of which are documented sites of prior drowning incidents. Diatoms were isolated from water samples using a stepwise centrifugation protocol and examined under light microscopy at 40x magnification, yielding twenty-two identifiable genera, with Navicula, Cyclotella, Cocconeis, Gomphonema and Amphora emerging as the most frequently encountered forms. The explicit forensic framing of this study, situating routine diatom taxonomy within the context of medico-legal drowning investigation, illustrates a second, applied dimension of diatom research that extends beyond conventional ecological monitoring.

2.4 A Mediterranean-climate river system: the Krom River, South Africa

Working in a markedly different climatic and hydrological setting, a two-season study of the Krom River, a tributary of the Olifants–Doring system in South Africa's Western Cape, identified 110 diatom species across twenty-two sampling sites stratified by dominant fish presence (invasive rainbow trout, and native rock catfish and sawfin zones). A boosted regression tree model identified sediment boron and copper, followed by iron and water depth, as the variables most strongly associated with diatom community structure, while fish community composition was shown to influence assemblage structure without substantially altering overall diversity. This study is valuable to the present review chiefly for its demonstration that diatom

community structuring in naturally variable, seasonally intermittent river systems reflects a combination of sediment chemistry, water chemistry and biotic (trophic) interactions, rather than any single driver in isolation.

3. Environmental Drivers of Diatom Community Structure

Across the studies reviewed, a consistent set of physico-chemical variables recurs as the principal correlates of diatom assemblage composition. Electrical conductivity, pH and temperature are the parameters most frequently measured and most often reported as significant, a pattern also confirmed at global scale by a systematic PRISMA-based review of forty-eight studies on diatoms in ephemeral freshwaters, which found electrical conductivity, pH and temperature to be considered in the majority of the studies examined, alongside nitrate and nitrite as additional strong community drivers. Nutrient species, principally nitrate, nitrite and phosphate, were similarly implicated in the Kanyakumari pond study, where their concentrations were traced to probable agricultural runoff, detergent use and domestic wastewater inputs. In the Krom River, sediment trace metals, particularly boron and copper, were found to outweigh conventional water-chemistry variables in structural importance, indicating that sediment geochemistry deserves greater attention in future regional surveys, which have to date focused predominantly on the water column.

Biotic interactions represent a further, comparatively underexplored driver. The Krom River study found that fish community zonation, distinguishing reaches dominated by invasive trout from those dominated by native catfish or sawfin, was associated with shifts in diatom community structure, consistent with the broader ecological principle that top-predator presence can indirectly shape primary producer assemblages through trophic cascades. This dimension has received little attention in the Indian studies reviewed here, none of which incorporated concurrent fish or invertebrate community data alongside diatom sampling.

4. Diatoms in Ephemeral and Temporary Freshwater Systems

A global systematic review following PRISMA guidelines screened 512 candidate records and retained forty-eight peer-reviewed studies published between 1982 and early 2024 on the use of diatoms as bioindicators in ephemeral waters, a category proposed to unify intermittent rivers and streams, temporary large wetlands such as lakes and lagoons, and temporary small waters such as ponds, pools and ditches. The review found that intermittent running waters were by far the most studied ephemeral category, that epilithic diatoms (those attached to stone or rock substrates) were sampled in over half of the studies reviewed, and that electrical conductivity, pH and temperature again emerged as the dominant physico-chemical correlates of community structure. Geographically, the Mediterranean basin, and Portugal and Spain in particular, accounted for the majority of study sites, while very large areas, including most of Asia, remained essentially unrepresented in the literature despite hosting extensive networks of seasonally intermittent rivers and ponds.

This global imbalance is directly relevant to the present review: none of the forty-eight studies identified in that systematic review were conducted in India, and the Indian studies reviewed here, though methodologically comparable, were not designed with ephemeral-water classification in mind. Given that many rivers and ponds across central India, including tributaries of the Tapti–Purna system, are seasonally intermittent, applying the ephemeral-water sampling and classification framework established in the global literature could substantially strengthen the design of future regional diatom surveys in this part of the country.

5. Sampling and Identification Methodologies

Across the reviewed studies, diatom sampling methodology varies principally according to substrate type and study objective, but converges on a small number of standard approaches. Epilithic diatoms are typically collected by scrubbing the upper surface of submerged stones or cobbles; epiphytic diatoms are collected from submerged macrophyte surfaces; epipelic diatoms are scraped from fine sediment; and planktonic diatoms are collected using fine-mesh plankton nets. Several of the reviewed Indian studies additionally employed centrifugation as a means of concentrating diatom valves from water samples prior to microscopic examination, a method particularly emphasised in the forensic Jabalpur study, where repeated centrifugation and resuspension cycles were used to isolate a clean diatom pellet suitable for slide preparation.

Species- and genus-level identification across all the reviewed studies relied on conventional bright-field light microscopy, typically at 40x to 100x magnification, combined with reference to classical taxonomic monographs, several of which, including the works of Gandhi, Hustedt and Cleve-Euler, are shared across multiple of the Indian studies reviewed here, indicating a degree of methodological continuity within the national diatomological literature. None of the primary Indian studies reviewed employed molecular or DNA-barcoding approaches, a limitation also noted explicitly in the Jabalpur forensic study, which identified DNA-based identification as a recommended direction for improving diatom-based forensic reliability. The global systematic review similarly recommended that future ephemeral-water studies adopt more standardised sampling protocols, such as those issued by the European Committee for Standardization, to improve cross-study comparability, a recommendation equally applicable to the regional Indian literature.

6. Forensic Significance of Diatom Analysis

Beyond ecological monitoring, diatom analysis retains a distinct and long-established role in forensic medicine, particularly in the medico-legal investigation of suspected drowning. Because diatoms possess resistant siliceous frustules, they can survive digestion procedures used to isolate them from lung tissue, bone marrow and other internal organs of a body recovered from water, and their presence in tissues beyond the respiratory tract has traditionally been treated as supportive evidence of ante-mortem drowning, historically summarised as the criterion of concordance. The Jabalpur study reviewed here explicitly situates its sixteen-site survey within this forensic context, noting that several of the sampled water bodies are documented sites of prior drowning incidents, and proposes that a regional reference database of diatom assemblages, such as the one it compiles, could assist future investigators in matching diatoms recovered from a victim to a probable site of drowning. This application illustrates that regional diatom surveys of the kind reviewed in Section 2 carry value that extends well beyond conservation biology or water-quality assessment alone.

7. Research Gap and Prospects for Washim District, Maharashtra

Taken together, the literature reviewed here demonstrates that systematic diatom documentation has now been undertaken for several individual districts of Maharashtra, including Dhule, on the river Tapti, and Akola, on the Purna River, both employing broadly comparable and readily replicable methodologies centred on light microscopy and standard taxonomic keys. Washim district lies within the same broader Purna–Tapti drainage system as Akola, sharing comparable climatic, hydrological and land-use characteristics, yet no dedicated diatom diversity, bioindication or forensic reference survey appears to have been published for water bodies within Washim district to date. Given the demonstrated taxonomic richness and pollution-sensitivity of diatom assemblages recorded in the immediately adjoining districts, and the methodological

precedent established by the Dhule, Akola, Jabalpur and Kanyakumari studies reviewed here, a systematic diatom survey of Washim district's rivers, tanks and ponds represents a clearly defined and readily achievable research opportunity. Such a survey could combine taxonomic inventory, correlation with basic physico-chemical parameters following the Kanyakumari model, and construction of a local reference diatom database of the kind proposed for forensic application in the Jabalpur study, thereby contributing simultaneously to regional biodiversity documentation, water-quality assessment, and forensic diatomology in a currently undocumented part of central India.

8. Conclusion

This review has synthesised diatom diversity, bioindication and forensic research spanning riverine, pond and reservoir systems across Maharashtra, Madhya Pradesh and Tamil Nadu in India, a Mediterranean-climate river system in South Africa, and a global systematic review of diatom research in ephemeral freshwaters. Despite considerable geographic and ecological variation, the reviewed literature converges on a consistent set of dominant, environmentally tolerant genera, principally Navicula, Gomphonema, Amphora, Cyclotella and Fragilaria, and a consistent set of structuring variables, principally electrical conductivity, pH, temperature and key nutrient and trace-metal species. Sampling and identification methodologies are similarly convergent, centred on substrate-specific collection, light microscopy and classical taxonomic monographs, while forensic diatomology emerges as a significant and growing applied extension of this research tradition. Against this backdrop, the absence of any published diatom survey for Washim district, situated within the already-documented Purna–Tapti system, constitutes a clear, specific and methodologically well-supported gap that future regional research is well placed to address.

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