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ORIGINAL ARTICLE

Impact of Catchment Wildfire on DOC, Nitrate and C:N Ratio in Two Closed Freshwater Lakes of Southern Rajasthan

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ABSTRACT
The carbon-to-nitrogen (C:N) ratio is a key stoichiometric indicator controlling nutrient cycling, microbial metabolism and eutrophication risk in freshwater ecosystems. This study evaluates C:N ratio dynamics in two closed tropical lakes near Udaipur, Rajasthan: Lake Badi (control, unburnt catchment) and Lake Baghdara (fire-affected catchment burned in March 2017. Dissolved organic carbon (DOC) and nitrate were measured pre- and post-monsoon in both lakes, and C:N ratios were calculated as DOC/nitrate. Pre-monsoon C:N ratio was almost double in Baghdara (0.658) compared to Badi (0.335), indicating higher carbon availability in the fire-affected system. Post-monsoon, Badi showed a moderate increase in C:N (0.412), while Baghdara showed a decline (0.508) despite strong absolute increases in both DOC and nitrate, reflecting proportionally greater nitrogen mobilization after fire. Fire-affected Baghdara also showed much higher conductivity, hardness, TDS, phosphate, BOD and reduced dissolved oxygen, indicating advanced eutrophication and oxygen stress. The results highlight the usefulness of C:N ratio as an integrative indicator of wildfire impacts on lake water quality in semi-arid, closed-basin systems.
Keywords: wildfire, DOC, nitrate, C:N ratio, closed lakes, eutrophication, Rajasthan.

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INTRODUCTION

Wildfires are increasingly frequent and severe at global and regional scales due to climate change and changing land use, with cascading impacts on soil, surface water and ecosystem services [1,2,40]. In forested catchments, fire reduces canopy cover, alters hydrology, and enhances erosion and runoff, thereby increasing the export of sediments, ash, dissolved organic matter and nutrients to downstream waters [29,32,50]. Closed inland lakes in semi-arid regions are particularly vulnerable because they lack through-flow, have long water residence times and respond rapidly to changes in catchment inputs and evaporation [3,37,55].

The carbon-to-nitrogen (C:N) ratio is a fundamental stoichiometric indicator that governs microbial metabolism, decomposition efficiency, oxygen consumption and nutrient limitation of primary producers in aquatic ecosystems [3,43,59]. Studies on lakes and streams show that DOC:NO_3^- (dissolved organic carbon to nitrate) ratios strongly influence nitrate uptake and the coupling between carbon and nitrogen cycles, with low DOC:NO_3^- ratios indicating carbon limitation and potential accumulation of inorganic nitrogen [44,45].

Wildfire can modify both the quantity and quality of dissolved organic carbon and inorganic nitrogen exported from catchments [31,41,44]. Experimental and observational work indicates that fire often elevates nitrate concentrations and can either increase or decrease DOC, depending on burn severity, vegetation type and post-fire precipitation patterns [14,29,50]. In some systems, wildfire causes a multi-year pulse of inorganic nitrogen and a reduction in DOC export, lowering DOC:DIN ratios and decreasing nitrate uptake efficiency in receiving waters [40,44,45]. At the same time, reviews show that many burned basins exhibit marked increases in DOC and nutrient concentrations during post-fire storm events, with consequences for drinking water treatment and eutrophication risk [10,19,30].

In southern Rajasthan, India, Lake Badi (control) and Lake Baghdara (fire-affected) are two closed, rain-fed freshwater lakes with forested catchments, comparable climate and low direct anthropogenic disturbance [36,37,55,56]. Lake Baghdara's catchment experienced a severe wildfire in March 2017, while Lake Badi has had no recent fire history, offering a paired-lake setting to isolate wildfire effects on lake water chemistry [23,55]. Previous work on these lakes has documented long-term changes in salinity, nutrient status and trophic state linked to catchment characteristics and anthropogenic inputs [37,55].

The present study focuses specifically on how catchment wildfire alters DOC, nitrate and their C:N ratio in these closed tropical lakes, in the context of broader water quality responses. The objectives are to:

- quantify DOC, nitrate and DOC:NO_3^--based C:N ratios in both lakes during pre- and post-monsoon periods;
- compare seasonal C:N shifts between fire-affected and control catchments;
- relate C:N changes to other water quality parameters such as conductivity, hardness, phosphate, DO and BOD; and
- interpret the implications for eutrophication and water resource management in fire-prone, semi-arid, closed-basin lakes.

MATERIAL AND METHODS

Study area

The study was conducted on two isolated rain-fed lakes near Udaipur city, Rajasthan, India, which has a sub-humid climate with strong seasonality and below-average Indian rainfall.

- Lake Badi (control lake): Closed freshwater body ~10 km from Udaipur (24.61605°N, 73.622127°E), surface area ~1.25 km^2, maximum depth ~15 m, forested catchment without recorded fires in recent years, minimal direct anthropogenic disturbance.
- Lake Baghdara (fire-affected lake): Closed freshwater body ~20 km SE of Udaipur (24°31′N, 73°48′E), surface area ~1.8 km^2, maximum depth ~8.5 m, dry tropical deciduous forest catchment, affected by a severe wildfire on 13 March 2017 that burned several hectares .

Both lakes are closed basins with no perennial inlets or outlets and are fed directly and indirectly by monsoon rainfall, making them highly sensitive to catchment inputs and evaporation.

Sampling and analytical methods

Water samples were collected in triplicate during:

- Pre-monsoon (summer, shortly after the 2017 fire in Baghdara), and
- Post-monsoon (after the 2017 rainy season) from both lakes.

Samples were taken from subsurface water using pre-sterilized BOD bottles between 8:00–10:00 AM, and in-situ measurements of temperature and pH were recorded. Laboratory analysis followed [4].

Parameters measured included temperature, pH, turbidity, electrical conductivity (EC), total hardness, total dissolved solids (TDS), alkalinity, nitrate, phosphate, dissolved oxygen (DO), biochemical oxygen demand (BOD) and dissolved organic carbon (DOC).

C:N ratio calculation

For this study, the operational C:N ratio was calculated as:

C:N ratio=DOC (mg L−1)/Nitrate (mg L−1)

using DOC as the dissolved carbon pool and nitrate-nitrogen as the dominant inorganic nitrogen species in lake water.

Statistical analysis

Paired t-tests ($p < 0.05$) were applied to test for significant differences between:

- pre- and post-monsoon values within each lake; and
- post-monsoon values between the two lakes (Badi vs Baghdara).

Significance for each water quality parameter is reported in the Results section, following standard approaches in post-fire water quality studies.

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RESULTS

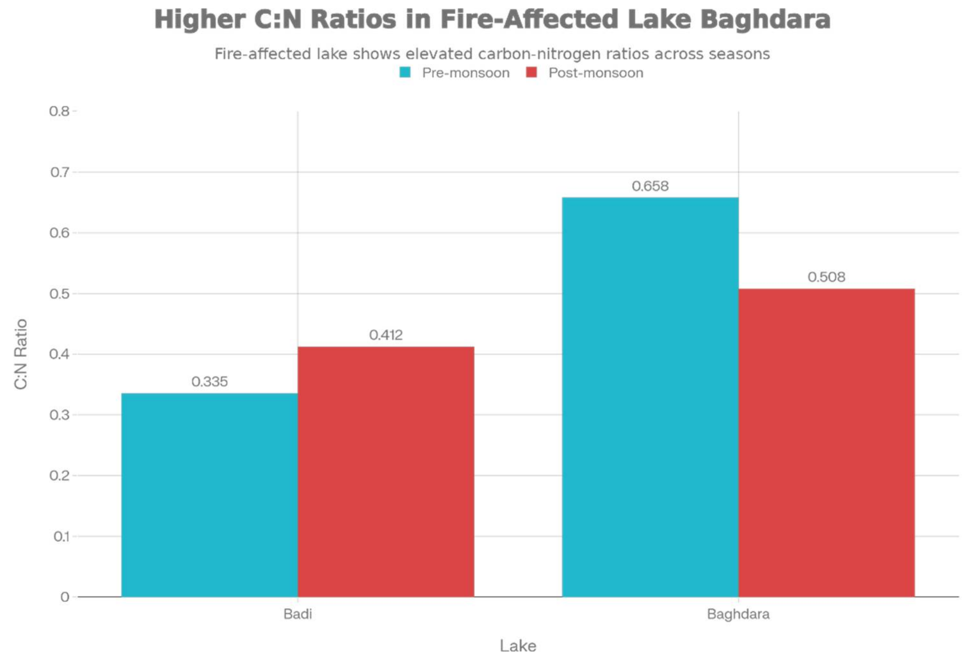

Figure 1. Comparison of C:N Ratios (DOC/Nitrate) in Lake Badi and Lake Baghdara

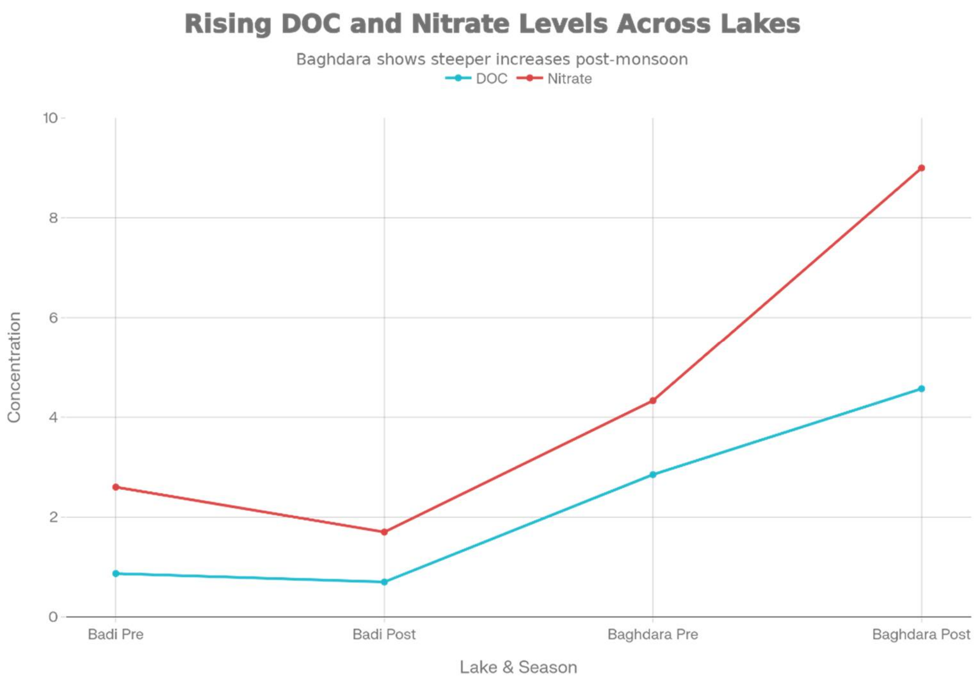

Figure 2: DOC and Nitrate Concentration Trends Across Seasons and Lakes

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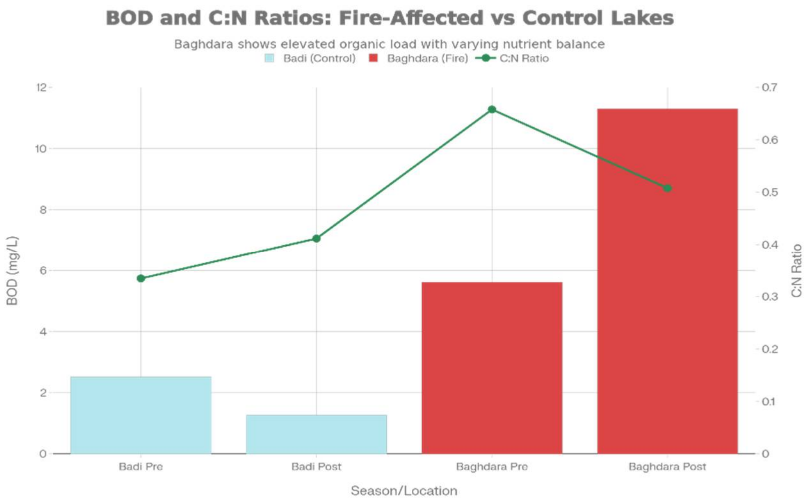

Figure 3: BOD Levels and C:N Ratios: Relationship Between Organic Load and Carbon-Nitrogen Balance

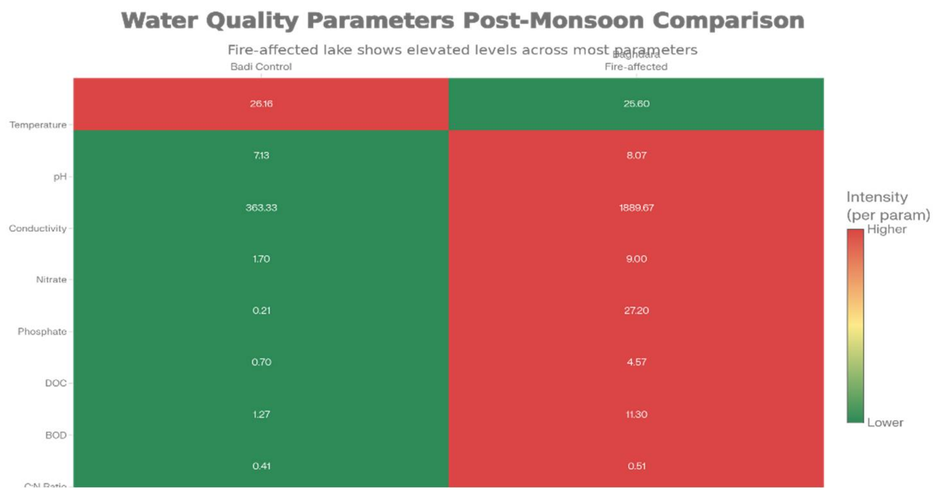

Figure 4: Post-Monsoon Water Quality Parameter Comparison: Heatmap of Badi vs Baghdara

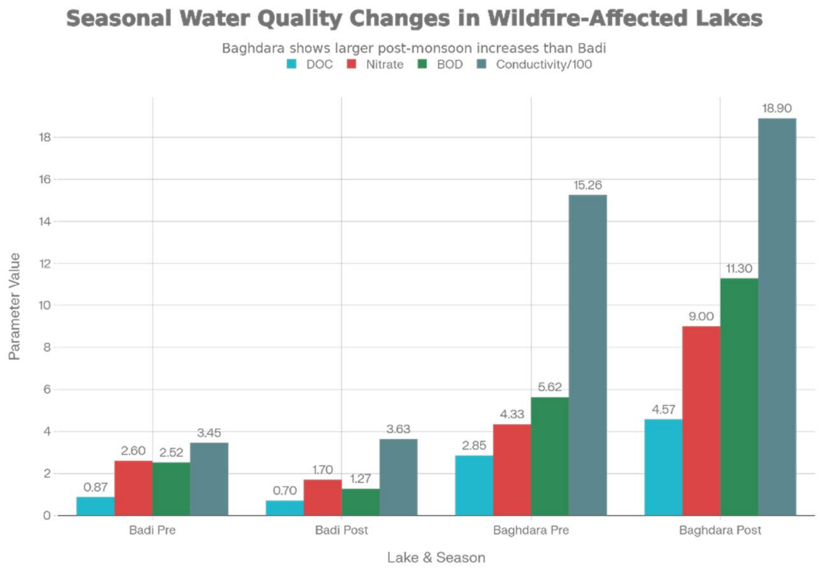

Figure 5: Seasonal Variation in Key Water Quality Parameters: Badi vs Baghdara

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Lake Baghdara showed substantially higher DOC and nitrate than Lake Badi in both seasons, with pre-monsoon C:N nearly double that of the control lake. Post-monsoon, the C:N ratio increased in Badi, whereas it decreased in Baghdara despite the marked rises in DOC and nitrate in Baghdara.

Seasonal DOC and nitrate dynamics

In Lake Badi, DOC decreased from 0.87 to 0.70 mg/L (−19.5%), and nitrate decreased from 2.60 to 1.70 mg/L (−34.6%) from pre- to post-monsoon. In Lake Baghdara, DOC rose from 2.85 to 4.57 mg/L (+60.4%), while nitrate more than doubled from 4.33 to 9.00 mg/L (+107.8%). These differences indicate normal seasonal dilution in the control lake and strong post-fire mobilization of both carbon and nitrogen in the fire-affected lake.

Statistical significance

Paired t-tests between pre- and post-monsoon within each lake showed significant seasonal changes in Badi for temperature, conductivity, nitrate, BOD and DOC, and in Baghdara for temperature, conductivity, hardness, TDS, alkalinity, nitrate, phosphate and BOD ($p < 0.05$). Paired comparisons between lakes for post-monsoon values indicated significant differences for all parameters except turbidity and alkalinity, demonstrating a strong wildfire signal on Baghdara water quality [29,40].

DISCUSSION

Fire-induced shifts in C:N ratio

The higher pre-monsoon C:N ratio in the fire-affected Lake Baghdara compared to the control Lake Badi indicates an immediate legacy of wildfire in the catchment, with proportionally greater export of carbon relative to nitrate shortly after the burn. This is consistent with evidence that combustion can volatilize part of the nitrogen pool while leaving behind charred, carbon-rich residues and ash with altered stoichiometry [48,57]. Fire can also produce more aromatic and nitrogen-rich DOC, but the net DOC response depends on burn severity, vegetation and subsequent hydrology [14].

Post-monsoon, both DOC and nitrate increased in Lake Baghdara, but nitrate rose proportionally more than DOC, leading to a decline in the DOC:NO_3^--based C:N ratio despite higher absolute concentrations of both elements. This pattern suggests strong post-fire mobilization and nitrification of soil nitrogen, combined with limited plant uptake and microbial immobilization due to carbon limitation [41]. Similar disproportionate increases in inorganic nitrogen, especially nitrate, have been reported in streams and lakes following wildfires in boreal, temperate and semi-arid regions, often persisting from several years up to a decade [28,45].

In contrast, the control Lake Badi showed modest decreases in both DOC and nitrate after the monsoon, with a slight increase in C:N ratio, reflecting dilution and normal seasonal flushing without additional fire-derived nutrient inputs. This divergence between the two lakes supports the interpretation that wildfire, rather than climate or regional deposition alone, is responsible for the altered stoichiometry and stronger post-monsoon nutrient pulses in Lake Baghdara [40,50].

The low C:N ratios (0.3–0.7) observed in both lakes are substantially below typical microbial biomass or seston C:N ratios, which are closer to or higher than the Redfield N proportion, indicating that dissolved inorganic nitrogen is relatively abundant compared to labile DOC [3,59]. Under such conditions, heterotrophic bacteria are likely carbon-limited, while nitrate remains available for export and for supporting primary production where phosphorus is sufficient [44,45]. The much higher BOD and lower DO in the fire-affected lake post-monsoon suggest that the DOC present is reactive enough to fuel intense microbial respiration, even if overall C:N is low. Elevated DOC and BOD following wildfire have been reported in other systems, with consequences for oxygen depletion, habitat degradation and treatment challenges for downstream water supplies [10,19].

The coupling between stoichiometry and oxygen dynamics is particularly critical in closed lakes, where long residence times, strong stratification and lack of flushing can favor hypoxia and internal nutrient loading [3,37]. In Lake Baghdara, the combination of high DOC, very high nitrate and phosphate, elevated BOD and depressed DO suggests an advanced eutrophication trajectory, with potential for periodic or persistent anoxia in deeper layers and further release of phosphorus from sediments via internal loading [61].

Eutrophication risk and trophic state shift

Long-term observations show that Lake Baghdara has shifted from oligotrophic toward mesotrophic conditions over the last two decades due to catchment runoff and indirect human activities, and the present results indicate that wildfire has accelerated this trend [36,37,55,56]. Post-monsoon phosphate and nitrate concentrations in the fire-affected lake far exceeded those in the control lake, with values comparable to those associated with severe eutrophication and harmful algal blooms in other freshwater systems [61]. Combined with elevated conductivity and TDS, this nutrient enrichment points to enhanced external and potentially internal loading, amplified by fire-induced erosion and ash deposition [24,29,44]. Wildfire-driven changes in water quality similar to those observed here—higher DOC, nitrogen, phosphorus, suspended solids and reduced clarity—have been documented in a variety of lake types, with effects sometimes lasting several years [10,57]. Multi-year analyses from North America and Europe indicate that post-fire water quality degradation can persist beyond the initial recovery of vegetation, and that the magnitude of change is related to burn severity, hydrologic connectivity and lake type [57]. The closed-basin nature of Baghdara, together with semi-arid climate and high evaporation, likely enhances the accumulation and persistence of these fire-derived solutes compared with more open, well-flushed systems [3,36].

C:N ratio as an integrative indicator and management tool

This study shows that a simple DOC:NO_3^--based C:N ratio, derived from routine monitoring parameters, is a useful integrative indicator of wildfire impacts on lake biogeochemistry. Changes in C:N captured both the immediate post-fire enrichment in carbon relative to nitrogen and the subsequent dominance of nitrate mobilization during the monsoon period. Coupling C:N ratio data with measurements of DOC, nitrate, phosphate, DO and BOD provides a mechanistic understanding of how fire alters the balance between carbon supply, nitrogen availability, microbial respiration and eutrophication risk [44,45].

From a management perspective, monitoring DOC, nitrate, C:N ratio and key supporting parameters in fire-prone watersheds can help identify windows of elevated vulnerability for drinking water treatment and aquatic ecosystem health [10,1940]. The strong post-monsoon responses observed here suggest that sampling should be intensified during and after storm events in the first years following wildfire, when the largest pulses of DOC and nutrients are likely to occur [29,30,57]. In closed or poorly flushed lakes, this information can support decisions regarding catchment rehabilitation, erosion control, early warning for algal blooms and adjustments in treatment processes to address higher organic loads and disinfection by-product formation potential [10,46].

CONCLUSION

Wildfire in the catchment of a closed tropical lake substantially altered DOC, nitrate and their C:N ratio, alongside wide-ranging changes in ionic content, nutrients and oxygen regime [31,50]. The fire-affected lake exhibited higher baseline C:N ratio pre-monsoon, strong post-monsoon increases in both DOC and nitrate but a declining C:N ratio due to disproportionate nitrate mobilization, and severe eutrophication indicators such as high phosphate, high BOD and low DO.

The DOC:NO_3^- C:N ratio, calculated from standard monitoring parameters, proved to be a useful integrative indicator of post-fire biogeochemical alteration in closed-basin lakes [3,44]. For water managers in fire-prone regions, concurrent monitoring of DOC, nitrate, C:N ratio, DO, BOD and key ions is recommended to assess post-fire risks to drinking water quality and lake ecosystem health [10,40]. In semi-arid systems with limited flushing, such as the studied lakes in southern Rajasthan, wildfire should be recognized as a major driver of long-term trophic state change and integrated explicitly into catchment and water resource management plans [37,40].

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