ABES

Revista Brasileira de Ciências Ambientais
Brazilian Journal of Environmental Sciences

Diffuse contribution of organic matter in the *Mata dos Cocais* Forest, Brazil

Contribuição difusa de matéria orgânica na floresta Mata dos Cocais, Brasil

Josiana do Nascimento Alves Feitosa[1], *Christine Farias Coelho*[1], *Olga Aline Rodrigues da Silva*[2], *José Carlos de Araújo*[1]

ABSTRACT

The *Mata dos Cocais* Forest, an ecotone between the Amazon, Caatinga, and Cerrado biomes, still lacks data on the diffuse contribution of organic matter to rivers. A 12-month study conducted along a 3.53 km stretch of the Saco River (1,540 km^2 basin), predominantly covered by dense forest, used the Streeter-Phelps model to estimate diffuse organic matter concentrations of 0.201 mg BOD L^{-1} km^{-2} and 0.95 mg BOD L^{-1} km^{-1} — values similar to those reported for tropical forests in Indonesia, Malaysia, and the Brazilian Cerrado. This organic matter input is attributed to the decomposition of plant biomass in densely forested areas. By providing previously unpublished primary data for the region, this study advances understanding of organic matter fluxes in the *Mata dos Cocais* Forest. It offers valuable insights for planning and formulating water and environmental management policies.

Keywords: diffuse pollution; surface runoff; biochemical oxygen demand; tropical ecotone; land use land cover.

RESUMO

A Floresta Mata dos Cocais, ecótono entre os biomas Amazônia, Caatinga e Cerrado, ainda carece de dados sobre a contribuição difusa de matéria orgânica para os rios. Um estudo realizado por 12 meses em um trecho de 3,53 km do rio Saco (bacia de 1.540 km^2), cuja bacia tem predominância de floresta densa, estimou, por meio do modelo Streeter-Phelps, concentrações difusas de matéria orgânica de 0,201 mg DBO L^{-1} km^{-2} e 0,95 mg DBO L^{-1} km^{-1}, valores semelhantes aos de florestas tropicais na Indonésia, Malásia e Cerrado Brasileiro. A entrada de matéria orgânica é atribuída à decomposição da biomassa vegetal em áreas de cobertura florestal densa. Ao fornecer dados primários inéditos para a região, este estudo contribui para o avanço do entendimento dos fluxos de matéria orgânica na floresta Mata dos Cocais e oferece subsídios relevantes para o planejamento e a formulação de políticas públicas voltadas à gestão hídrica e ambiental.

Palavras-chave: poluição difusa; escoamento superficial; demanda bioquímica de oxigênio; ecótono tropical; uso e cobertura da terra.

[1]Federal University of Ceará – Fortaleza (CE), Brazil.

[2]Federal University of Piauí – Teresina (PI), Brazil.

Corresponding author: Josiana Feitosa – Federal University of Ceará, Center for Agricultural Science, Agricultural Engineering Department – Avenida Mister Hull, s/n – Campus do Pici, Bloco 804 – Pici – CEP: 60356-000 – Fortaleza (CE), Brazil. E-mail: josinascimento1997@gmail.com

Received on: 07/18/2025. Accepted on: 05/26/2026.

https://doi.org/10.67790/rbciamb.026.2699

Introduction

To implement effective hydro-environmental policies, accurate knowledge of water quality is required. Organic matter is one of its main indicators, with Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) being its most common proxies (Lung, 2023). Nevertheless, monitoring these *proxies* in river systems remains challenging worldwide, since few studies have examined how changes in vegetation cover affect the molecular composition and bioavailability of organic matter (Neves et al., 2021; Vaughn et al., 2023).

Previous studies support this pattern: Leul et al. (2023) recorded higher organic matter content in natural forests (4.04%) than in commercial farms (1.82%), and Molla et al. (2022) similarly found that natural forest soils contained higher nutrient levels, with organic carbon averaging 1.75% compared to 1.20% in cultivated soil. Allochthonous organic matter is known to influence BOD dynamics in aquatic systems, a relationship well established in the literature (e.g., Wetzel, 2001; Nas and Nas, 2009). Notably, the diffuse contribution of organic matter from the drainage basin — such as humic and fulvic substances from terrestrial vegetation and soil — represents an important fraction of the organic load that controls BOD (Von Sperling, 2014; Amado et al., 2024). During surface runoff events — particularly heavy rainfall — large quantities of particulate and dissolved organic matter can be transported to the water body, intensifying sporadic peaks in diffuse BOD. This, in turn, can be interpreted as a functional proxy for the load of allochthonous organic matter mobilized by the basin, reflecting both hydrological processes and land use and land cover in the region. This relationship emphasizes the importance of integrated watershed management to mitigate impacts on water quality.

In this regard, this study estimated the easily oxidizable organic matter present in a water body based on the BOD associated with the diffuse contribution — *i.e.*, the fraction of biodegradable organic matter consumed by microbial activity that is transported to watercourses by surface runoff (Fattah et al., 2021; Jang et al., 2021; Bustos-Terrones et al., 2024) — which is why this study focuses on the rainy season.

The study area corresponds to the *Mata dos Cocais* Forest (MCF), a 32,609 km² ecotone (Caselli et al., 2019) located between the Amazon, Caatinga, and Cerrado biomes. This region, also known as the Cocais Palm Forest (Santos et al., 2023), is a hydroecologically relevant zone, yet the scarcity of hydrological and environmental data hampers policy decisions.

In this context, this study aims not only to quantify the diffuse contribution of BOD in this ecotone but also to provide new empirical evidence on the magnitude and dynamics of allochthonous organic matter inputs in a little-studied tropical transition zone. In doing so, the study advances current knowledge by: (i) establishing baseline data for diffuse BOD in the *Mata dos Cocais*, (ii) elucidating the relationship between dense forest cover and organic matter inputs into aquatic systems, and (iii) enabling comparisons with other regions, thereby contributing to a broader understanding of biogeochemical processes in these environments. This helps reduce knowledge gaps and inform more effective watershed management strategies, especially in regions where land use and hydrological variability strongly influence water quality.

Materials and methods

The study area is the *Mata dos Cocais*, in the municipality of Codó, Maranhão, Brazil. The experimental field comprises the downstream stretch of the Saco River basin (Figure 1), which is located within the Itapecuru River basin. This experimental stretch was chosen because it best characterizes the input of organic matter: it receives contributions from the entire basin. This stretch is 3.53 km long and has a direct contribution area of 16.45 km².

As previously detailed by Feitosa et al. (2024), land use and land cover in the Saco River basin (1,540 km²) is predominantly dense vegetation (58%), followed by exposed soil (23%, likely associated with agricultural activities); the remaining classes cover smaller areas, including sparse vegetation (15%), urban areas (2%), and water bodies (2%), as shown in Figure 2.

The Streeter-Phelps model (1925, Equation 1) was used to calibrate K_d and K_r. Equation 1 contains: C = oxygen concentration (mg L^{-1}); C_S = oxygen saturation concentration (mg L^{-1}); C_0 = oxygen concentration in the upstream section (mg L^{-1}); L_0 = BOD remaining at t = 0 (mg L^{-1}); K_d = deoxygenation coefficient; K_r = re-aeration coefficient. Travel time (t_t) is evaluated by Equation 2, where Δx = distance between sections; W_A = wetted area, and $\overline{Q}$ = average river flow. The oxygen saturation concentration (CS) is a function of water temperature and altitude, decreasing as these variables increase. Given that the municipality of Codó has a low average altitude (47 m) and is close to sea level, the effect of altitude on CS was considered negligible. Thus, the parameter was estimated exclusively as a function of water temperature, according to Equation 3, based on Pöpel (1979).

$$C = C_s - \left\{ \frac{k_d \cdot L_0}{k_r - k_d} \cdot \left(e^{-k_d \cdot t_t} - e^{-k_r \cdot t_t}\right) + (C_s - C_0) \cdot e^{-k_r \cdot t_t} \right\} \quad (1)$$

$$t_t = \frac{\Delta x}{\overline{Q}/W_A} \quad (2)$$

$$C_s = 14.652 - 4.1022.10^{-1}.T - 7.9910.10^{-3}.T^2 - 7.7774.10^{-5}.T^3 \quad (3)$$

To calibrate the deoxygenation and reaeration coefficients for the Saco River, measured data from the dry season were used. Firstly, initial values were adopted for K_d and K_r: the preliminary K_d was taken from Von Sperling (2014) and Chapra (1997), and the preliminary K_r was based on the equation of O'Connor and Dobbins (1958, *as cited in* Von Sperling, 2014). Table 1 shows the minimum, average, and maximum values, using the maximum K_d and K_r values as the starting point

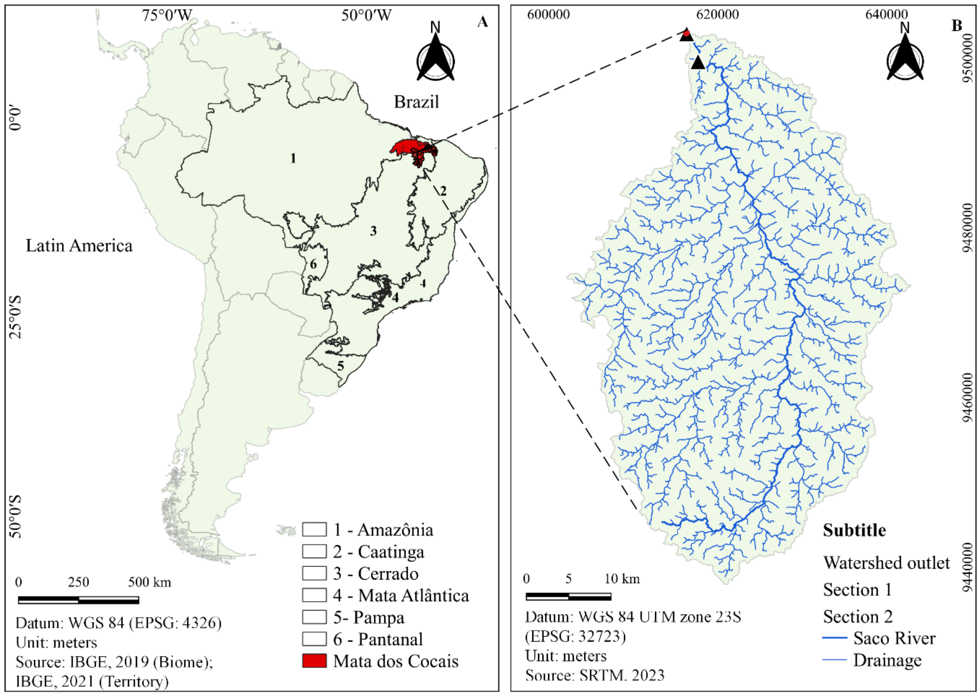

Figure 1 – Study area. (A) Brazilian biomes. (B) Saco River basin with highlighted experimental territory.

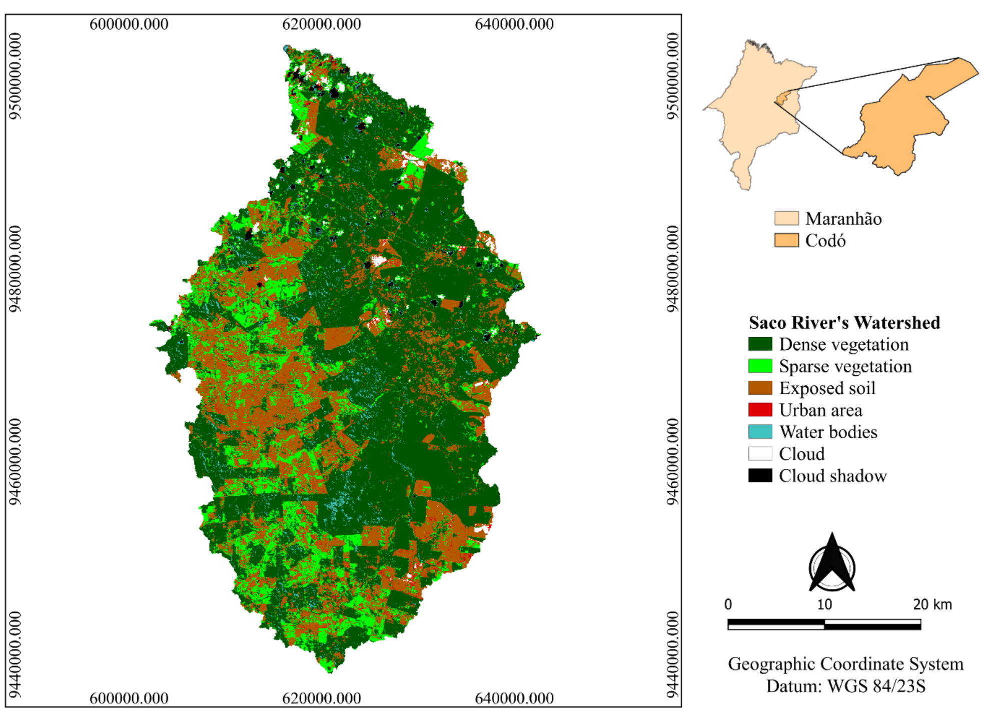

Figure 2 – Land use and land cover of the Saco River watershed

for calibration. We emphasize that these values correspond to a temperature of 20°C and therefore had to be corrected to the measured watercourse temperature, *i.e.*, 27.7°C on average (Equation 4).

$$K_{x_T} = K_{x_{20}} . \theta^{T-20} \quad (4)$$

in which T is the liquid temperature (°C); θ is the temperature coefficient. It should be noted that a value of θ equal to 1.047 is used for the K_d correction and a value of θ equal to 1.024 is used for the K_r correction (EPA, 1987); K_{xT} is K_x at any temperature T (day^{-1}); K_{x20} is K_x at a temperature T = 20°C (day^{-1}); K_x is the coefficient K_1 or K_2.

The dissolved oxygen content in the upstream section (C_0) was measured using the Winkler titulometric method (Clesceri et al., 1995), and BOD was determined according to APHA (2005) using the LineLab DO Eco oxygen measuring device, with a range of 0 to 20 mg L^{-1}, resolution of 0.01 mg L^{-1} and accuracy of ±2% full scale.

In the downstream section of the river (S2), the flow (Q) was measured *in situ* using the equal width increment method and with the help of a current meter. In the upstream section (S1), the Chiu Entropy method (Chiu et al., 2005, Equation 5) was used to assess river discharge, since this section of the river is inaccessible. We calibrated the Chiu parameter ($M = 2.16$) using measurements of the S2 section. This procedure is valid, as previously demonstrated by Rodrigues et al. (2025). The maximum velocity (u_{max}) was measured *in situ*.

$$Q = u_{max} \cdot \left(\frac{e^M}{e^M - 1} - \frac{1}{M} \right) \cdot W_A \quad (5)$$

The diffuse contribution of BOD was calculated from the analysis based on the difference between the measured and estimated values in the downstream section. This stage has been reached using Equation 6 (adapted from Von Sperling, 2014).

$$L_{dif} = L_m - L_0 . e^{-k_d \cdot t_t} \quad (6)$$

where L_{dif} corresponds to the concentration of the diffuse contribution of BOD (mg L^{-1}), L_m is the BOD measured in the downstream section, and L_0 is the BOD measured in the upstream section, both in mg L^{-1}.

The diffuse contribution of BOD (L_{dif}) was expressed both as a function of the length (ΔX) of the river section (Linear Diffuse Contribution of BOD - L_{CL}, Equation 7) and as a function of the direct contribution area ΔA (Area Diffuse Contribution of BOD — L_{CA}, Equation 8). Thus, the L_{CL} and L_{CA} values were obtained from the rainy-season data, which were considered because of the effective surface diffuse contribution of BOD (Li et al., 2020).

$$L_{CL} = \frac{\Delta L}{\Delta X} \quad (7)$$

$$L_{CA} = \frac{\Delta L}{\Delta A} \quad (8)$$

Results and discussion

A considerable BOD contribution was recorded for the MCF, including areas with preserved vegetation (L_{CL} = 0.94 mg L^{-1} km^{-1} and L_{CA} = 0.201 mg L^{-1} km^{-2}: see Table 2), which is in line with Vaughn et al. (2023). The results are limited to the rainy season, since this is when the diffuse contribution of BOD from surface runoff occurs. Jang et al. (2021) similarly reported that water quality declines during the rainy season owing to soil leaching in agricultural areas, which increases concentrations of nitrogen compounds, while Neves et al. (2021) found that higher surface runoff rates led to water quality deterioration in streams.

Although median BOD was generally lower during the dry season (Table 2), high peaks were recorded in the first weeks, particularly on August 4 and 11, 2023, with values of up to 13.60 mg L^{-1} at S1 and 12.50 mg L^{-1} at S2. These episodes indicate that the influx of organic matter can occur sporadically during the dry season, possibly due to localized events or a delayed hydrological response. Following these peaks, BOD levels decline, reflecting reduced surface runoff and a lower contribution of organic matter.

Figure 3 shows the difference between measured and estimated BOD (term $L_0 . e^{-k_d \cdot t_t}$ from Equation 6) in the downstream section. During the rainy season, the measured BOD exceeded the estimated BOD, indicating the influence of diffuse contributions.

Table 3 shows the diffuse contribution of BOD in the MCF, as well as values of this parameter in other regions for comparison.

Table 3 shows that the three regions most similar to MCF — since they are likewise made up of tropical forest and preserved vegetation (Cisadane and Cibanten, in Indonesia; and Batang Igan, in Malaysia) — have BOD contributions of the same order of magnitude as the MCF: L_{CL} values in these Asian basins range from 0.18 to 1.59 mg BOD L^{-1} km^{-1}. At the same time, the L_{CL} for our area is 0.94 mg BOD L^{-1} km^{-1}. The conditions of the Brazilian Cerrado Água Branca basin are partially comparable to those of the MCF: its climate is tropical, and it has preserved riparian vegetation; its L_{CA} is 0.077 mg BOD L^{-1} km^{-2}, which corresponds to 38% of the value measured in the Saco River (0.201 mg BOD L^{-1} km^{-2}).

These results suggest that climate, together with land use and land cover, are the predominant drivers of diffuse BOD contribution, confirming the conclusions of Yoder et al. (2019) and Ghosh and Panigrahi (2024). Leul et al. (2023) and Wu et al. (2023), for example, showed that plant litter and roots in natural forests contain substantial organic matter, particularly as dissolved and particulate organic carbon, which can be mobilized through leaching and subsurface transport, contributing significantly to BOD in these areas.

Table 1 – Starting values (minimum, average, and maximum) for the deoxygenation (K_d in day^{-1}) and reaeration (K_r in day^{-1}) coefficients at 20°C and adjusted to 27.7°C.

	K_d (20°C)	K_d (27.7°C)	K_r (20°C)	K_r (27.7°C)
Minimum	0.35	0.50	0.44	0.53
Average	0.43	0.61	0.73	0.88
Maximum	0.50	0.71	1.89	2.27

Table 2 – Summary of experimental results: average flow rate ($\overline{Q}$), average velocity (u_{avg}), travel time (t_t), BOD in the upstream section of the river (BOD_1), BOD in the downstream section of the river (BOD_2), linear diffuse contribution BOD (L_{CL}) and diffuse contribution by area (L_{CA}).

Date (mm/dd/yr)	$\overline{Q}$(m^3 s^{-1})	u_{avg} (m s^{-1})	t_t (days)	BOD_1 (mg L^{-1})	BOD_2 (mg L^{-1})	L_{CL} (mg L^{-1} km^{-1})	L_{CA} (mg L^{-1} km^{-2})
06/16/2023	4.61	0.38	0.11	6.78	8.75	0.649	0.139
07/14/2023	2.68	0.27	0.15	13.90	16.60	1.022	0.219
07/28/2023	2.06	0.21	0.20	10.70	12.85	0.861	0.185
08/04/2023	1.59	0.15	0.28	13.60	12.50	dry season	dry season
08/11/2023	2.18	0.22	0.18	10.93	9.21	dry season	dry season
08/18/2023	1.95	0.20	0.20	8.00	5.85	dry season	dry season
09/15/2023	1.86	0.20	0.20	4.10	1.55	dry season	dry season
09/22/2023	1.99	0.22	0.19	8.75	6.05	dry season	dry season
10/06/2023	2.00	0.22	0.18	2.90	2.45	dry season	dry season
11/17/2023	1.59	0.20	0.20	11.75	14.65	1.104	0.237
11/24/2023	1.93	0.23	0.18	10.70	13.45	1.012	0.217
12/15/2023	1.56	0.19	0.21	10.55	11.85	0.638	0.137
Median value (rainy)	2.00	0.48	0.19	10.70	13.15	0.936	0.201
Standard deviation (rainy)	1.05	0.05	0.04	2.11	2.43	0.183	0.039
Median value (dry)	1.97	0.43	0.20	8.38	5.95	dry season	dry season
Standard deviation (dry)	0.18	0.08	0.03	3.69	3.75	dry season	dry season

Table 3 – Diffuse contribution of linear BOD (L_{CL}, mg L^{-1} km^{-1}) and by area (L_{CA}, mg L^{-1} km^{-2}) in Brazil and the world during the rainy season. All regions have average annual precipitation (*AAP*, mm year^{-1}) above 1300.

Country (river)	Biomes	Land use land cover	Climate	*AAP*	L_{CL}	L_{CA}	Source
Indonesia (Cisadane)	Tropical Forest	Agriculture, preserved forest	Tropical Monsoon	2350	0.18	n/a	Gumelar et al. (2017)
Indonesia (Cibanten)	Tropical Forest	Agriculture, preserved forest	Tropical Monsoon	2350	1.59	n/a	Baherem et al. (2014)
Malaysia (Batang Igan)	Tropical Swamp Forest	Agriculture, preserved forest	Tropical	4000	0.85	n/a	Rosli et al. (2010)
Brazil (Água Branca)	Cerrado	Preserved riparian vegetation	Tropical highland	1464	n/a	0.077	Moruzzi et al. (2012)
China (Changshangang)	Subtropical Forest	Urban and industrial	Humid subtropical	1700	0.02	n/a	Fang et al. (2008)
China (Jinhua)	Subtropical Forest	Industrial	Humid subtropical	1700	0.04	n/a	Fang et al. (2008)
Brazil (Sinos)	Atlantic Forest	Urban and industrial	Temperate subtropical	1600	0.02	0.009	Gomes et al. (2018)
Brazil (Pardo)	Atlantic Forest	Urban	Hot tempered	1345	0.40	n/a	Rocha et al. (2021)
Brazil (Saco)	*Mata dos Cocais*	Preserved forest	Tropical subhumid	1600	0.94	0.201	*Present study*

n/a = not available

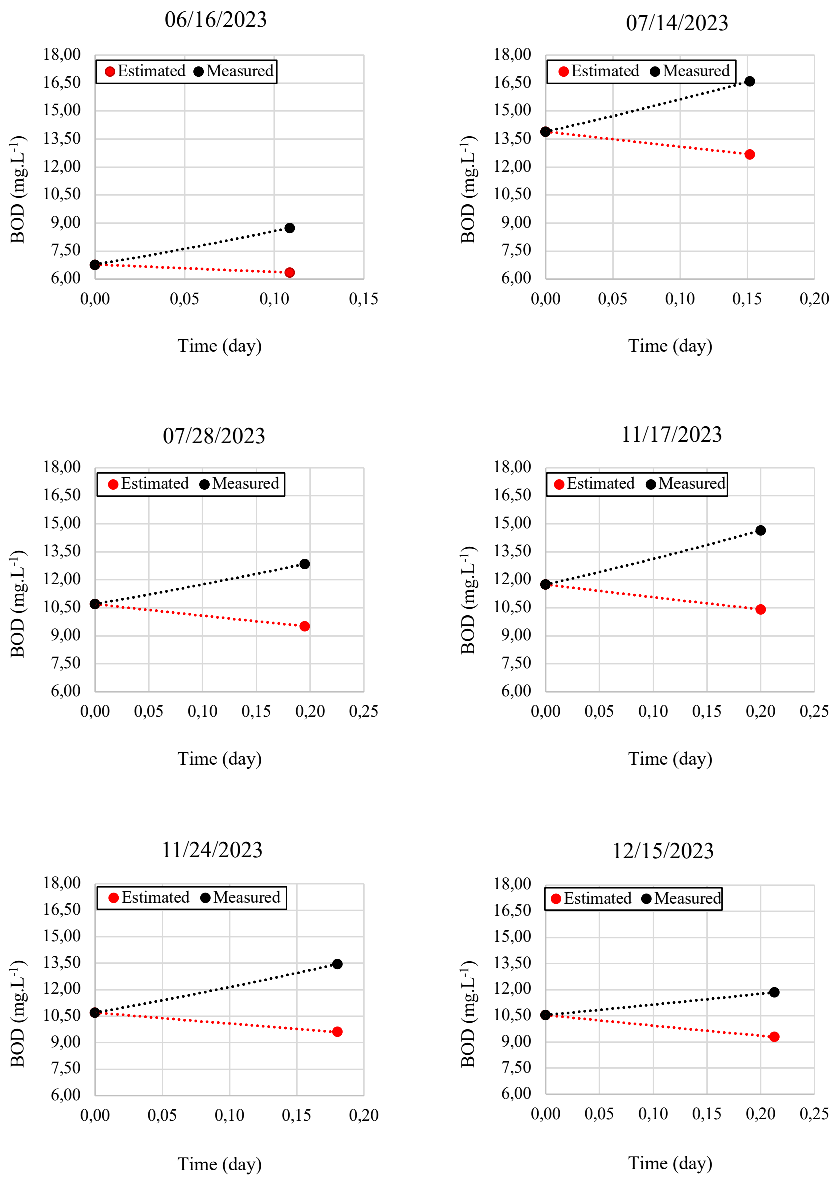

Figure 3 – Temporal variation of Biochemical Oxygen Demand (BOD, mg L^{-1}) showing estimated *versus* measured values in the upstream and downstream sections on different sampling dates.

In our study, the organic input may be due to the decomposition of plant biomass, which increases the availability of biodegradable organic substrates, thereby stimulating heterotrophic microbial respiration and, consequently, the consumption of dissolved oxygen. Furthermore, in areas of exposed soil, predominantly associated with agricultural activity, soil disturbance and the absence of vegetation cover favor surface runoff, soil erosion, and the transport of organic waste and nutrients into watercourses, thereby increasing the organic load, albeit to a lesser degree. Thus, both dense forest cover and agricultural practices, which are the predominant classes in the region (Feitosa et al., 2024), contribute, by different means, to the increase in organic matter available in the aquatic environment, highlighting their relevance to BOD in the basin.

The industrial and urban areas shown in Table 3 have a lower diffuse BOD contribution than the MCF: L_{CL} values in these catchments range from 0.02 to 0.04 mg BOD L^{-1} km^{-1}, while in the MCF they reach 0.94 mg BOD L^{-1} km^{-1}. This is because in these areas, fewer nutrients are washed away by rainfall, as much of the soil is sealed, meaning that organic matter has been significantly reduced and, therefore, there is not a high level of nutrient transport to watercourses (Leul et al., 2023).

Sanitized urbanized and industrial areas tend to contribute lower rates of organic matter than forests (Vaughn et al., 2023), but when they are not properly sanitized, their diffuse contributions of organic matter are high (Badin et al., 2008), which may explain the higher value in Pardo, since the city does not have a sewage treatment plant (STP).

It is worth noting that Chinese rivers also experience high pollution loads, but the lower L_{CL} values shown in Table 3 result from excluding illegal sewage discharges from the simulation model (Fang et al., 2008). The Sinos River, on the other hand, receives point loads that increase BOD, but the lower population density elsewhere in the river allows self-depuration to reduce organic matter (Von Sperling, 2014; Gomes et al., 2018).

Despite the overall consistency of the results, an important limitation should be acknowledged. The model employs average coefficients (L_{CL} and L_{CA}), which may inadequately capture the spatial and temporal heterogeneity of hydrological and biogeochemical processes. Moreover, unmonitored sources, such as illicit sewage discharges and unquantified diffuse inputs, were not explicitly accounted for, potentially leading to an underestimation of actual BOD loads. These limitations highlight opportunities for improving the model's representation of underlying processes.

Despite these limitations, the results suggest that the study's objectives were largely achieved. The work provides initial baseline estimates for diffuse BOD in the *Mata dos Cocais*, helping to fill a gap in the literature, and indicates a consistent relationship between forest cover and allochthonous organic matter inputs, highlighting the role of vegetation in aquatic systems.

Additionally, the results enable preliminary comparisons with other regions, broadening understanding of biogeochemical processes in tropical ecotones. Although the model's simplifications and associated uncertainties should be considered, the study makes relevant advances in understanding the dynamics of diffuse BOD. It can, with due reservations, support watershed management strategies in contexts influenced by land use and hydrological variability.

Conclusion

The MCF exhibits a diffuse contribution of organic matter caused by natural erosion during the rainy season of 0.201 mg BOD L^{-1} km^{-2}; 0.95 mg BOD L^{-1} km^{-1}. This result is consistent with those from the tropical forests of Indonesia and Malaysia, which share similarities in climate (tropical) and land-use patterns (*i.e.*, a mosaic of agriculture and preserved forest) with the MCF. In addition, the Brazilian Cerrado Biome showed results that were partially comparable to those of the MCF, since its climate is tropical and it has preserved riparian vegetation, corresponding to an L_{CA} of 38% of the value measured in the Saco River.

The *Mata dos Cocais* forms part of a strategic hydroecological zone that connects the Amazon, Caatinga, and Cerrado biomes. However, the scarcity of hydrological and environmental data on this ecotone limits understanding of its dynamics and hinders sustainable management. In this context, this study contributes primary data on the diffuse contribution of organic matter, supporting public policies for the conservation and sustainable use of the basin, and can further guide monitoring efforts and strategies to mitigate water quality degradation.

Overall, this study (i) provides initial baseline estimates for diffuse BOD in the *Mata dos Cocais*, filling a gap in the literature on this tropical ecotone; (ii) demonstrates a consistent relationship between forest cover and allochthonous organic matter inputs, highlighting the role of vegetation in aquatic biogeochemical processes; and (iii) advances the understanding of diffuse BOD dynamics under varying land use and hydrological conditions, offering a methodological basis for water quality assessment in other data-scarce environments.

Acknowledgements

The authors thank the Coordination for the Improvement of Higher Education Personnel – CAPES for awarding the scholarship to the first author; they also thank the Research and Extension Group in Soils and Water Management (GPEMSA) of the Federal Institute of Education, Science and Technology of Maranhão (IFMA), Codó campus, for supporting the fieldwork. Thanks also to Prof. Iran Lima Neto for the valuable discussions on the topic.

Authors' Contributions: Feitosa, J.N.A.: data curation, formal analysis, investigation, methodology, writing (original draft). Coelho, C.F.: formal analysis, investigation, supervision, writing (original draft, review & editing). Silva, O.A.R.: data curation, formal analysis. Araújo, J.C.: conceptualization, formal analysis, investigation, methodology, funding, supervision, validation, writing (original draft & review).

Conflicts of interest: the authors declare no conflicts of interest.

Funding: Coordination for the Improvement of Higher Education Personnel (CAPES) provided a scholarship to the first author, while National Council for Scientific and Technological Development (CNPq) granted a research productivity fellowship to José Carlos de Araújo.

Declaration on the use of generative artificial intelligence: The authors state that they did not use any artificial intelligence (AI) tools or services during the preparation of this manuscript. We take full responsibility for the content of the published article.

References

Amado, A.M.; Esteves, F.A.; Suhett, A.L.; Lima, A.L.R.L.; Fonseca, L.M.; Farjalla, V.F., 2024. Photochemical mineralization of DOM in high humic tropical aquatic ecosystems: ambiguous regulation by watercolor. Acta Limnologica Brasiliensia, v. 36, e39. https://doi.org/10.1590/S2179-975X0624

American Public Health Association (APHA), 2005. Standard Methods for the Examination of Water and Wastewater. 21st ed. American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC.

Badin, A.L.; Faure, P.; Bedell, J.P.; Delolme, C., 2008. Distribution of organic pollutants and natural organic matter in urban storm water sediments as a function of grain size. Science of the Total Environment, v. 403 (1-3), 178-187. https://doi.org/10.1016/j.scitotenv.2008.05.022

Baherem, B.; Suprihatin, S.; Indrasti, N.S., 2014. Strategi Pengelolaan Sungai Cibanten Provinsi Banten Berdasarkan Analisis Total Beban Maksimum Harian dan Kapasitas Asimilasi. Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan, v. 4 (1), 60-69. https://journal.ipb.ac.id/index.php/jpsl/article/view/10551/8181

Bustos-Terrones, Y.A.; Loaiza, J.G.; Rangel-Peraza, J.G.; Rojas-Valencia, M.N., 2024. Evidencing anthropogenic pollution of surface waters in a tropical region: a case study of the Culiacan River basin. Environmental Monitoring and Assessment, v. 196 (901). https://doi.org/10.1007/s10661-024-13018-x

Caselli, F.T.R.; Espindola, G.M.; Lopes, J.B., 2019. Análise temporal da cobertura do solo no Território dos Cocais usando sensoriamento remoto. Revista Tecnologia e Sociedade, v. 15 (37), 40-55. https://periodicos.utfpr.edu.br/rts/article/view/7778/6282

Chapra, S.C., 1997. Surface water-quality modeling. Tufts University, USA.

Chiu, C.L.; Hsu, S.M.; Tung, N.C., 2005. Efficient methods of discharge measurements in rivers and streams based on the probability concept. Hydrological Processes, v. 19 (20), 3935-3946. https://doi.org/10.1002/hyp.5857

Clesceri, L.S.; Greenberg, A.E.; Eaton, A.D., 1995. Standard Methods for the Examination of Water and Wastewater. 19th ed. Washington, D.C.: APHA.

Environmental Protection Agency (EPA), 1987. United States Environmental Protection Agency. The enhanced stream water quality models QUAL2E and QUAL2E-UNCAS. Documentation and user model, Athens.

Fang, X.; Zhang, J.; Chen, Y.; Xu, X., 2008. QUAL2K Model Used in the Water Quality Assessment of Qiantang River, China. Water Environment Research, v. 80 (11), 2125-2133. https://doi.org/10.2175/106143008X304794

Fattah, G.; Ghrissi, F.; Mabrouki, J.; Al-Jadabi, N., 2021. Modeling and assessment of the impact of land use in the western Rif region, Morocco, on water quality. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, v. XLVI-4/W5-2021, 225-230. https://doi.org/10.5194/isprs-archives-XLVI-4-W5-2021-225-2021

Feitosa, J. N. A.; Coelho, C.F.; Silva, R.C.C.; Ribeiro, A.T.; Simplicio, A.A.F., 2024. Land use and land cover mapping of the Saco River's watershed, State of Maranhão, Brazil. Revista Brasileira de Ciências Ambientais (RBCIAMB), v. 59, e2127. https://doi.org/10.5327/Z2176-94782127

Ghosh, P.; Panigrahi, A.K., 2024. Assessment of water quality and source apportionment of pollution in a tropical river in eastern India: A study utilizing multivariate statistical tools and the APCS-MLR receptor model. Environmental Monitoring and Assessment, v. 196 (861). https://doi.org/10.1007/s10661-024-13022-1

Gomes, S.H.R.; Guedes, H.A.S.; Siqueira, T.M.; Corrêa, L.B.; Andreazza, R.; Hüffner, A.N., 2018. Modelagem sazonal da qualidade da água do rio dos Sinos/RS utilizando o modelo QUAL-UFMG. Engenharia Sanitária e Ambiental, v. 23 (2), 275-285. https://doi.org/10.1590/S1413-41522018169332

Gumelar, A.R.; Alamsyah, A.T.; Gupta, I.B.H.; Syahdanul, D.; Tampi, D.M., 2017. Sustainable watersheds: assessing the source and load of Cisadane River Pollution. International Journal of Environmental Science and Development, v. 8 (7). https://www.ijesd.org/vol8/1001-B3002.pdf

Jang, S.; Ji, H.; Choi, J.; Suh, K.; Kim, H., 2021. Investigation of correlation between surface runoff rate and stream water quality. Water Supply, v. 21 (4), 1495-1505. https://doi.org/10.2166/ws.2021.023

Leul, Y.; Assen, M.; Damene, S.; Legass, A., 2023. Effects of land use types on soil quality dynamics in a tropical sub-humid ecosystem, western Ethiopia. Ecological Indicators, v. 147, 110024. https://doi.org/10.1016/j.ecolind.2023.110024

Li, Z.; Peng, H.; Xie, B.G.; Liu, C.; Nie, X.D.; Wang, D.; Huang, M.; Xiao, H.; Shi, L.; Zhang, X.; Jiang, J., 2020. Dissolved organic matter in surface runoff in the Loess Plateau of China: The role of rainfall events and land-use. Hydrological Processes, v. 34 (6), 1446-1459. https://doi.org/10.1002/hyp.13660

Lung, W.S., 2023. Progression of river BOD/DO modeling for water quality management. Water Environment Research, v. 95 (4). https://doi.org/10.1002/wer.10864

Molla, E.; Getnet, K.; Mekonnen, M., 2022. Land use change and its effect on selected soil properties in the northwest highlands of Ethiopia. Heliyon, v. 8 (8), e10157. https://doi.org/10.1016/j.heliyon.2022.e10157

Moruzzi, R.B.; Conceição, F.T.; Sardinha, D.S.; Honda, F.P.; Navarro, G.F.B., 2012. Avaliação de cargas difusas e simulação de autodepuração no Córrego da Água Branca, Itirapina (SP). Geociências, v. 31 (3), 447-458.

Nas, S.S.; Nas, E., 2009. Water Quality Modeling and Dissolved Oxygen Balance in Streams: A Point Source Streeter-Phelps Application in the Case of the Harsit Stream. Clean Soil Air Water, v. 37 (1), 67-74. https://doi.org/10.1002/clen.200800107

Neves, G.L.; Guimarães, T.T.; Anjinho, P.S.; Barbosa, M.A.G.A.; Santos, A.R.; Virgens Filho, J.S.; Mauad, F.F., 2021. Spatial and seasonal assessment of water quality in the Lobo Stream River Basin, Brazil using multivariate statistical techniques. Annals of the Brazilian Academy of Sciences, v. 93 (Suppl. 4), e20210072. https://doi.org/10.1590/0001-3765202120210072

Pöpel, H.J., 1979. Areation and gas transfer. 2nd ed. Delft University of Technology, Delft, 169 p.

Rocha, L.G.; Almeida, K.N.; Reis, J.A.T.; Mendonça, A.S.F.; Silva, F.G.B., 2021. Sewage treatment efficiencies estimation for urban areas located in the River Pardo's watershed by associating nonlinear programming and water quality modeling. Revista Brasileira de Ciências Ambientais (RBCIAMB), v. 56 (1), 65-75. https://doi.org/10.5327/Z2176-947820200731

Rodrigues, R.M.; Braga, B.B.; Costa, C.A.G., 2025. Efficiency in river discharge measurement: combining Chiu's method with particle image velocimetry techniques. Brazilian Journal of Water Resources, v. 30, e31. https://doi.org/10.1590/2318-0331.302520240125

Rosli, N.; Gandaseca, S.; Ismail, J.; Jailan, M.I., 2010. Comparative study of water quality at different peat swamp forest of Batang Igan, Sibu Sarawak. American Journal of Environmental Sciences, v. 6 (5), 416-421. https://thescipub.com/pdf/ajessp.2010.416.421.pdf

Santos, D.P.; Alvarado, S.T.; Almeida, E.B.; Figueiredo, F.A.M.M.A., 2023. The problem of conserving an ecosystem that has not been completely delineated and mapped: the case of the Cocais Palm Forest. Environmental Monitoring and Assessment, v. 195 (784). https://doi.org/10.1007/s10661-023-11345-z

Streeter, H.W.; Phelps, E.B., 1925. A study of the pollution and natural purification of the Ohio river. Public Health Bulletin No. 146, vol. 3, U.S. Public Health Service, Washington, D.C.

Vaughn, D.R.; Kellerman, A.M.; Wickland, K.P.; Striegl, R.G.; Podgorski, D.C.; Hawkings, J.R.; Nienhuis, J.; Dornblaser, M.; Stets, E.; Spencer, R.G., 2023. Bioavailability of dissolved organic matter varies with anthropogenic landcover in the Upper Mississippi River Basin. Water Research, v. 229. https://doi.org/10.1016/j.watres.2022.119357

Von Sperling, M., 2014. Introdução à qualidade das águas e ao tratamento de esgotos. 4th ed. Editora UFMG, Belo Horizonte, p. 321, 334.

Wetzel, R.G., 2001. Limnology: Lake and River Ecosystems. 3rd ed. Academic Press, San Diego.

Wu, D.; Yin, C.; Fan, Y.; Chi, H.; Liu, Z.; Jin, G., 2023. Effect of forest planting patterns on the formation of soil organic carbon during litter lignocellulose degradation from a microbial perspective. Frontiers in Microbiology, v. 14. https://doi.org/10.3389/fmicb.2023.1327481

Yoder, L.; Ward, A.S.; Dalrymple, K.; Spak, S.; Lave, R., 2019. An analysis of conservation practice adoption studies in agricultural human-natural systems. Journal of Environmental Management, v. 236, 490-498. https://doi.org/10.1016/j.jenvman.2019.02.009