Citation (APA)
De Carvalho, H., Moyo, W., Marques Arsenio, A., Rietveld, L., & Nkambule, T. T. I. (2026). Assessing natural organic matter (NOM) characteristics in South African surface waters using fluorescence-based surrogate tools: biodegradability and treatment optimization perspectives. *Water Practice and Technology*. https://doi.org/10.2166/wpt.2026.194

Water Practice & Technology

Water Practice & Technology Vol 00 No 0, 1 doi: 10.2166/wpt.2026.194

Assessing natural organic matter (NOM) characteristics in South African surface waters using fluorescence-based surrogate tools: biodegradability and treatment optimization perspectives

Helder De Carvalho[a], Welldone Moyo[a,*], André M. Arsénio[b], Luuk Rietveld[b] and Thabo T. I. Nkambule[a]

[a] Institute for Nanotechnology and Water Sustainability (iNanoWS), University of South Africa (UNISA), Johannesburg, South Africa
[b] Department of Sanitary Engineering, Faculty of Civil Engineering and Geosciences, Delft University of Technology, P.O. Box 5048, Delft, GA 2600, The Netherlands
*Corresponding author. E-mail: moyow@unisa.ac.za

WM, 0000-0003-0341-2919

ABSTRACT

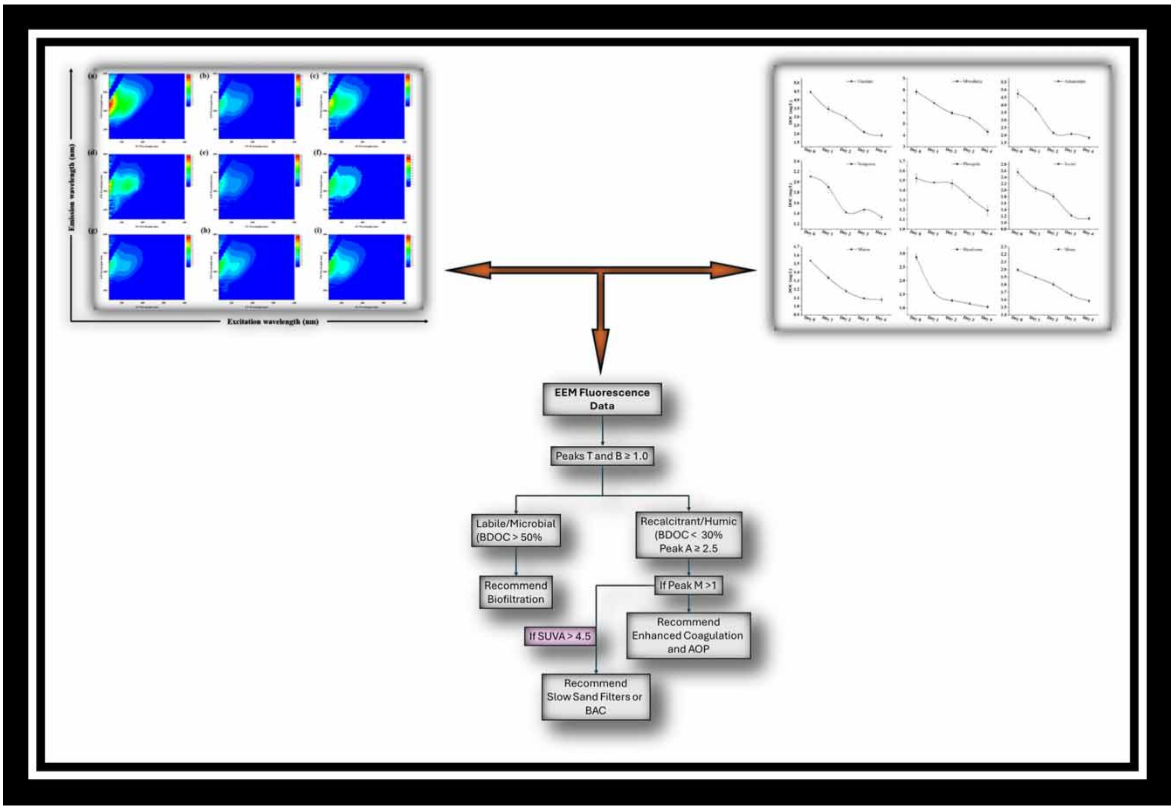
The variable biodegradability and compositional complexity of natural organic matter (NOM) in surface waters pose an appreciable challenge for drinking water treatment. The study characterized NOM found in nine South African water sources for predicting treatability under regional conditions by integrating biodegradability dissolved organic carbon (BDOC) analysis, fluorescence excitation-emission matrix (EEM) spectroscopy, optical analysis, and bulk parameters, such as specific UV absorbance (SUVA), UV254 and dissolved organic carbon (DOC). Water sources that exhibited the highest BDOC potential index included Umzinto, Hazelmere, Mona, and Mtwalume (3.55, 2.21, 2.06, and 1.73, respectively). Strong Peak B, T, and M intensities were experienced by these sites, for example, Umzinto peak intensities were 0.32, 0.74, and 2.49 RU, respectively, indicative of the presence of the NOM pool largely influenced by microbial activity, likely derived from diffuse anthropogenic inflow or recent biological production. Water sources exhibiting such fluorescence profiles characteristic of a NOM pool with high biological reactivity are expected to respond well to treatment stages such as slow sand filtration, biologically active carbon (BAC), or biofiltration. The findings demonstrate the need for developing tailored treatment strategies based on site-specific NOM characteristics. Data-driven approaches helping utilities move toward adaptive water quality management have been proven.

Key words: biodegradable dissolved organic carbon (BDOC), fluorescence spectroscopy, natural organic matter (NOM), optical indices, South African surface waters

HIGHLIGHTS

- Established a linkage between optical properties and biodegradable dissolved organic carbon.
- Appraised low-cost optical techniques applicable in data-limited and resource-constrained settings.
- Demonstrated how source water characteristics influence the adoption of upstream treatment strategies.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Rapid urbanization, climate variability, and catchment degradation are increasingly putting pressure on South Africa's water security due to dwindling levels of freshwater availability. The main sources of the country's drinking water supply are from surface waters, particularly dams and rivers. These sources are under threat of pollution by natural organic matter (NOM), which is derived from many sources, such as runoff from catchment activities, such as agricultural and urban land use variability, wastewater effluents, algal activity, decomposition of plant, and animal matter (Chear *et al.* 2025; Wu *et al.* 2025). In drinking water production, NOM is a nuisance because it is principally responsible for many problems, such as taste and odor, decline in water flux due to fouling of membranes, and precursor of carcinogens such as disinfection byproducts (DBPs) (Wu *et al.* 2025; Zafar *et al.* 2025). More detrimental, the survival and proliferation of microbial communities in distribution systems is supported by the presence of NOM because it serves as a substrate for the survival of harmful colonies of microbes (Vaughn *et al.* 2023). One-size-fits-all approach to the treatment of NOM is hampered by its heterogeneous nature, comprising hydrophilic low-molecular weight fractions to high molecular aromatic humic substances (Chear *et al.* 2025). This is particularly problematic for low-income and upper-middle-income countries, such as South Africa and many in the Global South, where treatment plants rely on legacy infrastructure and non-adaptive chemical dosing strategies not suitable to the ever-changing water quality characteristics.

Mitigatory approaches to water quality hazards include monitoring regimes at source and throughout the stages of the treatment train. However, the heterogeneous nature of NOM presents analytical complexities not fully deconvoluted by the bulk or aggregate measurements commonly monitored. The commonly monitored surrogate parameters in predicting NOM treatability include ultraviolet absorbance (UV254), dissolved organic carbon (DOC), and specific ultraviolet absorbance (SUVA) (Zafar *et al.* 2025). These bulk parameters do not fully capture NOM characteristics at source or its' reactivity. Additionally, one key parameter of NOM that impacts its treatability and stability of the distribution system is its biodegradability. The biodegradable fraction of NOM is termed the biodegradable dissolved organic carbon (BDOC) and represents the portion of NOM used as a source of carbon and energy by the heterotrophic microorganisms (Jiang *et al.* 2024). Biofilm formation in the distribution system, microbial regrowth potential, and associated health risks are because of high BDOC levels in treated water (Jiang *et al.* 2024). Furthermore, the efficacy of biologically active processes such as biofiltration depends on the extent of removal of BDOC. The usual assaying of BDOC includes complex microbial cultures, extended incubation periods, and labor-intensive protocols impeding practicality for routine monitoring and real-time decision-making, particularly in resource-constraint settings (Escobar & Randall 2001; Lim *et al.* 2008; De Vittor *et al.* 2009; Jiang *et al.* 2024).

To address this limitation, fluorescence excitation-emission matrix (FEEM) spectroscopy has emerged as a useful technique for NOM characterization due to its ability for rapid analysis, high sensitivity, and ability to identify specific fluorescent fractions within complex NOM mixtures (Antonio *et al.* 2025; Komatsu *et al.* 2025). Peak picking has emerged as a widely adopted technique for interpreting EEM data due to its simplicity and practical advantages over multivariate methods such as parallel factor analysis (PARAFAC), which is computationally intensive. Peak picking identifies distinct fluorophoric groups using well-established excitation-emission coordinate pairs. Peak picking has been used to identify five key fluorescent regions: proteinaceous fluorophores (Peak T – tryptophan-like, Peak B – tyrosine-like), microbial humic-like (Peak M), and terrestrial humic-like substances of terrestrial origins (Peaks C and A) (Dechesne *et al.* 2025). These fluorescence fingerprints have been used to identify the origin and transformation of NOM in natural and engineered environments. Lately, fingerprint regions have been used to predict NOM reactivity and treatability (Xu *et al.* 2023; Dechesne *et al.* 2025). Peak picking offers many advantages in NOM characterization: simplicity and rapid implementation, standardization and comparability, basis for index derivation, high interpretability, low data and computational requirements, thus offering an indispensable tool in applied water research (Xu *et al.* 2023). Additionally, when used with advanced chemometric techniques such as principal component analysis or hierarchical clustering in conjunction with peak picking, the resulting product gives deeper insights feeding into a framework for both confirmatory analysis and screening of NOM fluorescence characteristics (Xu *et al.* 2023).

Literature reports that protein-like fractions (Peak B and Peak T), which are often derived from recent algal production or microbial activity, are more labile and susceptible to microbial degradation and contribute primarily to the BDOC pool (Xu *et al.* 2023). In contrast, humic-like fractions (Peaks A and C) are typically more hydrophobic, aromatic, and recalcitrant to microbial degradation. The humic-like fractions originate from the soil organic matter and the degradation of higher plants. The occurrence and distribution of these fractions can, therefore, serve as useful indicators of NOM biodegradability, thus extending the utility of EEM fluorescence as a rapid and non-invasive surrogate for tedious BDOC measurements. Despite the evident potential of EMM fluorescence to predict NOM biodegradability, its application is largely underexplored, more so in resource-constrained regions, particularly in Southern Africa. The land use patterns, such as informal settlement, agricultural activities, and wastewater discharge in South Africa, have a bearing on the surface water quality, particularly the quantity and quality of allochthonous and autochthonous NOM received by water bodies (Nkambule *et al.* 2011). Compounding this variability, climatic and anthropogenic activities create complex and dynamic NOM pools that present a challenge to conventional treatment methods in keeping with changing NOM profiles. Understanding the relationship between NOM biodegradability and specific fluorescence in the context of optimizing treatment processes, such as advanced oxidation, biofiltration, coagulation, and mitigating DBP formation risks, is essential.

To date, besides a few studies by our group (Institute for Nanotechnology and Water Sustainability, University of South Africa), no other study has systematically evaluated the correlation between BDOC and EEM-derived NOM fractions in South African waters (Moyo *et al.* 2020; Sambo *et al.* 2020). Further, reported work worldwide focuses on DBP precursor potential or general characteristics of NOM without drawing linkages of fluorescence features with biodegradability or microbial accessibility (Akcay *et al.* 2016; Phan *et al.* 2023). The critical need to develop real-time field deployable probes for NOM biodegradability indicators tailored to site-specific water sources was the motivation for this work in line with the growing emphasis on sustainable and cost-effective water treatment drive. Using South African surface waters, the study aimed to bridge the disconnect by integrating experimental BDOC assays and EEM fluorescence spectroscopy to elucidate the correlation between fluorescent NOM components and their biodegradability. The envisioned insights will support treatment optimization strategies under local conditions, informed by data-driven approaches, helping utilities move toward adaptive water management. The specific objectives of the study were (1) to characterize the optical and physicochemical properties on NOM in selected surface water sources across South Africa, using fluorescence spectroscopy, SUVA, UV254, and DOC, (2) to evaluate the relationship between the biodegradability of NOM components and bulk NOM highlighting implications for treatability under local conditions, (3) to propose a framework based on fluorescence for predicting NOM treatability and guiding treatment selection. The study sought to link functional biodegradability metrics to molecular-level fluorescence signals to gain a deeper understanding of NOM dynamics in diverse water sources in a bid to provide functional, practical tools for water quality management at a regional scale and beyond.

2. METHODOLOGY

2.1. Sampling

Nine surface water sources (Umzinto, Mtwalume, Amanzimtoti, Nongoma, Phongola, Jozini, Mkuze, Hazelmere, and Mona) geographically spread across the province of KwaZulu-Natal, South Africa, represent different NOM profiles and catchment characteristics (Figure 1). Sampling at all water sources was done in duplicate. Samples were collected using thoroughly cleaned 500 mL glass bottles by means of grab sampling and stored in a cooler box with ice. The water sources chosen included both rivers and reservoirs, representing diverse hydrogeographic distribution, variability in NOM profiles (fluorescence indices, UV254, and DOC), and land use patterns ranging from forested, agricultural and urban catchments. Selection was further guided by the need to align with ongoing water quality monitoring, relevance to potable water supply and safety and accessibility concerns. The diversity in location and characteristics of source water types enabled a comparative assessment of BDOC across the region, supporting site-specific and tailored treatment strategies.

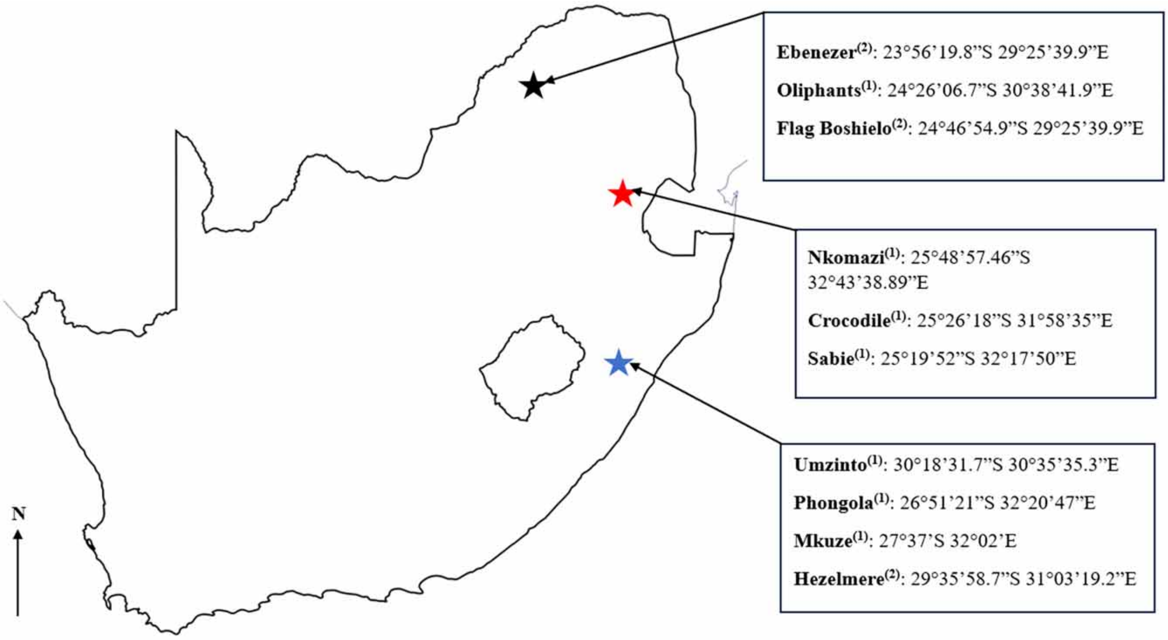


Figure 1 | The location of selected rivers (1) and dams (2) in South Africa.

2.2. Physicochemical characterization of source waters

Water samples from the selected sites were subjected to standard physicochemical analysis relevant to NOM characterization and treatability. The following parameters were measured: (a) the turbidity, conductivity, and pH of the samples were measured using a turbidity meter (Thermo Scientific Orion AQUAfast® AQ3010, USA), a conductivity meter (XS Instruments, Carpi, MO, Italy), and a pH meter (XS Instruments Carpi MO); (b) The fraction of total organic carbon that filters through the 0.45 μm filter is termed DOC, its determination was done using a Torch Total Organic Carbon Analyzer (Teledyne Tekmar, Mason, Ohio, USA); (c) Ultraviolet-visible absorbance was determined using an FEEM spectrometer (Aqualog®, HORIBA Scientific, New Jersey, USA) over a range of 200–600 nm; (d) Specific UV absorbance (SUVA) was calculated as the quotient of UV254 (m^{-1}) and DOC ($mg{\cdot}L^{-1}$), SUVA is an index of NOM aromaticity. Certified standards were used daily to calibrate instruments to ensure reproducibility, and all analyses were conducted in triplicate.

2.3. Fluorescence excitation-emission matrices

The characterization of fluorescent components of NOM was done using fluorescent excitation-emission matrices (EEMs) (Aqualog®, HORIBA Scientific, New Jersey, USA). Before analysis, samples were filtered through a 0.45 μm syringe filter to remove particulate matter. The scanning wavelengths ranged from 200 to 800 nm at 2 nm intervals, and the emission wavelength ranged from 248.58 to –830.59 nm at 3.28 nm intervals. Raman and Rayleigh scatter bands were masked to remove interference. Integrated area at excitation wavelength of 350 nm of Raman water was used to normalize the fluorescence intensities to Raman units (RU).

2.4. Optical indices derived from fluorescence EEMs

Optical indices calculated from EEM data were used to argument the peak based fluorescence characterization to provide further insights into the biodegradability, composition, and source of NOM (Lidén *et al.* 2017): (a) Humification index: calculated by integrating the emission intensity between 435 and 480 to the sum of intensities ranging 300–345 nm and 435–480 nm under an excitation wavelength of 254 nm; (b) Biological or freshness index (BIX): determined as the quotient of emission at 380 nm to that at 430 nm under an excitation wavelength of 310 nm and fluorescence index (FI): computed as the quotient of emission intensity at 470 nm to that at 520 nm under an excitation wavelength of 370 nm. These ratios served to inform treatment strategies as they provide rapid and non-destructive methods of estimating NOM origin and lability when used alongside BDOC measurements, UV254, and DOC measurements.

2.5. Peak picking method for fluorescent NOM characterization

The identification and quantification of specific fluorescent NOM components were conducted using the peak picking method. Peaks well reported in the literature were identified (Cohen *et al.* 2014): Peak A Ex/Em (260/380–460 nm), Peak C Ex/Em (320–360/420–460 nm), Peak M Ex/Em (290–310/370–410 nm), Peak B Ex/Em (270/300–320), and Peak T Ex/Em (275/340–360 nm). The intensity of respective peaks was recorded in Ramana units (RU), and the position and intensity of each peak were used to infer the origin, composition, and potential biodegradability of NOM.

2.6. Biodegradable DOC

An inoculum of biologically active sand (BAS) was collected from the slow sand filters at Hazelmere water treatment plant. Excess carbonic matter from the BAS was washed and removed with 0.1 M $Na_2S_2O_3$ solution until a steady supernatant gave a steady UV254 absorbance value close to zero. Thereafter, the sand was rinsed several times using deionized (DI) water, and the supernatant was analyzed for fluorescence, UV254, and DOC; the respective values were used as baseline. The washed BAS (100 g) and water samples (300 mL) were placed in 500 mL Erlenmeyer flasks covered with aluminum foil. Control solutions of glucose (5, 8, and 10 mg/L) were prepared and subjected to similar conditions as the samples. The flasks were incubated at 22 °C in a water bath, and for 5 days, daily measurements of fluorescence, UV254, and DOC were carried out. Fractions of fluorescent NOM making up the BDOC components were determined using the following equation (Moyo *et al.* 2020):

$$\mathrm{EEM_{BDOC}} = \mathrm{EEM_{day0}} - \mathrm{EEM_{min}} \tag{1}$$

where $\mathrm{EEM_{day0}}$ is the quantity of components of fluorescent NOM determined on day 0, and $\mathrm{EEM_{min}}$ is the minimum quantity of components of fluorescent NOM determined during the 5 days.

2.7. Statistical analysis

The analysis of relationships between BDOC values, fluorescence peak intensities, optical indices, and physicochemical parameters across the nine selected water sources was statistically treated using PAST v4.06b. Statistical significance was set at $p < 0.05$. The grouping of water sources with similar NOM properties and biodegradability was determined using hierarchical cluster analysis (HCA) and k-means clustering. The reduction in dimensionality and visualization of patterns in NOM profiles across the source waters was determined using principal component analysis (PCA).

3. RESULTS AND DISCUSSION

3.1. Bulk organic indicators of NOM

3.1.1. Implications of DOC quantity to the anticipated biodegradability and treatment strategy

The highest DOC concentration was at Mtwalume (7.85 mg/L), indicating a substantial organic load compared with the rest of the sites (Figure 2(a)). The quantity and quality of DOC received by the Mtwalume River were influenced by catchment anthropogenic activities. Anthropogenic activities within the catchment include commercial sugarcane cultivation and subsistence farming, which influence DOC loading through surface runoff. Further, informal settlements with little to no sanitation facilities within the proximity of the river result in the discharge of poorly or untreated wastewater into the river, thus introducing labile forms of DOC such as surfactants, amino acids, and carbohydrates. The variability of DOC quantity and quality received by the Mtwalume River calls for continuous monitoring of catchment activities and source water quality to anticipate treatment challenges. Amanzimtoti and Umzinto had moderately high DOC (4.76 and 4.46 mg/L, respectively), while Phongola and Mkuze had the lowest recorded DOC (1.52 and 1.54 mg/L, respectively). Phongola and Mkuze are situated in less disturbed, rural sub-catchments with lower levels of informal settlements, urbanization, and intensive agriculture.

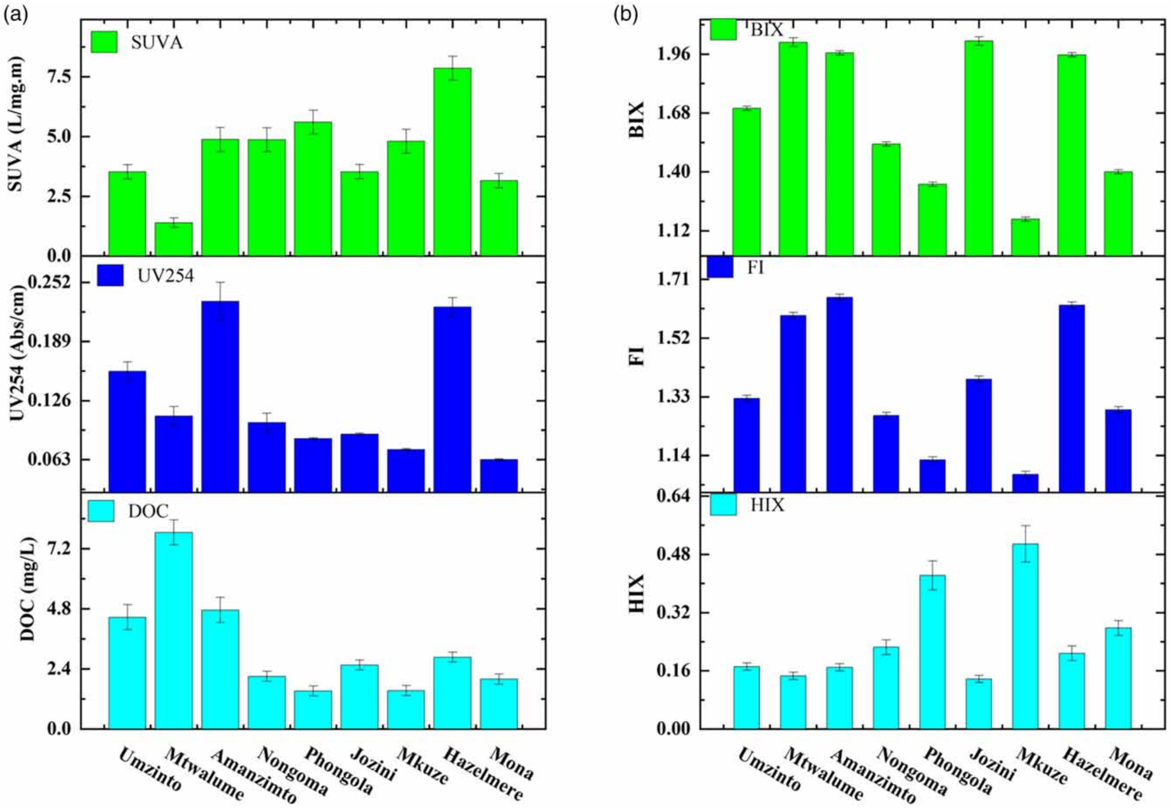


Figure 2 | Characterization of water sources: (a) bulk water characterization; (b) optical characterization of water sources.

It must be noted that high DOC concentrations in source waters do not necessarily translate to high BDOC. Literature indicates significant contribution to BDOC is attributed to high amounts of labile DOC (e.g., proteins, amino acids, carbohydrates) in the source water, while high concentrations of refractory DOC, such as aromatic humic substances, which are resistant to microbial degradation, contribute little to the pool of BDOC in the sample (Sambo *et al.* 2020). Therefore, further elucidation of the quality of DOC in the sample is required to anticipate the potential for biodegradability. SUVA, ultraviolet absorbance at 254 nm (UV254), and DOC are regarded as bulk or conventional parameters that offer crucial insights into NOM character with regard to reactivity, aromaticity, and concentration, respectively. These quantitative and optical parameters offer valuable initial insights guiding source water assessment and treatment process selection and optimization.

3.1.2. Implications of UV254 absorbance on the anticipated biodegradability and treatment optimization

Hazelmere and Amanzimtoti exhibited the highest UV254 absorbance (0.226 and 0.232 cm^{-1}), indicative of high aromatic carbon content, suggesting the highest potential to form DBPs (Figure 2(a)). Such compounds are recalcitrant to biodegradation processes, thus exhibiting low microbial bioavailability. Literature reports an inverse correlation between UV254 absorbance and BDOC (Zhang *et al.* 2016; Li *et al.* 2017). Thus, the observed high UV254 absorbance at Hazelmere and Amanzimtoti was indicative of greater terrestrial-derived chromophoric dissolved organic matter, and hydrophobic in nature is expected to be exhibited. The nature of organics found in these sites was consistent with the catchment activities, largely dominated by intensive sugarcane farming on a sloped terrain. These activities increase the leaching of decomposed plant matter, leading to elevated input of aromatic fulvic and humic acids carried in runoff into the respective water sources. On the other hand, low UV254 absorbance of 0.085 and 0.074 cm^{-1} recorded at Phongola and Mkuze, respectively, was suggestive of low content aromatic NOM. The dissolved organic matter (DOM) profile from these sites was likely composed of aliphatic, low-molecular weight organic carbon fractions of microbial sources. Reports indicate that such organic compositions are more labile and influence the BDOC pool in the sample (Jiménez-Ramos *et al.* 2022; Mirzaei *et al.* 2025). Consequently, low UV254 absorbing waters are often associated with high BDOC fractions concentration; therefore, water treatment plants receiving such waters should prioritize the removal of such BDOC precursors because if not properly removed, these labile organics can persist in treated water, stimulating microbial proliferation and regrowth in the distribution systems. Interestingly, Mtwalume had the highest DOC concentration but low UV254 absorbance (0.11 cm^{-1}), which meant organic matter contained was mainly composed of non-UV-absorbing labile carbon species such as carbohydrates and aliphatic carbon. This finding calls for a robust approach in elucidating the character of NOM in source waters for the purposes of process optimization. To note, UV254 absorbance is a chemical proxy of aromaticity, not biodegradability. However, when used in conjunction with other optical indices, such as biological index and FI, the utility and contribution of UV254 absorbance in assessing treatability and biological reactivity of organics in source waters is enhanced. The aromatic character indicative of the presence of humic substances of natural waters is quantified by measuring the UV absorbance value at 254 nm because aromatic rings strongly absorb UV light at 254 nm. Literature indicates a strong correlation between high UV254 absorbance and the presence of humic substances, known precursors of DBPs, for example, trihalomethanes and haloacetic acids (Jian *et al.* 2016; Beauchamp *et al.* 2020).

3.1.3. SUVA as a proxy for biodegradable organic carbon formation

In this study, SUVA values ranged from 1.39 to 7.86 L/mg m across all sampling sites, indicating substantial variation in NOM composition (Figure 2(a)). Interestingly, Mtwalume recorded the least SUVA value (1.39 L/mg · m) despite having the highest DOC concentration across all samples. The findings reinforce our earlier hypothesis that the organics contained at Mtwalume are labile, hydrophilic, and low molecular. Thus, we anticipate the highest biodegradability values from Mtwalume, which could pose challenges, such as microbial proliferation and regrowth in the distribution systems if not adequately removed. The SUVA values for Umzinto, Jozini, and Mona (3.52, 3.53, and 3.16 L/mg · m, respectively) were indicative of transphilic fractions, a reflection of a balanced composition of hydrophilic and hydrophobic NOM fractions. Therefore, moderate BDOC levels are anticipated from these source waters. Further, it is expected that the water from these sources should respond well to conventional water treatment combining coagulation and biofiltration. Sites that exhibited the presence of hydrophobic, humic-like substances included Amanzimtoti, Nongoma, Mkuze, and Phongola with SUVA values of 4.87, 4.86, 4.80, and 5.61 L/mg · m, respectively. The labile nature of organics found in these sites was indicative of compounds recalcitrant to biodegradability; however, these compounds are known precursors of DBPs. The highest SUVA value was recorded at Hazelmere (7.86 L/mg · m), indicative of the presence of considerable aromatic and recalcitrant NOM profile compared with the rest. A multi-barrier treatment approach, including enhanced coagulation, activated carbon, and advanced oxidation process (AOPs), would be required to ensure compliance with disinfection byproduct regulations. Further, a low risk of post-treatment due to microbial proliferation and regrowth in the distribution BDOC was anticipated from such water. Specific ultraviolet absorbance (SUVA) is UV254 absorbance normalized to DOC concentration. SUVA is widely used as an indicator of the aromatic character in natural water samples. Natural water with high SUVA values is suggestive of terrestrially derived hydrophobic and high molecular weight humic substances, low SUVA values typically reflect microbially derived hydrophilic and low-molecular weight organic matter. SUVA serves as an indirect measure or insight into the anticipated BDOC and implications for treatment performance (Bai *et al.* 2023; Begum *et al.* 2023). The study demonstrated that SUVA can be a useful predictive tool to anticipate biodegradability and can be used to plan for a tailored and cost-effective treatment approach to site-specific water quality conditions.

3.2. Optical indices as predictors of NOM origin, reactivity, and biodegradability

As previously indicated, high SUVA values were recorded for Mkuze, Amanzimtoti, Nongoma, Phongola, and Hazelmere (4.80, 4.87, 4.87, 5.61, and 7.86 L/mg · m, respectively), indicative of high aromatic and terrestrially derived NOM, typically associated with low biodegradability. The HIX values supported the observed aromaticity trend. Mkuze, Phongola, and Mona exhibited high HIX values of 0.51, 0.42, and 0.28, respectively, indicative of the dominance of fulvic and humic acids, which are recalcitrant to microbial degradation (Figure 2(b)). These sites exhibited low DOC concentrations but showed high SUVA and HIX values, demonstrating a refractory NOM pool with anticipated low levels of BDOC. On the other hand, lower SUVA values for Mtwalume and Jozini (1.39 and 3.53 L/mg · m) and the corresponding lower HIX values of 0.15 and 0.14, respectively, suggested the presence of microbially derived NOM, which is of lower molecular weight and aliphatic in nature, typical of highly biodegradable organic content. Lessons learnt from such a distinction inform treatment strategies, as high SUVA and high HIX water require advanced treatment processes such as pre-oxidation, activated carbon, and enhanced coagulation, while biologically based processes, such as granular activated carbon or sand filtration, would be beneficial for low SUVA and low HIX waters. The source and freshness of NOM are elucidated by the FI and BIX indices, respectively. A mix of sources (microbial and terrestrial), autochthonous and allochthonous derived organic, is operationally assigned to waters with FI values between 1.4 and 1.8, while BIX values greater than 1 operationally define freshly produced labile organic matter with high biodegradability potential. Mtwalume, Amanzimtoti, and Hazelmere exhibited FI values of 1.59, 1.65, and 1.63, respectively, while the HIX values of the same sources were 2.02, 1.97, and 1.96, respectively. While the FI indices are less than 1.8, appreciably close to1.8 implies a greater proportion in the respective sites reflect microbial activity typical of highly biodegradable organic matter, particularly Mtwalume, which also had a low SUVA value. Interestingly, Hazelmere displayed a dual signature of high SUVA and high BIX (7.86 L/mg · m and 1.96, respectively). Such an unusual combination suggests the presence of a complex NOM mixture of both recalcitrant humic substances and labile microbial products. A multi-barrier treatment approach is advised for receiving water treatment plants, processes such as enhanced oxidation or coagulation for the removal of the aromatic fractions and biological filtration to manage residual biodegradable organics. Failure to remove the aromatic fraction runs a risk of DBP formation, while inadequate removal of the labile fraction impacts downstream processes, resulting in microbial regrowth and biological instability post-treatment.

Overall, the results demonstrated that DOC concentration alone cannot succinctly determine treatability, but rather, a holistic approach to NOM characterization of source water is required to inform downstream treatment strategies. For example, the DOC and SUVA values for Mtwalume were 7.85 mg/L and 1.39 L/mg m, respectively, indicated high NOM quantity of largely non-aromatic and hence expected to be largely biodegradable, requiring less coagulant and more emphasis on biofiltration. On the other hand, Phongola and Hazelmere exhibited lower DOC values (1.52 and 2.87 mg/L, respectively) but high SUVA (5.61 and 7.86 L/mg m, respectively) and HIX values (0.42 and 0.21, respectively), indicating low BDOC expectations and high treatment difficulty, including strict monitoring of DBP formation potential. Importantly, as climatic patterns and land use pressures continue to evolve, multi-parameter application to source water NOM characterization can support data-driven decision-making and increase operational resilience and sustainability in drinking water treatment systems.

A balanced understanding of the character of NOM in source waters is critical for informing strategies for treatment optimization, notwithstanding the utility of bulk parameters, such as SUVA, UV254 absorbance, and DOC, which offer insights into the aromaticity and concentration of organic matter. Contextualizing bulk parameters with source water optical indices, such as biological index (BIX), FI, and humification index (HIX), in the elucidation of anticipated biodegradability and subsequent process optimization offers a holistic picture toward NOM treatability.

3.3. The utility of fluorescence peak signatures as predictors of NOM biodegradability

The highest Peak A intensity was observed at Umzinto, Mona, and Hazelmere (4.01, 2.48, and 2.24 RU), indicating a strong presence of aromatic precursors and humic acids (Figure 3). Peak A (Ex/Em = 260/400–460 nm) is

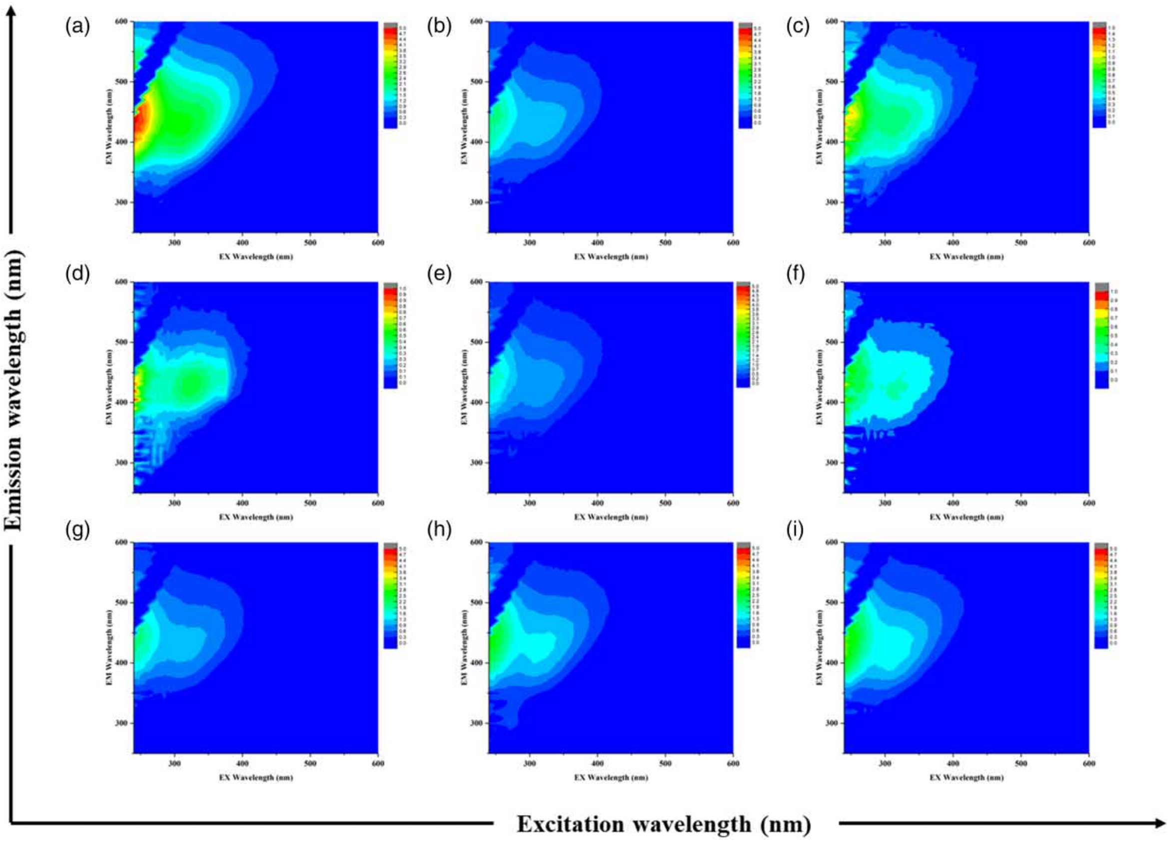


Figure 3 | Fluorescence excitation-emission matrix spectra for water samples collected in (a) Umzinto; (b) Mtwalume; (c) Amanzimtoti; (d) Nongoma; (e) Phongola; (f) Jozini; (g) Mkuze; (h) Hazelmere; and (i) Mona.

an indicator of refractory and poorly biodegradable substances of allochthonous and terrestrial sources composed of high molecular weight aromatic humic acids. Further, the water sources exhibited high SUVA values (3.2, 3.5, and 7.9 L/mg. m for Mona, Umzinto, and Hazelmere, respectively), confirming the aromatic and UV-absorbing nature of the NOM in these sources.

Interestingly, Umzinto, Mona, and Hazelmere exhibited the highest intensity of Peak C (1.97, 1.14, and 1.14 RU, respectively). This implies a fraction of the NOM in these water sources was amenable to biodegradation or oxidation, notwithstanding the bulkier fraction, mainly composed of humic substances. Peak C (Ex/Em – 320–350/420–480 nm) signaled the presence of low-molecular weight fulvic substances which are more hydrophilic and susceptible to biodegradation (REF). Jozini and Nongoma had the lowest Peak C intensity values (0.27 and 0.4 RU), implying the source and character of NOM was more *in situ* derived and potentially more labile and less impacted by terrestrial runoff. Umzinto exhibited the highest intensities, Peak B (Ex/Em – 275/305 nm) and Peak T (Ex/Em – 275/340 nm) (0.32 and 0.74 RU, respectively), implying inputs of humic and microbial nature. This is common in eutrophic or impacted water sources. Peak B and Peak T are associated with protein-like substances, including microbial byproducts and amino acids. These fractions are commonly biodegradable and are often produced *in situ* or autochthonous. Umzinto, Mona, and Hazelmere exhibited higher intensities of Peak M (Ex/Em – 290–310/370–410 nm) (2.49, 1.51, and 1.36 RU, respectively), while Nongoma and Jozini showed lower peak M intensities (0.45 and 0.32 RU, respectively). High Peak M intensities indicated active microbial processing and regeneration of organic matter. Peak M is composed of microbial humic-like substances emanating from the breakdown and transformation of organic matter within the complex aquatic microbial environment (Komatsu *et al.* 2025).

The utility of excitation-emission matrix (EEM) rests upon its ability for rapid and non-destructive compositional characterization of NOM in different matrices. The discrete fluorophore peaks commonly labeled A, B, C, T, and M are each associated with specific NOM sources and treatability profiles. Their occurrence and distribution reveal key trends in NOM origin, composition, and biodegradability. Such information is useful for treatment process design and optimization.

3.3.1. Fluorescence-derived NOM fractions as a proxy for the anticipated biodegradability

The utility of fluorescence spectroscopy provides molecular-level insights into the NOM character, and it provides useful information for understanding the biodegradability potential of the water sources. Research proves that Peaks B, T, and M are closely linked to labile organic matter, which is low-molecular and biogenic, the hallmarks of BDOC (Gan *et al.* 2016; Komatsu *et al.* 2025). To this effect, a composite BDOC potential index expressing the cumulative presence of biodegradable NOM fractions was derived from adding the intensities of Peaks M, T, and B.

Water sources that exhibited the highest BDOC potential included Umzinto, Hazelmere, Mona, and Mtwalume (3.55, 2.21, 2.06, and 1.73, respectively) (Figure 3). Strong peak B, T, and M intensities were experienced by these sites; for example, Umzinto peak intensities were 0.32, 0.74, and 2.49 RU, respectively, indicative of the presence of a NOM pool largely influenced by microbial activity, likely derived from diffuse anthropogenic inflow or recent biological production. Water sources exhibiting such fluorescence profiles characteristic of a NOM pool with high biological reactivity were expected to respond well to treatment stages such as slow sand filtration, biologically active carbon (BAC) or biofiltration. Consequently, high biodegradability potential warrants careful residual disinfection control to curb the regrowth and proliferation of microbial colonies in the distribution systems.

On the other hand, the lowest BDOC potential index values were experienced by Amanzimtoti, Nongoma, and Jozini (0.88, 0.79, and 0.48, respectively). These water sources recorded the least protein-like fluorescence signals and subdued microbial humic-like signal. For instance, the peaks B, T, and M signals for Jozini were 0.11, 0.05, and 0.32 RU, respectively, suggesting a refractory NOM pool dominated by humic substances. Biological treatment is poorly suited for such waters exhibiting low biodegradability. Instead, advanced treatment methods, including advanced oxidation processes (AOPs), adsorption using powdered activated carbon (PAC), or enhanced coagulation, can be applied to optimize the reduction of DBP formation potential. Intermediate BDOC potential was experienced at Mkuze and Phongola (1.44 and 1.28, respectively), indicative of balanced contributions of aromatic and microbial fractions. Interestingly, Phongola exhibited a high SUVA value (5.61 L/mg m) and elevated Peaks B, T, and M (1.69, 0.23, and 0.88 RU, respectively), suggesting a dual-natured NOM pool comprising humic and aromatic components together with labile and microbially derived fractions. A multi-barrier treatment approach, including biological processes and chemical processes such as oxidation and coagulation, is required for treating water sources exhibiting such characteristics.

3.4. Assessment of the biodegradability of fluorescent NOM fractions

The treatability, reactivity, and origin insights of biodegradable fluorescent NOM fractions were followed using fluorescence spectroscopy. Figure 4 reveals the distribution of fluorescent biodegradable fractions of NOM across nine water sources.

Peak B and T constantly exhibited high intensities and consistently contributed to the observed BDOC values, supporting their classification as labile and biodegradable. Particularly, Peak T exhibited pronounced biodegradability reaching 87% (Jozini) and exceeding 60% in several water sources, e.g., 63% at Amanzimtoti, Nongoma, Mkuze, respectively, and at 61% Mtwalume. In the same manner, peak B showed elevated biodegradability, peaking at 74% at Amanzimtoti and exceeding 50% in several water sources such as Mtwalume, Nongoma, Mkuze, and Mona. The algal or microbial origin of peaks T and B was affirmed by these results. These peaks are susceptible to degradation during biological treatment processes such as biologically active carbon or biofiltration systems. Biological treatability of source waters for BDOC reduction can be followed by assessing the presence and abundance of these peaks (Begum *et al.* 2023; Sari *et al.* 2023).

Microbial humic-like substances (Peak M) exhibited moderate biodegradability; the peaks' contribution to BDOC ranged from 4% (Umzinto) to 46% (Jozini). Interestingly, elevated peak M values at Jozini, Nongoma, and Amanzimtoti (46, 41 and 30%, respectively) indicate that in some environments, microbial degradation of microbial humic-like substances occurs likely due to inflow of fresher organic matter or recent microbial activity. Water sources, such as Umzinto and Mona, exhibited lower peak M intensities (4 and 14%, respectively) and suggest limited or slow microbial activities or environments exhibiting the presence of recalcitrant microbial byproducts.

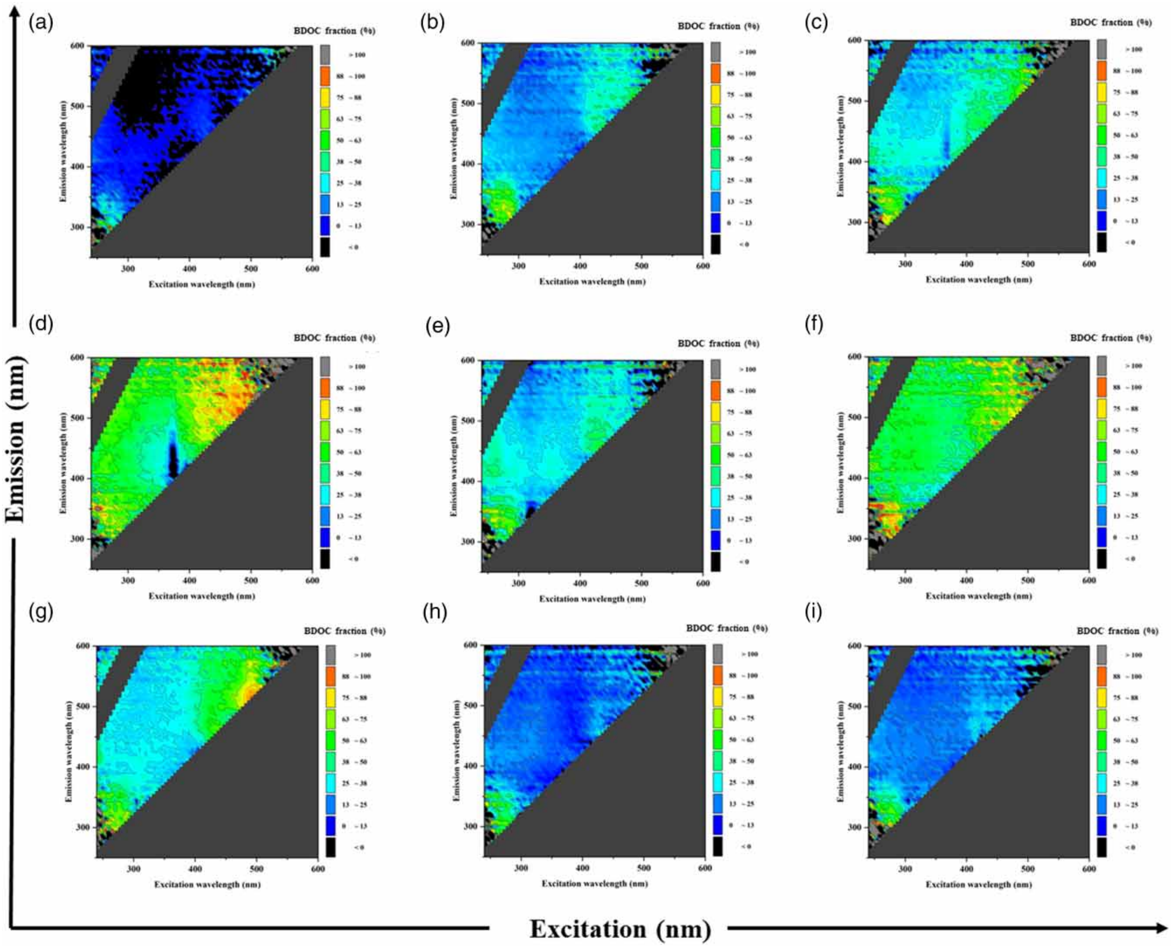


Figure 4 | Fluorescent NOM fraction contribution to BDOC for water samples collected in (a) Umzinto; (b) Mtwalume, (c) Amanzimtoti, (d) Nongoma, (e) Phongola, (f) Jozini, (g) Mkuze, (h) Hazelmere, and (i) Mona.

Biodegradability of peak C (fulvic-like microbial matter) exhibited low-to-moderate BDOC contributions ranging from 1% (Umzinto) and 44% (Jozini). Because of the aromatic nature and origin from terrestrial decomposition, peak C is traditionally considered recalcitrant, the variability observed demonstrated environmental or compositional influences having a bearing on its biodegradability. Jozini, Phongola, and Amanzimtoti exhibited high BDOC for peak C (44, 28, and 27%, respectively) suggesting fractional susceptibility to microbial activity, likely due to the presence of lower molecular fractions or oxygenated functional groups.

High molecular weight humic-like fractions (Peak A) consistently exhibited the lowest BDOC contributions, for example, Umzinto, Hazelmere, and Mona (5, 13, and 14%, respectively), consistent with previous reports that indicate humic substances are resistant to biodegradation and recalcitrant to biological treatment (Komatsu *et al.* 2025). Although Nongoma and Jozini exhibited higher BDOC contributions of peak A (52 and 49%, respectively), this could be because of the presence of partially oxidized humic substances that are susceptible to microbial breakdown.

Overall, the results point to the importance of fluorescence peak deconvolution in forecasting biodegradability for tailoring treatment strategies. In summary, (a) elevated peak B and T intensities indicated the potential success of biological processes such as biofiltration; (b) significant peak C or M contributions are an indicator for tailored treatment strategies including combined chemical and biological processes, more so, if microbial humic-like or fulvic substances are moderately biodegradable, and (c) when the water source is dominated by peak A with low BDOC contributions signals the need for pre-treatment processes such as AOPs or coagulation to break down the refractory fraction to more biodegradable substances. For informed and adaptive treatment, the value of site-specific NOM profiling is indispensable given the BDOC variability of each peak across sites.

3.5. Correlation of fluorescent NOM fractions and biodegradability index

The relationship between the biodegradability index (BI) of NOM and corresponding fluorescence-derived BDOC fractions is crucial for planning and anticipating treatment efficacy in drinking water production. The sum of fluorescence intensities from peaks T, B, and M (BI) was evaluated against the actual fluorescent BDOC contributions of these peaks (Figure 5).

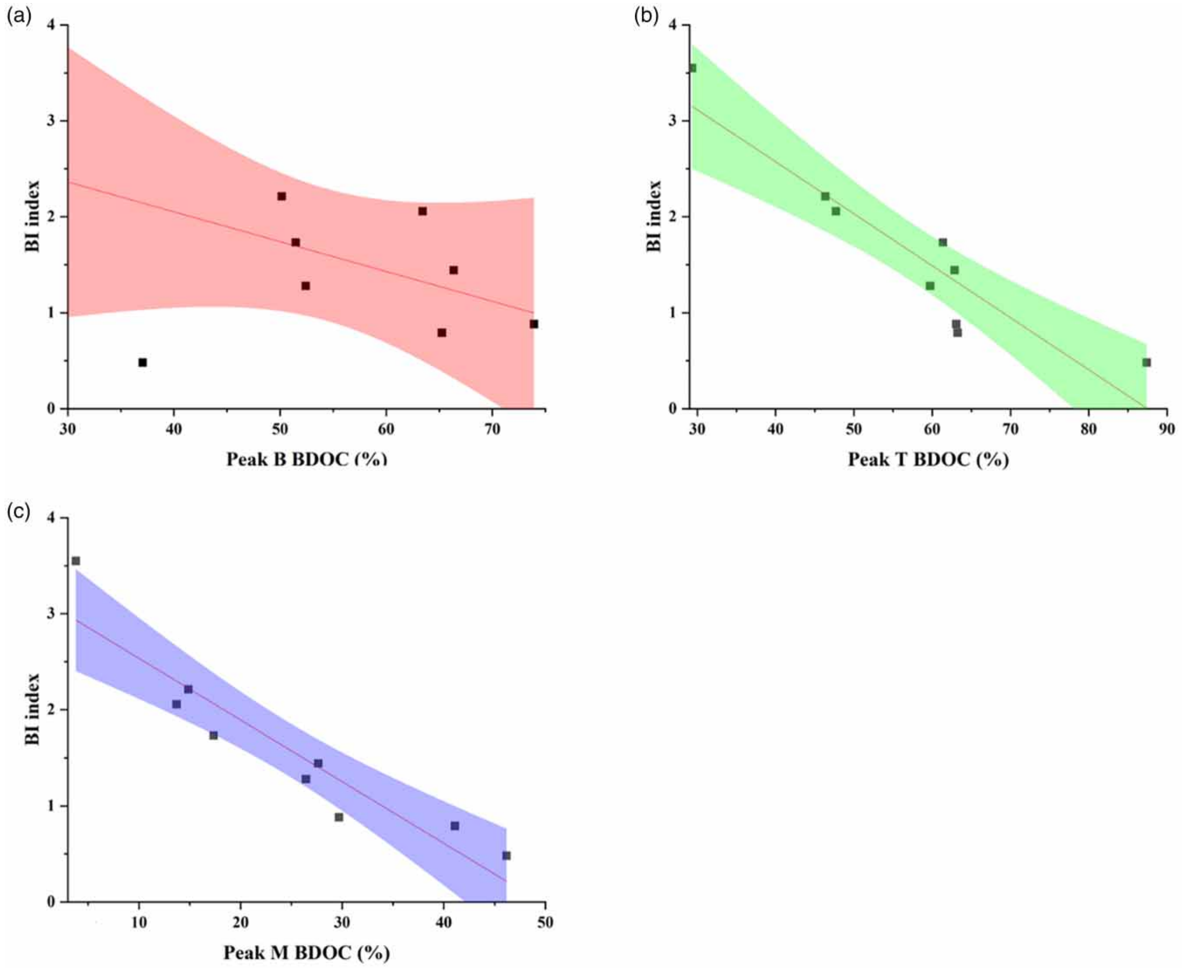


Figure 5 | Correlation studies between biodegradability index and (a) Peak B BDOC contribution; (b) Peak T BDOC contribution; and (c) Peak M BDOC contribution.

Pearson correlation was utilized to assess the relationship between the calculated BI and the actual biodegradability of the respective fluorescent fractions. A summary of the correlations of peak B, T, and M with BI is as follows: (a) BI and BDOC contribution of peak B exhibited a weak and negative correlation ($r = -0.48$, $p = 0.189$) (Figure 5(a)). Despite tyrosine-like fractions being associated with fresh and biodegradable organic matter, the results are not statistically significant implying peak B cannot be a reliable and a standalone predictor for bulk NOM biodegradability; (b) BI and BDOC contribution of peak T exhibited a strong and statistically significant negative correlation ($r = -0.92$, $p = 0.0004$) (Figure 4(b)). This means an inverse relationship exists between tryptophan-like fractions' contribution to BDOC and BI. This counterintuitive relationship is an indicator of saturation effects, limitations in microbial activity, or highly fluorescing and yet poorly degradable proteinaceous matter in some samples, and (c) BI and BDOC contribution of peak M exhibited a strong and statistically negative correlation ($r = -0.94$, $p = 0.0002$) (Figure 4(c)). Traditionally, peak M is associated with microbial byproducts and known to be moderately labile; however, the results suggest an inverse relationship whereby higher microbial humic-like BDOC fractions correspond to lower BI values. The results point to the possibility of the presence of refractory microbial-derived NOM in some samples.

Overall, the strong inverse relationship of Peaks M and T with BI instead of a positive correlation reveals the limitations of fluorescence peak intensities as predictors for bulk NOM biodegradability. The possibilities of microbial activity inhibition by high concentrations of these fractions affect the overall biodegradability, as the high concentrations of these fractions present structurally complex compounds not amenable to mineralization by microorganisms. Furthermore, peak B presented a weak correlation with BI, which reinforces the need for an approach that utilizes integrated and multivariate means to model NOM treatability. Further studies should use advanced tools such as partial least squares regression or machine learning algorithms to understand the complex interdependencies among NOM fractions, their origins, and their biodegradability kinetics.

3.6. Trends in measured bulk biodegradable dissolved organic carbon

Biodegradable dissolved organic matter is the labile portion of NOM that can be readily assimilated by microorganisms during biological treatment. In this study, BDOC was experimentally determined by monitoring the net reduction in DOC over the 5-day incubation period. The BDOC values of the nine water sources varied between 21 and 64% (Figure 6).

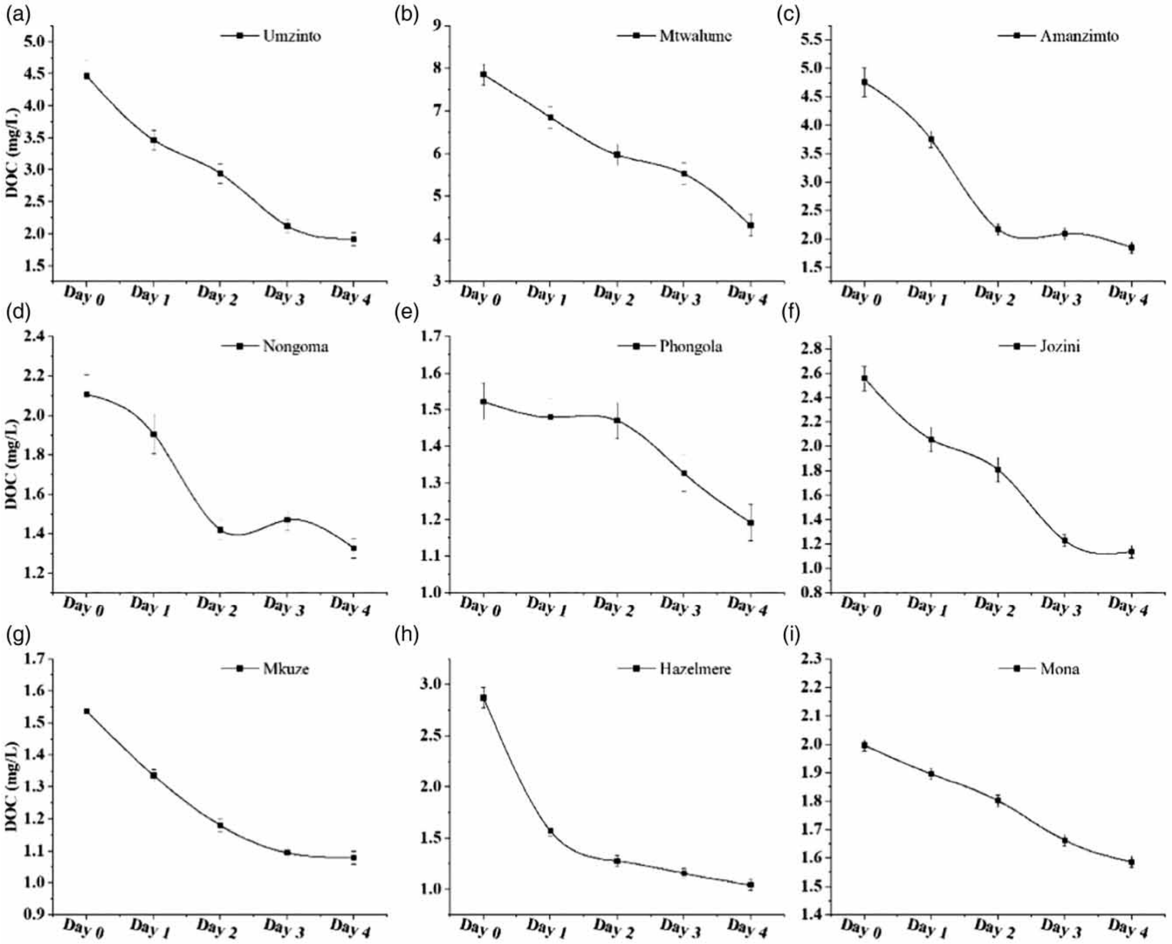


Figure 6 | Bulk BDOC for water samples collected in: (a) Umzinto, (b) Mtwalume, (c) Amanzimtoti, (d) Nongoma, (e) Phongola, (f) Jozini, (g) Mkuze, (h) Hazelmere, and (i) Mona.

Water sources that experienced the highest BDOC included Hazelmere, Amanzimtoti, Umzinto, and Jozini (64, 61, 57, and 56%, respectively). These water sources likely contained a greater proportion of labile organic matter of low-molecular weight, such as carbohydrates, amino acids, and other proteinaceous matter of algal or microbial origins. Water sources with elevated BDOC values are subject to easy removal by biological treatment processes such as biologically activated carbon (BAC) filtration or biofiltration. Complementary to the elevated bulk BDOC values, the water sources exhibited higher peak B and peak T intensities, reinforcing the consistency between fluorescence indices and bulk BDOC trends in some cases.

Water sources that exhibited mixed NOM composition and experienced intermediate BDOC levels included Mtwalume, Nongoma, and Mkuze (45, 37, and 30%, respectively). These water sources likely contained a mixture of refractory and biodegradable constituents such as fulvic and humic acids, resulting in fractional biodegradability. In terms of treatability, biological processes alone may be insufficient in removing NOM fractions in such waters. Pre-treatment stages, such as oxidation and coagulation, may be required to improve treatability.

Water sources that exhibited the least bulk BDOC values included Phongola and Mona (22 and 21%, respectively). These water sources were likely dominated by terrestrially derived refractory organic matter. These sources likely contained structurally complex compounds such as condensed tannins and aromatic humics that can withstand microbial activity. Biological treatment alone can be a challenge in treating such waters; additional processes such as advanced oxidation, enhanced coagulation, and tailored adsorptive processes can be used to effectively remove the problematic NOM fractions.

The observed BDOC variations underscore the relevance of site-specific biodegradability profiling for the purposes of optimizing treatment strategies. Biological treatment can be feasible for water sources like Hazelmere and Amanzimtoti; however, an integrated treatment train combining biological and physicochemical steps can be beneficial to water sources such as Phongola and Mona. Additionally, BDOC profiling offers water utilities a practical guide in forecasting DBP precursor behavior allowing for planning and design of nutrient removal systems and prediction of biological stability of the produced water.

3.7. Applicability of measured intensity of fluorescent NOM fractions as predictors for bulk BDOC

To evaluate the applicability of fluorescent fractions in predicting bulk BDOC, the biodegradability contribution of peaks B, T, and M was compared to bulk BDOC measured as the reduction in DOC over time. The BDOC percentage contribution of the tyrosine-like fraction (peak B) varied from 30 to 74%, reflecting a wide spectrum of its availability across the nine water sources. Interestingly, no positive correlation between the measured BDOC and the observed Peak B could be deduced. For example, only Amanzimtoti exhibited high Peak B contribution and high bulk BDOC (74 and 61%, respectively); water sources, such as Mkuze and Mona, exhibited high Peak B contribution (66 and 63%, respectively); however, they showed substantially lower BDOC (30 and 21%, respectively). This suggests limitations in relying on the abundance of tyrosine-like matter as a predictor for bulk BDOC. The inconsistency could be due to matrix effects or competition for microbial uptake.

The tryptophane-like components (Peak T) are often considered more bioavailable and their presence dominated some water sources, contributing to as high as 87% (Jozini). However, for Jozini, the high Peak T contribution did not translate to high bioavailability measured as bulk BDOC, indicating a decoupling of the two measured parameters. Overall, peak T performed better than peak B in showing alignment with bulk BDOC; however, it still lacked predictive reliability in samples containing refractory or humic matter.

Peak M (microbial humic-like substances) demonstrated better alignment with bulk BDOC; for example, water samples such as Nongoma and Jozini exhibited high Peak M values (41 and 46%, respectively) with corresponding high bulk BDOC values (37 and 56%, respectively). However, universality was not achieved because samples such as Mona and Hazelmere presented moderate peak M contributions (14 and 15%, respectively) but divergent bulk BDOC values (21 and 64%, respectively), further emphasizing the heterogeneity of NOM biodegradability in real water samples.

3.8. Grouped analysis of NOM characteristics with implications on treatment strategies

The principal variance in the measured NOM parameters was captured by applying PCA (Figure 7). The analysis allowed for the reduction in dimensionality in evaluating NOM variability patterns across sampling sites. The k-means clustering was carried out using the first two components that accounted for most of the data variance (76%). The silhouette coefficient maximization was used to determine the maximum cluster number ($k = 3$). The Euclidean distance metrics and Ward's linkage were used to validate the separation, and cluster validity, respectively, via agglomerative hierarchical clustering.

The determined clusters grouped the water sources based on NOM characteristics such as potential treatability, biodegradability, and composition. The characteristics of each cluster were reflective of similar optical and physicochemical composition, implying water sources could be grouped with emphasis on applying similar water treatment processes and DBP control.

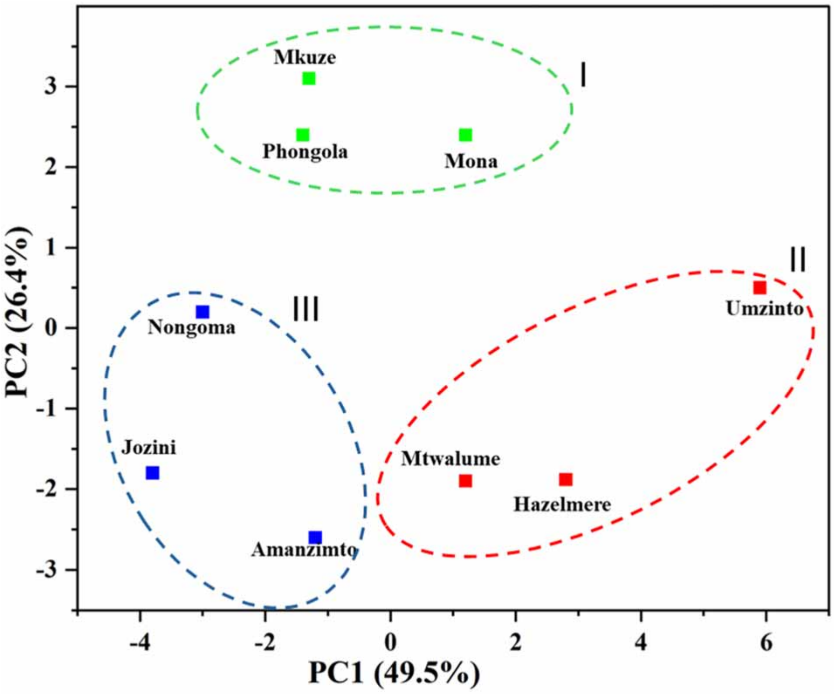


Figure 7 | PCA scatter plot grouping NOM profile clusters based on source NOM characteristics.

(a) Cluster I: Humic-dominant (high aromaticity and low DOC)

Cluster I was composed of water sources with the lowest DOC and UV254 absorbance, ranging between 1.53–1.99 mg/L and 0.06–0.08 cm^{-1}, respectively. However, cluster I water sources exhibited the highest ranges for SUVA and HIX values (3.1–5.6 L/mg m and 0.3–0.5, respectively), indicating the abundance of terrestrially derived humified and aromatic NOM fraction. Further, the cluster exhibited the lowest FI index range (1.08–1.29) and BIX (1.18–1.40), indicative of the presence of a NOM profile of allochthonous and refractory nature with minimum microbial influence. Consequently, the cluster exhibited the least BDOC content, ranging from 20.5 to 29.7%. Nonetheless, possibilities of elevated DBP formation potential due to the presence of proteinaceous fluorophores Peak B (0.13–0.17 RU) and Peak T (0.22–0.41 RU) warrant targeted removal strategies. Pre-oxidation (e.g., permanganate or ozone) to reduce DBP precursor loads, followed by enhanced coagulation to destabilize recalcitrant NOM, would be ideal for treating waters predominated by aromatic, humic-like substances with low biodegradability. This type of NOM is largely unperturbed by biological treatment alone.

(b) Cluster II: Protein-like dominant (labile NOM, high DOC)

The cluster exhibited the highest DOC and BDOC range (2.87–7.87 mg/L and 45–64%, respectively). Further, elevated FI and BIX values were experienced in the cluster (1.32–1.63 and 1.70–2.02, respectively), indicative of the dominance of microbially sourced NOM fractions. Further, the cluster exhibited a low HIX range (0.15–0.21), an indication of labile organic matter of low aromaticity. Water sources from this cluster exhibited fluorescence signatures dominated by proteinaceous and tryptophan-like fluorophores (Peak C, Peak T, and Peak M), which are typically susceptible to biological degradation. Treatment options, including optimized biofiltration of biologically activated carbon (BAC), would be ideal for treating the NOM type found in this cluster, given the microbial origin with high biodegradability. The recommended treatment process offers effective NOM removal with minimum coagulant use and minimal residual sludge production.

(c) Cluster III: Mixed NOM sources with moderate DOC concentration

Cluster III demonstrated moderate ranges for DOC (2.1–4.75 mg/L), UV254 (0.09–0.23 cm^{-1}), SUVA (3.53–4.87 L/mg m), and BDOC (37–61%). Fluorescence peaks (A, M, and T) for this cluster were higher than for cluster I but lower than for cluster II, suggesting the composition of NOM included both biodegradable and refractory fractions. Cluster III likely represents water sources undergoing transitional changes due to incoming heterogeneous sources of NOM. A combined or hybrid approach is recommended for treating the NOM type (labile and refractory) found in this cluster. Appreciable amounts of NOM could be removed by a hybrid treatment train combining coagulation-flocculation proceeded by biological filtration.

This study illustrated the synergy of integrating multivariate statistical techniques, optical indices, and fluorescence spectroscopy in characterizing NOM. An integrated approach allows for a bird's-eye view in terms of actionable insights for source water quality with implications for tailored or optimized treatment, particularly in the wake of stringent regulatory compliance, including DBP minimization.

3.9. Fluorescence-based decision-support framework for predicting biodegradability and recommendation of treatment strategies

The combination of optical indices, such as HIX, BIX, FI, and SUVA, together with FEEM spectroscopy, revealed strong relationships between the biodegradability potential of NOM and its chemical nature. For example, Nongoma, Mkuze, and Phongola exhibited high SUVA values (>4.5 L/mg m), an indication of high aromatic and hydrophobic NOM content, consistent with high humic substance content. Low BDOC values were observed from these samples (<40%), underscoring the recalcitrance of aromatic, humified NOM. On the other hand, higher BDOC values (>50%) indicative of labile and microbially sourced NOM were observed at Mtwalume, Amanzimtoti, and Jozini. These samples exhibited higher microbial indices (BIX > 1.8; FI > 1.4) and moderate SUVA values ranging from 1.37 to 3.52 L/mg m. Interestingly, samples from Mtwalume, Amanzimtoti, and Jozini demonstrated high Peak T and Peak B (tryptophan-like and tyrosine-like, respectively) signatures, and also exhibited the highest biodegradability profiles (BDOC > 50%). Conversely, Mkuze and Phongola samples were dominated by humic-like signal (e.g., Peak A > 2.5), which is less biodegradable (BDOC = 21.7 and 29.7%, respectively), despite moderate DOC levels. Additional insights were obtained from Peak M signal (microbial metabolic byproducts-like) whereby Amanzimtoti, Mkuze, and Jozini exhibited elevated Peak M signal and intermediate to high BDOC values contributed by non-proteinaceous and yet labile components. These findings affirm the predictive capabilities of combined optical parameters and fluorescence spectroscopy in delineating the biodegradability of NOM.

3.9.1. Fluorescence-based framework for predicting the treatment strategy

Figure 8 encapsulated our findings into a fluorescence-based decision-support framework for predicting biodegradability and recommendations for treatment strategies. The framework leveraged the following key findings:

- Fluorescence peak thresholds (T + B > 1.0 implies high biodegradability potential)
- Optical indices (BIX > 1.8, FI > 1.5 imply microbial/labile character)
- HIX and SUVA (HIX > 0.4; SUVA > 4.5 implies humic, refractory NOM)

Biologically active filtration treatment strategies, such as slow sand filtration and BAC, are best suited for water sources with elevated microbial indices and high protein-like fluorescence signatures. On the other hand, treatment strategies, including AOP or enhanced coagulation, are best suited to water sources dominated by humic substances with characteristic high SUVA values.

The developed fluorescence-based framework expedites the approximation of the biodegradability potential of source waters, thus reducing the reliance on laborious BDOC tests. Additionally, the framework provided a rational decision-making basis for selecting or adapting site-specific treatment strategies based on NOM properties, thus circumventing high capital and subsequent operational costs, resulting in sustainable water treatment planning, especially in poor-resourced or data-scarce regions.

3.9.2. Opportunities for real-time monitoring and design

The wider application of *in situ* UV254 monitoring platforms and fluorescence sensors provides an opportunity for the proposed framework to be utilized for real-time decision-making for operational control. For example, during storm events, fluorescence peaks B or T usually surge; real-time tracking of these peaks can inform adaptive adjustment of pre-oxidant dosing or biofilter residence time. Also, the framework can be useful in advanced treatment settings to inform blending strategies of high BDOC and low BDOC water sources to optimize the performance of the biofilters and reduce DBP formation.

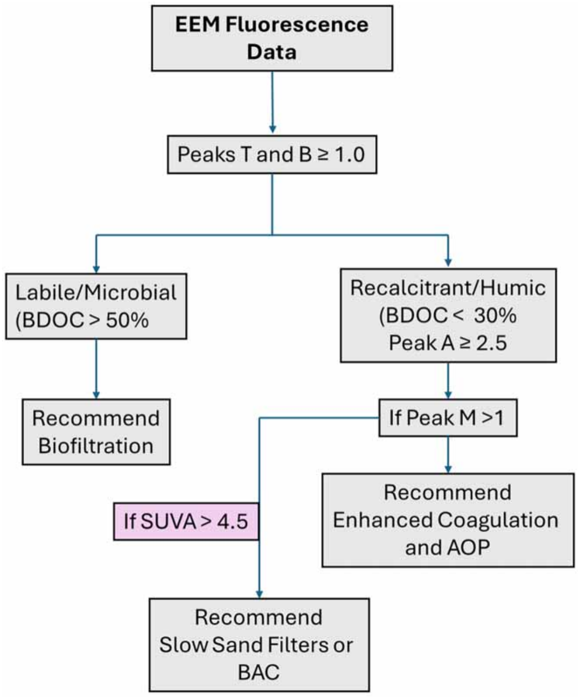


Figure 8 | Fluorescence-based framework for selecting a treatment strategy.

4. CONCLUSION

The study demonstrated the usefulness of an integrated approach in determining the treatability of NOM in surface water sources serving South African drinking water treatment plants. Biodegradability of aromatic, humified NOM fractions was less likely, as exhibited by a strong negative correlation between BDOC and both SUVA and UV254 values. Greater biodegradability was expected for NOM fractions that demonstrated positive correlations between fluorescence indices (FI, BIX) and protein-like fluorescence peaks. Typically, rivers generally receive microbial-sourced NOM fractions exhibiting high BDOC concentrations, indicating better suitability for treatment processes such as biofiltration. On the other hand, dam waters exhibit higher humification and consequently lower BDOC concentration. Treatment strategies for such source waters include intensive approaches such as advanced oxidation, activated carbon, or enhanced coagulation. The study demonstrated the importance of source water characteristics and how these influence the adoption of treatment strategies to be used.

The study demonstrated the utility of low-cost optical techniques with opportunities for application in data-limited and resource-constrained settings such as South Africa. Furthermore, the study addressed water security challenges by tackling NOM assessment and surveillance issues in the context of the optimization of DBP precursor reduction strategies and enhanced treatment efficiencies. By drawing advantage of the linkage between optical properties and BDOC, water companies can transition toward resilient, sustainable, and adaptive treatment systems by minimizing energy and chemical usage and in hindsight, safeguarding the integrity of public perceptions and health.

It is recommended that further studies should monitor the influence of temporal variations on source water quality, with an emphasis on climatic variability, algal productivity, and land use changes.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 20 October 2025; accepted in revised form 17 December 2025. Available online 14 January 2026