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Research Article

Geographical differentiation of riverine DOM composition and source apportionment: A case study of a riverine network of a mountainous stream, a Plain River, and an artificial canal

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Abstract: To elucidate the geographical differentiation characteristics and driving mechanisms of Dissolved Organic Matter (DOM) in typical rivers, this study conducted a multi-spectral investigation on three representative river types within Shandong Province: The mountainous Dawen River, the plain Tuhai River, and the artificial East Grand Canal. The DOM composition was analyzed using Ultraviolet-Visible (UV-Vis) absorption spectroscopy, Excitation-Emission Matrix (EEM) fluorescence spectroscopy, and parallel factor analysis (PARAFAC), while Principal Component Analysis (PCA) was employed to quantify the synergistic effects of natural processes and anthropogenic activities. Results revealed significant spatial heterogeneity in DOM composition and sources. The plain river exhibited the highest aromaticity (humic-like components: 43.3%) due to long-term agricultural non-point source inputs and urban wastewater discharge. The mountain stream, shaped by complex terrain and relatively intact ecosystems, was dominated by autochthonous DOM derived from microbial metabolism, with higher Fluorescence Index (FI = 2.12) and biological index (BIX = 1.35) than other river types. The artificial canal retained protein-like components (64.2%), largely attributed to winter hydrological stagnation and disturbances from shipping activities. Further analysis demonstrated that geographical settings (e.g., mountain terrain) and anthropogenic activities (e.g., agriculture, shipping) jointly regulated DOM composition by altering the balance between input and transformation processes. Integrated fluorescence parameters and PCA results suggested differentiated management strategies: protecting ecological integrity in mountain streams to sustain self-purification, enhancing non-point source interception in plain rivers, and mitigating shipping pollution in canals. This study systematically reveals the natural-anthropogenic coupling mechanisms driving DOM dynamics in northern China rivers, providing critical insights for precision water environment management at the watershed scale.

Keywords: Dissolved organic matter (DOM); UV-Vis spectroscopy; Parallel factor analysis (PARAFAC); Geographical settings; Anthropogenic activities

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Introduction

Dissolved Organic Matter (DOM), a structurally heterogeneous mixture of organic compounds ubiquitously present in aquatic environments, plays a pivotal role in regulating carbon cycling and pollutant fate within ecosystems (He et al. 2022; Rodríguez-Vidal et al. 2022). As critical conduits for terrestrial DOM transport to lakes and oceans (Wipfli et al. 2007), riverine DOM compo-

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sition and sources are shaped by natural factors such as climate and geomorphology (Hong et al. 2012; Xu, 2024), with anthropogenic influences across watersheds (He et al. 2022). Under geographical differentiation, distinct river types—mountain streams, plain rivers, and artificial canals—may exhibit pronounced spatial heterogeneity in DOM source-sink dynamics due to variations in topographic gradients, hydrological connectivity, and human intervention patterns. However, current understanding of such spatial variations remains fragmented.

The complexity of DOM sources poses significant analytical challenges (Shi et al. 2024). Inputs from terrestrial vegetation degradation, agricultural non-point sources, industrial/domestic wastewater discharge, and in situ microbial metabolism (Zhang, 2014) collectively alter DOM composition (e.g., humic-to-protein ratios) and functional group characteristics, thereby influencing water quality (Rodríguez-Vidal et al. 2022; Zhang et al. 2018). To disentangle these multi-source contributions, advanced analytical techniques such as Excitation-Emission Matrix (EEM) fluorescence spectroscopy coupled with parallel factor analysis (PARAFAC) and ultraviolet-visible spectroscopy (UV-Vis) have been widely adopted for their high sensitivity and multi-component resolution (Chen et al. 2015). For example, Zhang et al. (2021) identified one protein-like and three humic-like fluorescent components in DOM from Beijing's North Canal, highlighting urbanization-induced perturbations. Similarly, Lu (2022) demonstrated anthropogenic enhancement of autochthonous DOM in urbanized reaches of the Puhe River. Nevertheless, most existing studies focus on single watersheds or homogeneous river systems (Wilson et al. 2009; Zhang et al. 2024), leaving a critical gap in comparative analyses of DOM across geographically diverse river networks, particularly those spanning mountain-plain-canal composite systems.

To address these gaps, this study investigates a riverine network consisting of three river types in Shandong Province, China: The Dawen River (mountain stream), the Tuhai River (plain river), and the Shandong section of the Grand Canal (artificial canal). Through UV-Vis and EEM-PARAFAC analyses, we aim to answer two key questions: (1) How does the topographic gradients (across montane, lowland, and canal rivers) drive spatial heterogeneity in DOM composition and sources by regulating erosion intensity and land-use patterns? (2) Do significant differences exist in the degree of humification and autochthonous contributions among mountain streams (dominated by natural processes), plain rivers (influenced by agricultural non-point pollution), and canals (strongly regulated by anthropogenic activities)? The findings are expected to establish a geographical differentiation framework for DOM source apportionment at the watershed scale and provide a scientific basis for targeted pollution control strategies.

1 Materials and methods

1.1 Study area

The study area is located in Shandong Province, China, which is characterized by a warm-temperate semi-humid monsoon climate with annual precipitation of 550–950 mm concentrated in June–September. Three representative types of rivers were selected for investigation (Fig. 1). The Dawen River (mountain stream) originates in the central Shandong hills (100–500 m elevation). This 209 km long river flows westward through mountainous (31%) and hilly terrain (37%) before discharging into the Yellow River. The basin with an area of 8,633 km^2 features dominant land use of cropland and forest, though urbanization has reduced agricultural areas (Li et al. 2023). The Grand Canal (artificial canal) stretches 480 km across the western Shandong plains (150–350 m elevation). In addition to its shipping function, the canal forms part of the South-to-North Water Diversion Project. Hydrological stagnation in regulated sections increases pollution risks, particularly from ship waste and domestic sewage (Hu et al. 2024). The Tuhai River (plain river) is a 390 km long channel in the North China Plain at an elevation of less than 40 m. This river supports flood control and irrigation for intensive agriculture. Chronic nutrient pollution (e.g., NH_4-N: 2.8 mg/L; TP: 0.4 mg/L) has degraded its water quality to the Class V level (Cao et al. 2024; Wang et al. 2024).

1.2 Sampling and analytical procedures

Twenty sites were selected for sampling across the three river types in the winter of 2023: The mountain stream (S1–S7), the plain river (P1–P7), and the canal (R1–R6), covering upper, middle, and lower reaches (Fig. 1). These sites represented natural erosion zones (Dawen River), agricultural non-point sources (Tuhai River), and shipping hubs (Grand Canal). Surface water samples were collected at 0.5 m depth using a plexiglass sampler.

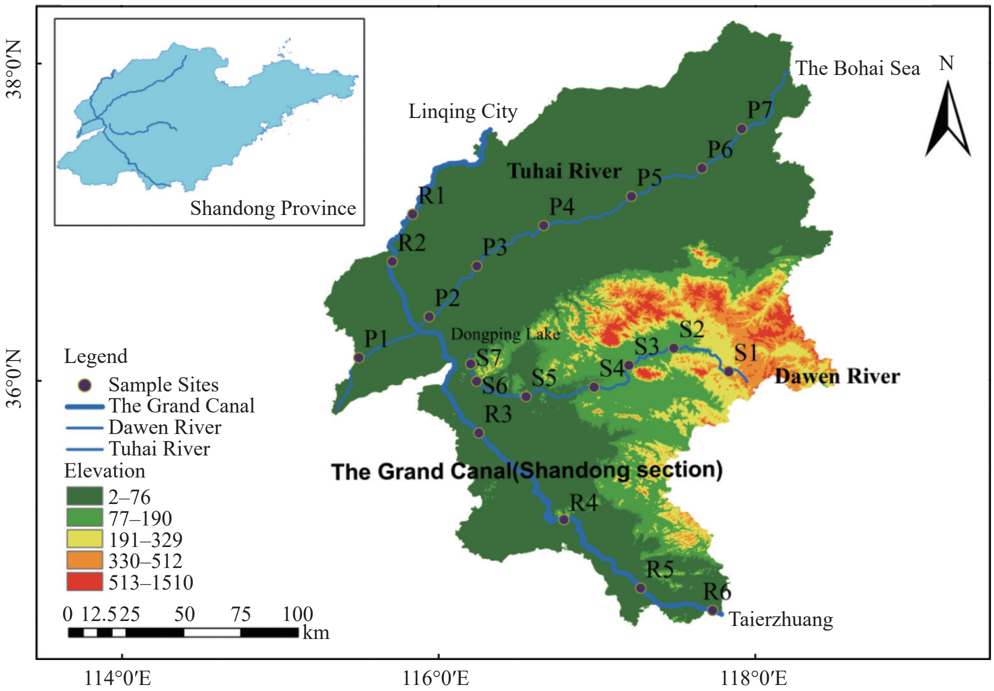

Fig. 1 The sampling sites of the three types of rivers in the study area

In situ measurements of pH and ORP were conducted with a multiparameter water quality meter (HI98196, Hanna Instruments, USA). All water samples were stored in pre-cleaned 500 mL polyethylene bottles at 4°C in the dark and processed within 24 h.

The filtered (0.45 μm GF/F, Whatman) water samples were analyzed for Dissolved Organic Carbon (DOC) concentration using a TOC analyzer (Vario TOC Cube, Elementar, Germany) after inorganic carbon removal via HCl acidification. UV–Vis absorbance spectra were recorded from 200 to 700 nm at 1 nm resolution (Hitachi U-4100), with Milli-Q water as blank correction. Specific ultraviolet absorbance at 254 nm (SUVA$_{254}$, L/(mg·m)) and the E2/E3 ratio (A_{250}/A_{365}) were calculated to assess DOM aromaticity and molecular weight (Cao et al. 2024). Fluorescence excitation–emission matrices (EEMs) were recorded using a spectrofluorometer (Hitachi F-4600) with excitation wavelengths from 250 nm to 450 nm and emission wavelengths from 300 nm to 550 nm at 5 nm increments and a scanning speed of 1,200 nm/min. Raman-normalized fluorescence intensities (R.U.) were corrected for scattering artifacts following Lawaetz et al. (2009). Three widely used fluorescence indices were calculated to assess DOM sources: (1) the humification index (HIX = Em435–480/Em300–345 at Ex255; Zhang et al. 2010), (2) the biological index (BIX = Em380/Em430 at Ex310; Huguet et al. 2009), and the fluorescence index (FI = Em450/Em500 at Ex370; Li et al. 2022).

1.3 Data processing

The PARAFAC fluorescent components were extracted using N-way and DOMFluor toolboxes (MATLAB R2023a) and validated via split-half analysis and residual diagnostics. Component spectra were matched against the OpenFluor database (http://www.openfluor.org) for spectral validation.

Data preprocessing (outlier removal, normality tests) and descriptive statistics (mean ± SD) were performed in Excel 2019. EEMs were visualized using MATLAB, while correlation heatmaps were generated in Origin 2021 with significance set at $p < 0.05$. Principal Component Analysis (PCA) was employed in Origin 2021 with DOM indices to discern the natural vs. anthropogenic factors for DOM occurrence across the three river types.

2 Results and discussion

2.1 Basic physicochemical characteristics

The basic physicochemical parameters of the three river types are summarized in Table 1. The average pH values of the mountain stream, artificial canal, and plain river were 8.88 ± 0.42, 8.44 ± 0.45, and 8.80 ± 0.30, respectively, all indicating weakly alkaline conditions. The Oxidation-Reduction Potential (ORP) ranged from 40.02 ± 12.93

Table 1 Physicochemical parameters of river water bodies

Type	pH	ORP (mV)	DOC (mg/L)
Mountain stream	8.88±0.42	40.02±12.93	13.89±1.81
Artificial canal	8.44±0.45	60.02±10.73	15.10±5.66
Plain river	8.80±0.30	55.07±9.93	13.02±5.19

mV in the mountain stream to 60.02 ± 10.73 mV in the canal and 55.07 ± 9.93 mV in the plain river, reflecting an overall oxidizing environment. The DOC concentrations (13.02–15.10 mg/L) significantly exceeded those typically reported for natural rivers (Liu et al. 2015; Zhang et al. 2024), highlighting elevated organic carbon loads and potential pollution accumulation in the study area.

Significant spatial differences in $SUVA_{254}$ were observed (ANOVA, $p < 0.05$), with values following the order: The plain river (1.07 ± 0.46 L/(mg·m)) >mountain stream (0.80 ± 0.18) > canal (0.73 ± 0.14) (Fig. 2a). Elevated $SUVA_{254}$ in plain rivers reflects DOM enriched in aromatic compounds (Xu, 2020), likely originating from agricultural pesticide residues (e.g., benzene-ring herbicides) and urban wastewater inputs (Zhang et al. 2023). In contrast, E2/E3 ratios (inversely related to molecular weight) showed no significant differences across river types ($p > 0.1$), with mean values of 6.41 ± 1.35 (mountain), 5.79 ± 0.67 (canal), and 6.13 ± 0.94 (plain) (Fig. 2b). This suggests a dominance of low-molecular-weight DOM during the dry season (Shi et al. 2024). The slightly higher E2/E3 in mountain stream may result from rapid degradation of macromolecules under strong UV radiation and accelerated turnover of biogenic DOM (Soto Cárdenas et al. 2017).

2.2 Fluorescence spectral signatures

Fluorescence indices (FI, BIX, HIX) revealed DOM sources and transformation pathways (Fig. 3) (Deng et al. 2022; Lin et al. 2023). All samples exhibited FI >1.9 (mountain: 2.12 ± 0.15; canal: 2.05 ± 0.18; plain: 1.98 ± 0.21), confirming microbial metabolism as the dominant DOM source (Li et al. 2022). The highest FI in the mountain stream reflects its extensive forest cover (22%), which enhances terrestrial organic matter transformation. BIX values >1 (mountain: 1.35±0.11; canal: 1.28 ±0.09; plain: 1.21±0.13) further support an autochthonous source, with the decreasing trend (the mountain stream >the canal >the plain river) reflecting reduced biological activity and ecosystem integrity along the disturbance gradient (Huguet et al. 2009).

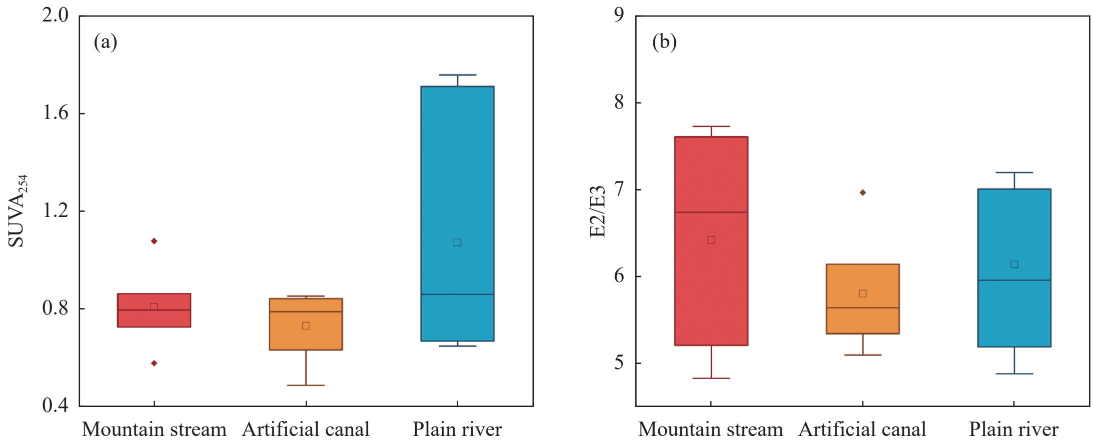

Fig. 2 UV–Vis s spectral parameters of DOM in the three types of waters

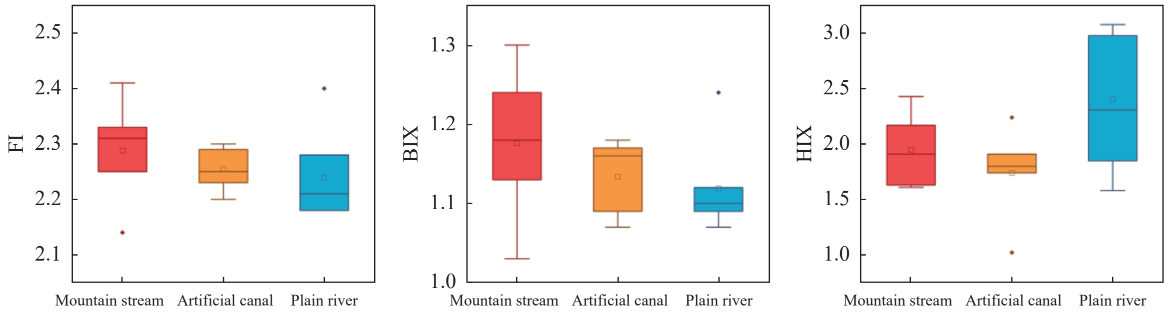

Fig. 3 Typical Fluorescence spectral parameters of DOM in the three types of waters

HIX values < 4 (plain river: 3.62 ± 0.45; canal: 3.15 ± 0.38; mountain stream: 2.89 ± 0.51) indicate low humification. The relatively higher HIX in plain rivers likely stems from long-term agricultural inputs (Wang et al. 2021; Wang, 2024), while lower HIX in canals may be attributed to inhibitory effects of ship-derived oils on humic substance formation (Mao et al. 2025; Yang et al. 2008).

Overall, the mountain stream exhibited the strongest autochthonous signals (highest FI and BIX), linked to diverse microbial diversity fostered by complex topography and higher elevation gradients (Fig. 1). In contrast, plain river faced dual pressures from agricultural activities (highest HIX) and urbanization (highest $SUVA_{254}$), while canal DOM was primarily influenced by hydrological stagnation and shipping-derived pollutants, collectively reducing their self-purification capacity.

2.3 DOM compositional features

PARAFAC analysis identified five fluorescent components (Fig. 4, Table 2). C1 (Ex/Em: 320/400 nm) and C2 (350/445 nm) represented humic-like and fulvic-like substances, typically associated with recalcitrant aromatic compounds (Liu et al. 2023; Marcé et al. 2021). The plain river showed the highest C1 + C2 contribution (43.26%), likely due to agricultural humic inputs (Wang et al. 2021; Wang et al. 2024), whereas the mountain stream

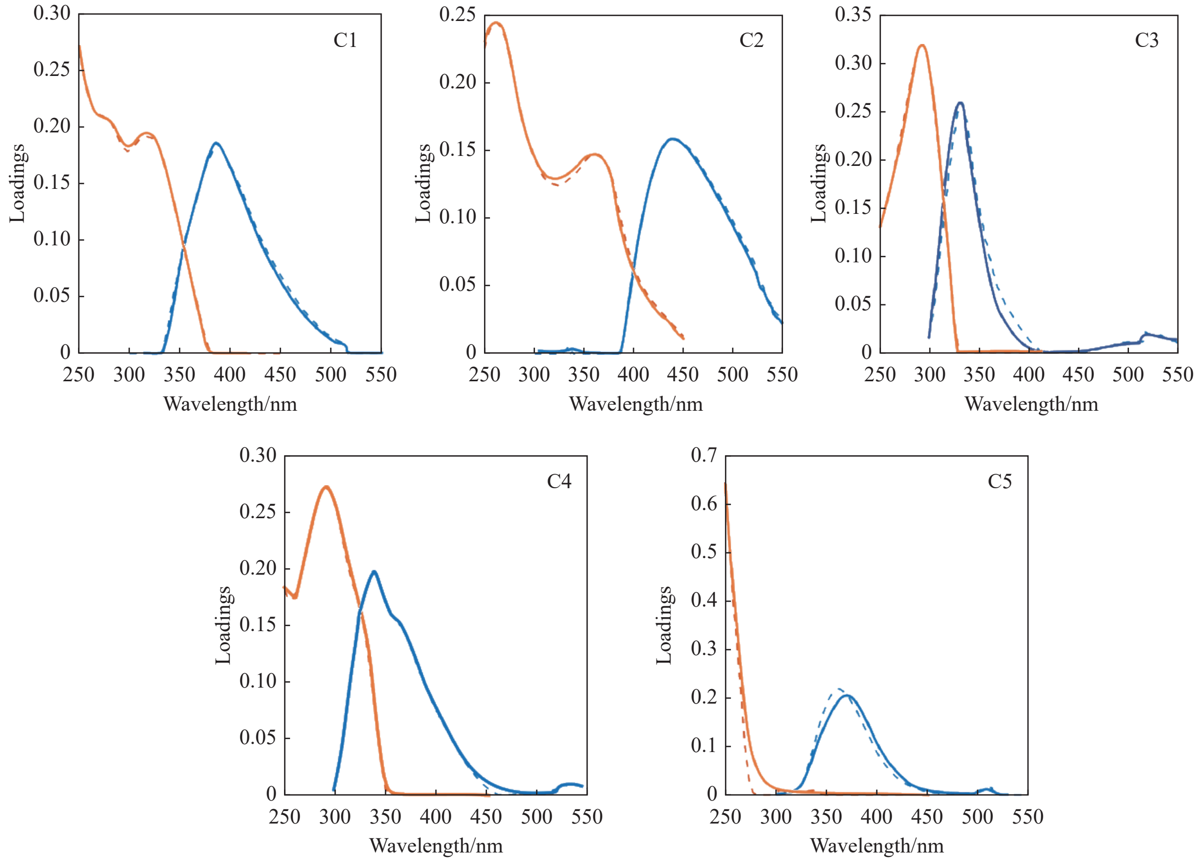

Fig. 4 The PARAFAC fluorescence components of DOM and the split-half analysis results

Table 2 Characteristics of DOM fluorescent components

Components in this study	$\lambda_{Ex}/\lambda_{Em}$ (nm)	Compound type	Components in previous studies
C1	<250(320)/400	Humic-like	250(325) /400–425 nm (Liu et al. 2023); 245 (320)/442 nm (Yang et al. 2024)
C2	255(350)/445	Fulvic acid	(240–260)/(379–457) nm (Marcé et al. 2021); 250 (355)/461 nm (Ouyang et al. 2025)
C3	270/320	Tyrosine-like	275/312 nm (Yang et al. 2024); 275/325 nm (Ren et al. 2021)
C4	285/350	Tryptophan-like	290/345 nm (Ren et al. 2021); (275–290)/(305–351) nm (Ouyang et al. 2025)
C5	<250/370	Tryptophan-like	<250/338–370 nm (Marcé et al. 2021)

(39.93%) and canal (35.83%) contained lower proportions.

C3 (tyrosine-like, 270/320 nm), C4 (tryptophan-like, 280/350 nm), and C5 (tryptophan-like, 250/370 nm) corresponded to protein-like components (Yang et al. 2024; Ouyang et al. 2025; Ren et al. 2021). Protein-like fractions (C3 + C4 + C5) dominated in the mountain stream (60.07%) and canal (64.17%), but were reduced in the plain river (56.74%), reflecting weaker protein signals in agriculturally impacted waters. Total fluorescence intensity ranked plain river (0.30 ± 0.009 R.U.) > canal (0.25 ± 0.011) > mountain stream (0.21 ± 0.013) (Fig. 5), aligning with pollution gradients (urban > shipping > natural). The highest protein contribution in canals likely arise from winter hydrological stagnation concentrating wastewater inputs (Coble et al. 2022). Notably, the protein-like dominance (>56%) observed in this study substantially exceeds values reported for the rivers in southern China (Li et al. 2024; Wu et al. 2017; Liang et al. 2023; Song et al. 2024; Zhang et al. 2018), underscoring the suppressed degradation of protein-like DOM under cold and dry northern conditions.

2.4 Principal component analysis

Principal component analysis (PCA) elucidated the factors responsible for DOM distinctions across river types (Fig. 6). For the mountain stream, PC1 (57.7% variance) strongly associated with BIX, FI, and protein-like components (C3, C4), emphasizing the role of microbial metabolism. PC2 (26.5%) was linked to HIX and C2, indicating terrestrial humic inputs (Shafiquzzaman et al. 2014). In the canal, PC1 (53.7%) grouped autochthonous indices (BIX, FI) with protein-like components, while PC2 (23.7%) linked humic-like substances (C1, C2), suggesting that sediment resuspension induced by shipping may contributed to DOM composition (Yuan et al. 2022). Plain rivers showed PC1 (50.4%) driven by SUVA_{254}, humic-like components, and HIX, reflecting agricultural aromatic inputs. PC2 (33.4%) was associated with protein accumulation (Bu, 2024), consistent with winter degradation limitations.

Based on the identified impacting factors for DOM occurrence, the managements suggested for rivers could include protecting mountain ecosystems to sustain microbial self-purification, controlling agricultural and urban discharges in plain rivers, and enforcing stricter shipping regulations along with ecological water replenishment for canals.

3 Conclusions

This study provides a multidimensional spectral analysis to explore the spatial variability and driving mechanisms of Dissolved Organic Matter (DOM) in typical rivers of northern China. The results highlight the coupled effects of geographical settings and anthropogenic activities on DOM dynamics. The main conclusions are as follows:

(1) Spatial Differentiation of DOM Characteristics: DOM concentrations in the study area exceeded typical levels, with distinct spatial heterogeneity in molecular composition and pollution sources. The DOM of the plain river exhibited higher aromaticity and humic substance accumulation due to agricultural non-point sources and urban wastewater discharge. The mountain stream was dominated by autochthonous DOM, sustained by intact ecosystems and microbial metabolism. The canal showed protein-like DOM retention, influenced by hydro-

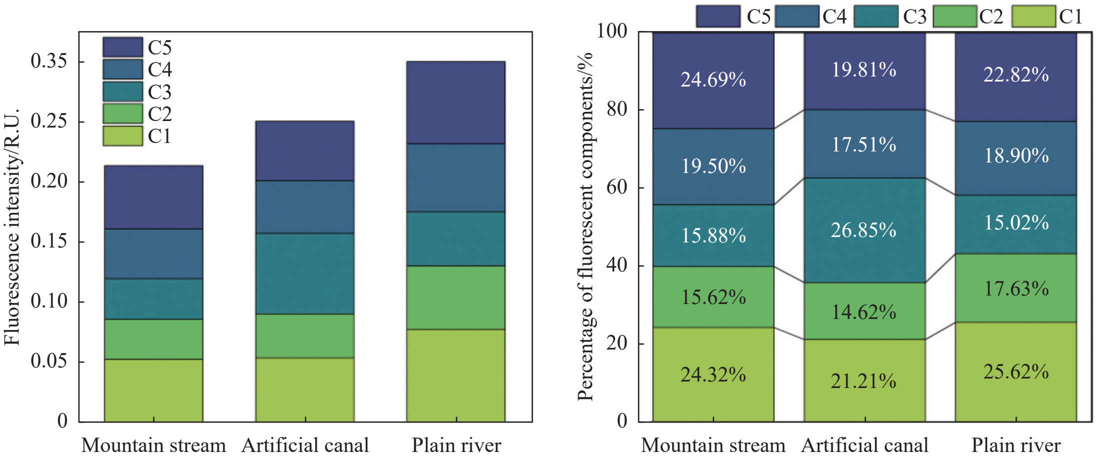

Fig. 5 Fluorescence intensity and percentage of PARAFAC components

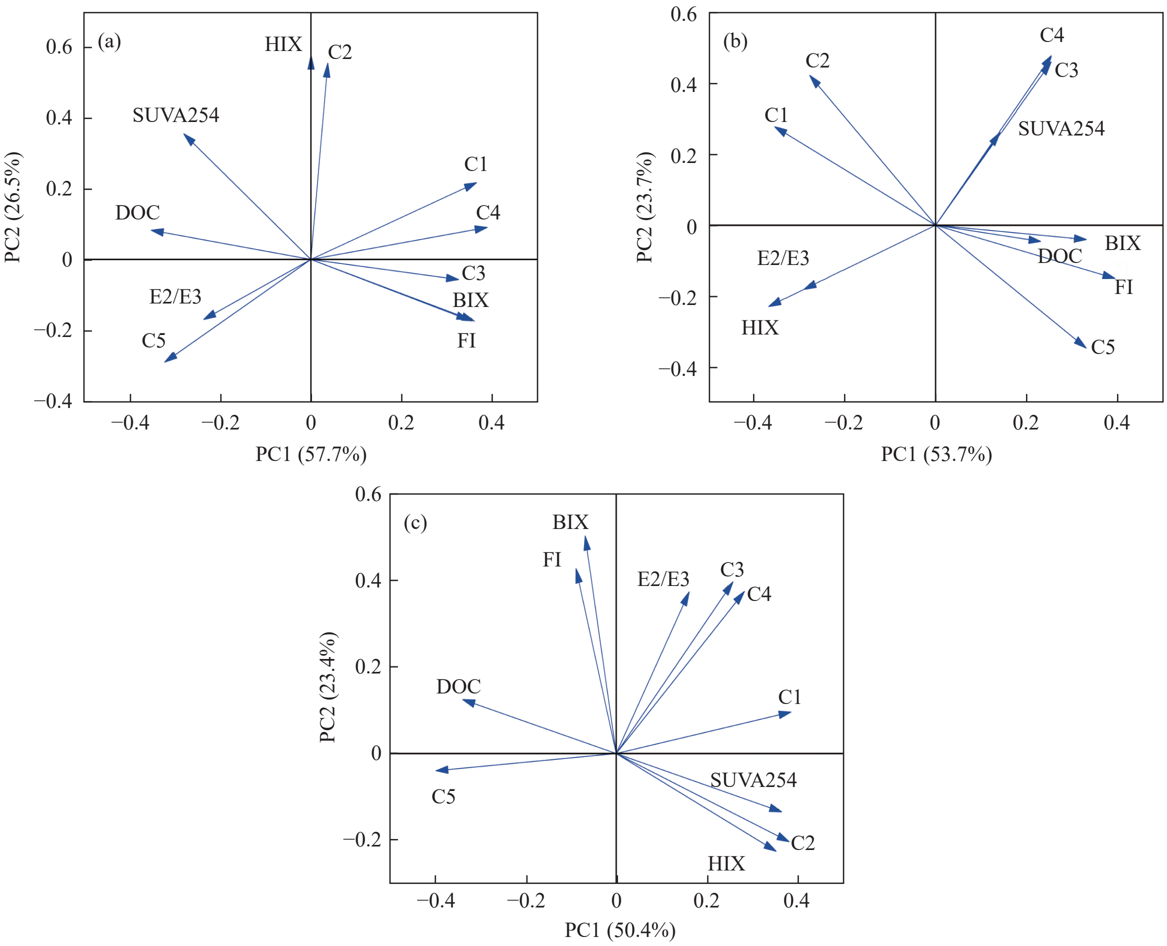

Fig. 6 PCA of DOM indices: (a) Mountain stream, (b) Artificial canal, and (c) Plain river

logical stagnation and shipping activities.

(2) Source-transformation mechanisms: Fluorescence indices and PARAFAC results indicated that microbial metabolism primarily dominated DOM dynamics during the dry season. However, natural and anthropogenic drivers diverged across river types: steep topography enhanced biotransformation in mountain stream; agricultural practices intensified terrestrial humic inputs in plain river, and hydraulic stagnation in canal restricted endogenous degradation.

(3) Targeted management strategies: Principal Component Analysis (PCA) quantified key drivers—microbial activity (mountain stream), agricultural inputs (plain river), and shipping disturbance (canal)—providing a basis for spatially differentiated management. Recommended measures include protecting ecological integrity in mountain rivers through ecological red lines and vegetation restoration, mitigating non-point pollution interception in agricultural basins with buffer strips or constructed wetlands, and strengthening canal management via dynamic pollution monitoring and ecological flow replenishment.

While this study advances understanding of DOM dynamics in northern watersheds, limitations remain in resolving seasonal variations and long-term climate change impacts. Future work should integrate multi-temporal observations to better elucidate DOM transformation mechanisms under evolving environmental conditions.

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References

Bu XY, 2024. Study on spectral characteristics of DOM in typical farmland river marsh system in Sanjiang Plain. M. S. thesis, Harbin: Northeast Agricultural University: 81. (in Chinese)

Cao Q, Zong X, Qi C, et al. 2024. Changes in runoff and sediment loads in the Tuhai River basin and the factors influencing these changes. Water, 16(14). DOI:10.3390/w16142064.

Chen W, Habibul N, Liu XY, et al. 2015. FTIR and synchronous fluorescence heterospectral two-dimensional correlation analyses on the binding characteristics of copper onto dissolved organic matter. Environmental Science and Technology, 49(4): 2052−2058. DOI：10.1021/es5049495.

Coble AA, Wymore AS, Potter JD, et al. 2022. Land use overrides stream order and season in driving dissolved organic matter dynamics throughout the year in a river network. Environmental Science and Technology, 56(3): 2009−2020. DOI：10.1021/acs.est.1c06305.

Deng JJ, Ma H, Wang XF, et al. 2022. Measurement report: Optical properties and sources of water-soluble brown carbon in Tianjin, North China–insights from organic molecular compositions. Atmospheric Chemistry and Physics, 22(10): 6449−6470. DOI：10.5194/acp-22-6449-2022.

He J, Wu X, Zhi GQ, et al. 2022. Fluorescence characteristics of DOM and its influence on water quality of rivers and lakes in the Dianchi Lake basin. Ecological Indicators, 142: 109088. DOI：10.1016/j.ecolind.2022.109088.

Hong HS, Yang LY, Guo WD, et al. 2012. Characterization of dissolved organic matter under contrasting hydrologic regimes in a subtropical watershed using PARAFAC model. Biogeochemistry, 109(1): 163−174. DOI：10.1007/s10533-011-9617-8.

Hu HZ, Zhou G, Tong SC, et al. 2024. Pollution characteristics and eutrophication assessment in plain river network areas: A case study of the Beijing–Hangzhou grand canal (Changzhou section). Water, 16(23): 3353. DOI：10.3390/w16233353.

Huguet A, Vacher L, Relexans S, et al. 2009. Properties of fluorescent dissolved organic matter in the Gironde Estuary. Organic Geochemistry, 40(6): 706−719. DOI：10.1016/j.orggeochem.2009.03.002.

Lawaetz AJ, Stedmon CA. 2009. Fluorescence intensity calibration using the Raman scatter peak of water. Applied Spectroscopy, 63(8): 936−940. DOI：10.1366/000370209788964548.

Li JC, Shan R, Yuan WH. 2023. Constructing the landscape ecological security pattern in the dawen river basin in China: A framework based on the circuit principle. International Journal of Environmental Research and Public Health, 20(6): 5181. DOI：10.3390/ijerph20065181.

Li XS, Li WY, Wang Y, et al. 2024. 3D-EEM spectral characteristics of dissolved organic compounds in the main natural water bodies of Nanning. Acta Scientiae Circumstantiae, 44(11): 215−229. (in Chinese) DOI：10.13671/j.hjkxxb.2024.0303.

Li YZ, Zhang YB, Li Z, et al. 2022. Characterization of colored dissolved organic matter in the northeastern South China Sea using EEMs-PARAFAC and absorption spectroscopy. Journal of Sea Research, 180: 102159. DOI：10.1016/j.seares.2021.102159.

Liang EH, Li JR, Li B, et al. 2023. Roles of dissolved organic matter (DOM) in shaping the distribution pattern of heavy metal in the Yangtze River. Journal of Hazardous Materials, 460: 132410. DOI：10.1016/j.jhazmat.2023.132410.

Lin YY, Hu E, Sun CS, et al. 2023. Using fluorescence index (FI) of dissolved organic matter (DOM) to identify non-point source pollution: The difference in FI between soil extracts and wastewater reveals the principle. Science of The Total Environment, 862: 160848. DOI：10.1016/j.scitotenv.2022.160848.

Liu D, Pan DL, Bai Y, et al. 2015. Variation of dissolved organic carbon transported by two Chinese rivers: The Changjiang River and Yellow River. Marine Pollution Bulletin, 100(1): 60−69. DOI：10.1016/j.marpolbul.2015.09.029.

Liu Y, Liu XF, Wen YJ, et al. 2023. A snapshot on vertical variability of dissolved organic matter in the epilagic zone of the eastern Indian Ocean. Marine Pollution Bulletin, 192: 114985. DOI：10.1016/j.marpolbul.2023.114985.

Lu KT, 2022. Research on the composition structure, source, and water quality response of DOM in Puhe River. M. S. thesis, Beijing: Chinese Academy of Environmental Sciences: 113. (in Chinese)

Mao XR, Zhu L, Liu BY, et al. 2025. Shifts in phytoplankton communities in inland waterways: Insights from the Beijing–Hangzhou Grand Canal, China. River, 4(1): 36−43. DOI：10.1002/rvr2.116.

Marcé R, Verdura L, Leung N. 2021. Dissolved organic matter spectroscopy reveals a hot spot of organic matter changes at the river–reservoir boundary. Aquatic Sciences, 83(4): 67. DOI：10.1007/s00027-021-00823-6.

Ouyang WJ, Zhao YJ, Li Z, et al. 2025. Hydraulic residence time thresholds and seasonal regimes governing DOM transformation in Upper Yangtze River cascading reservoirs. Water Research, 287: 124325. DOI：10.1016/j.watres.2025.124325.

Ren WX, Wu XD, Ge XG, et al. 2021. Characteristics of dissolved organic matter in lakes with different eutrophic levels in southeastern Hubei Province, China. Journal of Oceanology and Limnology, 39(4): 1256−1276. DOI：10.1007/s00343-020-0102-x.

Rodríguez-Vidal FJ, García-Valverde M, Ortega-Azabache B, et al. 2022. Monitoring the performance of wastewater treatment plants for organic matter removal using excitation-emission matrix fluorescence. Microchemical Journal, 175: 107177. DOI：10.1016/j.microc.2022.107177.

Shafiquzzaman M, Ahmed AT, Azam MS, et al. 2014. Identification and characterization of dissolved organic matter sources in Kushiro river impacted by a wetland. Ecological Engineering, 70: 459−464. DOI：10.1016/j.ecoleng.2014.06.023.

Shi K, Zhao YT, Wu CB, et al. 2024. Revealing the distribution characteristics and key driving factors of dissolved organic matter in Baiyangdian Lake inflow rivers from different seasons and sources. Science of The Total Environment, 951: 175768. DOI：10.1016/j.scitotenv.2024.175768.

Song H, Gao LM, Xu J, et al. 2024. Spectral characteristics of dissolved organic matter (DOM) in the middle reaches of the Huai River in a dry season. Environmental Science: Water Research & Technology, 10(12): 3308−3318. Doi: 10.1039/D4EW00499J.

Soto Cárdenas C, Gerea M, Garcia PE, et al. 2017. Interplay between climate and hydrogeomorphic features and their effect on the seasonal variation of dissolved organic matter in shallow temperate lakes of the Southern Andes (Patagonia, Argentina): A field study based on optical properties. Ecohydrology, 10(7): e1872. DOI：10.1002/eco.1872.

Wang D, 2024. Simulation of water quality and typical water ecological factors in the Shandong Section of the Tuhai River Mainstream. M. S. thesis. Jinan: Jinan University: 113. (in Chinese)

Wang KF, Xie W, Liu W, et al. 2021. Chemical characteristics and evolution of shallow groundwater of Yellow River and Tuhai River Basin in Huimin area, Shandong Province, China. IOP Conference Series: Earth and Environmental Science, 804(2): 022052. DOI：10.1088/1755-1315/804/2/022052.

Wang X, Zhang XY, Gao XM, et al. 2024. Pollution load estimation and influencing factor analysis in the Tuhai River Basin in Shandong Province of China based on improved output coefficient method. Environmental Science and Pollution Research, 31(20): 29549−29562. DOI：10.1007/s11356-024-33107-1.

Wang X, Zhang XY, Guo YF, et al. 2024. Temporal and spatial evolution of grey water footprint in the Tuhai River Basin and its influencing factors. Journal of Jinan University (Natural Science Edition), 38(5): 517−525. (in Chinese) DOI：10.13349/j.cnki.jdxbn.20240902.002.

Wilson HF, Xenopoulos MA. 2008. Effects of agricultural land use on the composition of fluvial dissolved organic matter. Nature Geoscience, 2(1): 37−41. DOI：10.1038/ngeo391.

Wipfli MS, Richardson JS, Naiman RJ. 2007. Ecological linkages between headwaters and downstream ecosystems: Transport of organic matter, invertebrates, and wood down headwater channels. JAWRA Journal of the American Water Resources Association, 43(1): 72−85. DOI：10.1111/j.1752-1688.2007.00007.x.

Wu YW, Li YJ, Lv JJ, et al. 2017. Influence of sediment DOM on environmental factors in shallow eutrophic lakes in the middle reaches of the Yangtze River in China. Environmental Earth Sciences, 76(4): 142. DOI：10.1007/

s12665-017-6427-x.

Xu JX, 2020. Study on spectral characteristics of dissolved organic matter in urban rivers. M. S. thesis, Shanghai: Shanghai Normal University: 80. (in Chinese)

Xu L, Hu Q, Liu ZT, et al. 2024. Hydrological alteration drives chemistry of dissolved organic matter in the largest freshwater lake of China (Poyang Lake). Water Research, 251: 121154. DOI：10.1016/j.watres.2024.121154.

Yuan HD, Liu R, Ni MF, et al. 2022. Study on the biodegradation characteristics and temperature sensitivity of dissolved organic matter in typical karst rivers. Journal of Environmental Science, 42(3): 218−226. (in Chinese) DOI：10.13671/j.hjkxxb.2021.0333.

Yang LY, Chen LW, Zhuang WE, et al. 2024. Unveiling changes in the complexation of dissolved organic matter with Pb(II) by photochemical and microbial degradation using fluorescence EEMs-PARAFAC. Environmental Pollution, 341: 122982. DOI：10.1016/j.envpol.2023.122982.

Yang ZF, Xia XH, Huang GH, et al. 2008. Effect of sediment on the biodegradation of petroleum contaminants in natural water. Petroleum Science and Technology, 26(7−8): 868−886. DOI: 10.1080/10916460701824516.

Zhang FF, Gao N, Wu SZ, et al. 2023. Effects of long-term film mulching and nitrogen application on soil dissolved organic matter content and structure characteristics in different soil layers. Journal of Environmental Science, 43(11): 300−313. (in Chinese) DOI：10.13671/j.hjkxxb.2023.0188.

Zhang SR, Bai YJ, Wen X, et al. 2018. Seasonal and downstream alterations of dissolved organic matter and dissolved inorganic ions in a human-impacted mountainous tributary of the Yellow River, China. Environmental Science and Pollution Research, 25(18): 17967−17979. DOI：10.1007/s11356-018-1972-8.

Zhang SH, Li X, Ren Z, et al. 2025. Influence of precipitation and temperature variability on anthropogenic nutrient inputs in a river watershed: Implications for environmental management. Journal of Environmental Management, 375: 124294. DOI：10.1016/j.jenvman.2025.124294.

Zhang YL, Gao G, Shi K, et al. 2014. Absorption and fluorescence characteristics of rainwater CDOM and contribution to Lake Taihu, China. Atmospheric Environment, 98: 483−491. DOI：10.1016/j.atmosenv.2014.09.038.

Zhang YL, Zhang EL, Yin Y, et al. 2010. Characteristics and sources of chromophoric dissolved organic matter in lakes of the Yungui Plateau, China, differing in trophic state and altitude. Limnology and Oceanography, 55(6): 2645−2659. DOI：10.4319/lo.2010.55.6.2645.

Zhang YN, Zhang L, Sun QX, et al. 2021. Characteristics of DOM component content in the overlying water of the North Canal and its impact on water quality. Chinese Environmental Science, 41(8): 3816−3824. (in Chinese) DOI：10.19674/j.cnki.issn1000-6923.2021.0333.

Zhang ZH, Chen X, Li HB, et al. 2025. Spectral characteristics of dissolved organic matter in the Yangtze River Basin and its response to natural and anthropogenic activities. Environmental Science, 46(4): 2135−2144. (in Chinese) DOI：10.13227/j.hjkx.202403243.