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Land use and hydrological seasonality jointly regulate the composition and sources of riverine dissolved organic matter in the Three Gorges Reservoir region

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Abstract: Dissolved organic matter (DOM) is the most active form of organic carbon in rivers and plays a key role in biogeochemical processes. Understanding how land use change and seasonal hydrology regulate DOM dynamics is critical, particularly in monsoon regions with intensive human activities and hydrological variability. This study investigated the spatiotemporal variations in DOM composition and sources across different land use/land cover (LULC) types in representative rivers of the Three Gorges Reservoir (TGR) region during dry and wet seasons. In the dry season, DOM was dominated by protein-like, autochthonous components, whereas the wet season showed increased humic-like, terrestrial DOM with higher molecular weight and aromaticity. These seasonal variations were closely associated with changes in hydrological conditions. Rivers with higher forest cover exhibited more aromatic and allochthonous DOM signatures. In contrast, rivers influenced by urban and cultivated land use showed stronger signals of protein-like, autochthonous DOM, which were associated with higher nutrient levels and anthropogenic inputs. These results highlight the combined effects of monsoonal hydrology and land use on riverine DOM dynamics and provide insights for biogeochemical modeling and watershed management in the TGR region.

Key words: Dissolved organic matter (DOM); Temporal and spatial variation; land use/land cover (LULC); Three Gorges Reservoir (TGR) region; Carbon biogeochemistry

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1. Introduction

Carbon (C) is one of the most fundamental elements necessary for all life on Earth [1]. The global carbon cycle connects the Earth's major spheres (atmosphere, hydrosphere, biosphere, and geosphere) and is essential for global material and energy cycles [2]. Riverine systems represent critical interfaces between terrestrial and marine carbon reservoirs, and simultaneously, serve as important natural conduits for carbon transport as well as bio-transformational zones for carbon [3,4]. Dissolved organic matter (DOM) is the most biologically active pool of organic carbon in aquatic systems [5]. It provides carbon and energy sources for the microbial metabolism [6]. DOM also influences nutrient cycling, acts as a carrier for contaminants, and affects the bioavailability of metal ions [7]. In this way, DOM plays an important role in maintaining the biogeochemical stability and supporting the carbon cycle in rivers.

Significant anthropogenic interferences and seasonal hydrological modulation greatly affect carbon dynamics in rivers [8]. These interferences cause great changes in land use/land cover (LULC) and subsequently alter water quality as well as the sources, composition, and concentrations of DOM. For example, DOM from agricultural catchments would generally exhibit higher dissolved organic carbon (DOC) and nutrient contents [9], and an increased proportion of microbial humic-like compounds from affected streams [10]. Rivers notably influenced by urbanization generally have DOM with enhanced bioavailability [11], while DOM from native forests and grasslands generally contains more humic-like compounds with higher aromaticity [12,13]. Monsoon rainfall and temperature variations also greatly affect DOM characteristics [14,15]. Intense precipitation can increase both the concentration and aromaticity of riverine DOM [16], while temperature modulates the microbial consumption rate of DOM [17].

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Hence, it is essential to know how the sources, composition, and optical properties of DOM respond to both human disturbances and seasonal hydrological changes to assess river quality and biogeochemical processes.

The Three Gorges Reservoir (TGR) region is located in the upper reaches of the Yangtze River basin with complex geology, considerable hydrological variability, and distinct monsoonal characteristics [18]. Previous studies reported clear correlations between river discharge, hydrological connectivity and DOM behavior [19,20]. The TGR region is patchily covered by land use types dominated by forest and cultivated land [21]. In recent years, urban and agricultural areas have expanded rapidly [22]. Obviously, significant human-induced LULC changes can induce considerable alterations in terrestrial inputs and surface runoff conditions in the TGR region, as well as in organic matter inputs and microbial processes [23]. These changes will not only shape DOM composition and reactivity but also exert large impacts on water quality and biogeochemical processes in river ecosystems. However, the relationships among varied LULC patterns and hydrological conditions in the TGR region are complicated, and the specific processes by which these factors affect DOM are not well understood.

In this study, we carried out a detailed investigation of how natural factors (such as seasonal hydrological variation) and anthropogenic factors (such as land use and human activities) jointly influence the composition and spatiotemporal behavior of DOM in the TGR region. While previous studies have often considered land use or hydrological variability separately, their combined effects on DOM dynamics in monsoon-regulated reservoir systems remain insufficiently understood. Therefore, this study aims to examine the interactive roles of LULC and seasonal hydrology in shaping DOM characteristics across different rivers. We hypothesized that (1) diverse LULC types may affect the origin, composition, and properties of DOM either directly or indirectly; and (2) hydrological variability might modulate the impact of LULC on DOM characteristics. The results of this work are expected to provide scientific insights for the protection and sustainable management of aquatic ecosystems in the TGR region and across the broader Yangtze River Basin.

2. Materials and methods

2.1. Study area

This study focused on three rivers in the TGR region of southwestern China (28.44°N–31.40°N, 106.10°E–111.10°E): the Taohua River, the Zhuxi River and the Luzixi River (Fig. 1). The Taohua River and the Luzixi River are first-order tributaries of the Yangtze River, whereas the Zhuxi River is a second-order tributary within the Yangtze River basin. The Taohua River (THX, 29.84°N–30.13°N, 107.06°E–107.18°E) flows through the Changshou District. The Zhuxi River (ZXH, 29.81°N–30.02°N, 106.55°E–106.66°E) flows through Jindaoxia Town in Beibei District, while the Luzixi River (LZX, 28.87°N–29.05°N, 106.11°E–106.25°E) is located in Jiangjin District. The study area features a subtropical humid monsoon climate. The mean annual temperature ranges from 17 to 19°C and annual precipitation is between 1000 and 1800 mm [23]. The rainfall is highly seasonal with a wet season from April to October and a dry season the rest of the year. The biggest rainfall amounts are reached during the summer months [24].

The LULC types in the study area were classified into six classes: grassland, farmland, water, forest, urban land and unused land (Fig. 1). LULC compositions vary significantly among the three watersheds. The THX watershed is primarily composed of urban and township land use (21.60%) and agricultural land use (54.54%), with many sampling sites located in built-up areas. In the ZXH watershed, agricultural land use (57.44%) is primarily concentrated along riverbanks, thereby increasing the risk of pollutant input via rainfall runoff [25]. Compared to the other two watersheds, the LZX watershed maintains a relatively undisturbed natural landscape, with high forest coverage (60.12%) and the lowest proportion of urban land (0.70%). Detailed LULC statistics are provided in Table S1. In this study, the three selected rivers represent catchments with contrasting dominant land use characteristics (forest-dominated, agricultural, and urban-influenced). The differences in DOM characteristics among rivers can provide meaningful information about DOM variations under different land use backgrounds at the catchment scale.

2.2. Water sampling and analysis

A total of 34 water samples were collected from the three rivers in March and July 2023, with 17 samples collected during each sampling event. The two sampling campaigns were designed to represent typical hydrological conditions of the dry and wet seasons in the TGR region. The sampling for each campaign was completed within a short period (within a few consecutive days) to minimize temporal variability. All samples were collected during daytime under non-rainfall and relatively stable weather conditions to avoid short-term disturbances and ensure comparability among sampling sites. Acid-washed high-density polyethylene (HDPE) containers were used to collect water samples at a depth of 0.1–0.2 m. The samples were filtered through pre-combusted Whatman GF/F filters (0.7 μm pore size) on the sampling days, and the filtrates were stored in 100 mL pre-cleaned HDPE bottles. The filtrates were immediately transported to the laboratory on ice and stored at 4°C for subsequent analysis within one week.

In-situ measurements of pH, water temperature (Twater), dissolved oxygen (DO), and electrical conductivity (EC) were performed using a multiparameter water quality meter (PCD 650; Thermo Fisher Eutech, Singapore), with measurement accuracies of ± 0.02 pH units, ± 0.5°C, ± 2.0% and ± 1%, respectively. Total dissolved nitrogen (TDN) concentrations were determined using the alkaline potassium persulfate digestion method followed by ultraviolet spectrophotometry [26]. DOC and DIC concentrations were measured using a total organic carbon analyzer (multi N/C 2100S; Analytik Jena, Germany), with a measurement error of ± 2%.

UV–visible absorption spectra were measured using a spectrophotometer (UV-5500 PC; METASH, China), scanning from 200 to 700 nm at 1 nm intervals. Milli-Q ultrapure water was used as the blank. The optical indices included the specific UV absorbance at 254 nm ($SUVA_{254}$), and the absorbance ratios at 200/300 nm (E2:E3) and 300/400 nm (E3:E4). $SUVA_{254}$ is positively associated with the aromatic content [27], while the E2:E3 and E3:E4 ratios provide information on DOM molecular weight and humification degree [28]. Three-dimensional fluorescence spectra were recorded using a fluorescence spectrometer (F-7000; Hitachi, Japan), with excitation wavelengths (Ex)

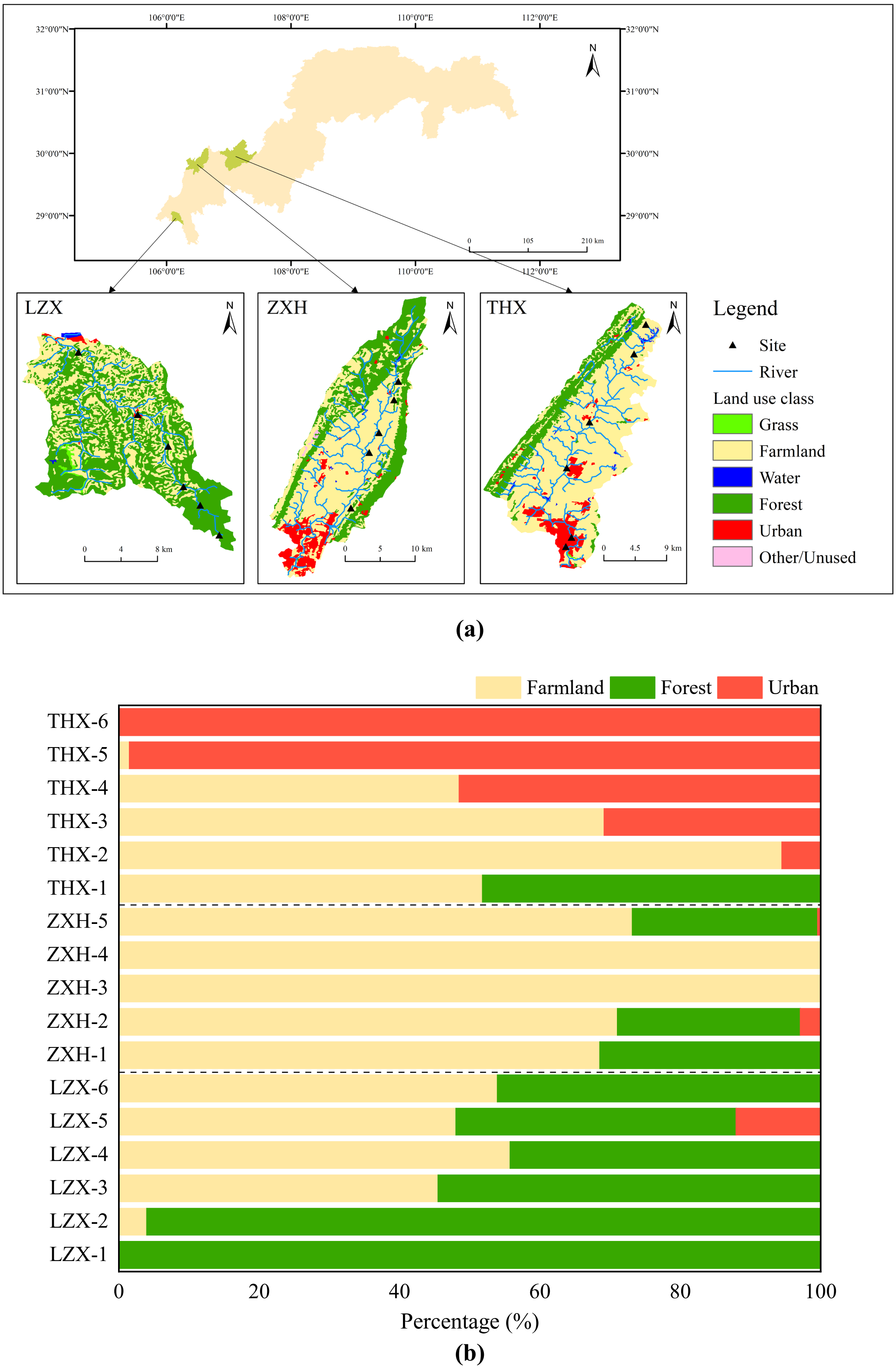

Fig. 1. (a) Distribution of sampling sites in LZX, ZXH, and THX, and the surrounding land use/land cover (LULC) of sampled rivers in the TGR region. (b) Percentages of LULC types within a 1,000 m upstream buffer around each sampling site.

from 220 to 450 nm and emission wavelengths (Em) from 250 to 550 nm, both at 2 nm intervals. Milli-Q water was used as the blank. All the measurements were conducted at a constant temperature.

Fluorescence indices were applied to characterize the composition and sources of DOM. These were the fluorescence index (FI), the biological index (BIX), and the humification index (HIX). FI is widely used to discriminate between the terrestrial and microbial DOM sources [29]. HIX represents the level of humification. The higher the value, the more humified and allochthonous DOM becomes [30]. BIX indicates the contribution and bioavailability of freshly produced biological DOM, with values greater than 0.8 suggesting high microbial activity [31]. Additional details on the optical indices are provided in Table S2.

2.3. Statistical analyses

The overview map of the study area was generated using ArcGIS 10.8. LULC composition for each sampling site was calculated using an upstream buffer approach in ArcGIS. A 1,000 m upstream buffer distance was adopted to better reflect the surrounding LULC types and provide sufficient variation in LULC proportions among sampling sites, while still focusing on the landscape close to the river channel. Other visualizations were created with MATLAB 2018a and Origin 2022. Statistical analyses were performed using Excel 2021 and SPSS 2022.

The compositional information of DOM was obtained using excitation–emission matrix (EEM) fluorescence spectroscopy combined with parallel factor analysis (PARAFAC) in MATLAB 2018a with the DOMFluor toolbox. Prior to modeling, EEM data were preprocessed following standard procedures. Specifically, raw EEMs were corrected by subtracting the Milli-Q water blank to remove background signals, inner-filter effects were corrected based on absorbance measurements, and Raman normalization was applied using the Raman peak of pure water. In addition, Rayleigh and Raman scattering regions were removed and replaced by interpolation [32]. PARAFAC models were developed separately for the dry and wet seasons. The number of components was determined based on residual analysis and model diagnostics. Model reliability was evaluated using split-half validation and Tucker's congruence coefficient (TCC). The models for both seasons successfully passed the split-half validation, and the TCC results presented a diagonal structure without cross-loadings, indicating strong agreement between split datasets and supporting the stability of the model. A detailed explanation of the DOMFluor validation output (split-half validation and TCC matching matrix) is provided in Table S3. To further validate the robustness of the seasonal PARAFAC models, an additional PARAFAC analysis was conducted using all 34 EEM samples from both seasons together.

A non-parametric Mann–Whitney U test was used to evaluate seasonal (dry vs. wet seasons) and spatial (across the three rivers) differences in key water quality indicators, as well as in DOM optical properties derived from UV–Vis and fluorescence spectroscopy. Seasonal variations between dry and wet seasons were further evaluated using paired t-tests, as samples were collected from the same sites in both seasons. Correlation analysis was conducted to explore the relationships among the concentrations of DOC, DIC, DO, TDN, $SUVA_{254}$, E2:E3, E3:E4, FI, BIX, HIX, the fluorescent components (C1, C2, C3), and land use characteristics. The percentages of different LULC types surrounding each sampling site were calculated using GIS analysis and were then used together with the optical parameters and fluorescence component intensities measured at the corresponding sampling sites to perform the correlation analysis.

To further evaluate the combined effects of hydrological season and LULC type on DOM optical properties, a two-way permutational multivariate analysis of variance (PERMANOVA) was conducted. Hydrological season (dry and wet) and LULC type were included as factors, and their interaction term was incorporated to evaluate their combined influence on DOM characteristics.

3. Results

3.1. Parameters of water quality

The key water quality parameters, including pH, DO, EC, and TDN concentrations are presented in Table 1 and Table S4. Significant seasonal differences were observed in pH (p < 0.05), DO (p < 0.001), and TDN (p < 0.05). The average pH in the dry season (8.10 ± 0.32) was higher than in the wet season (7.81 ± 0.81). Mean TDN concentrations were significantly lower in the dry season (0.92 ± 0.68 mg·L^{-1}, Table 1) compared to the wet season (1.63 ± 0.57 mg·L^{-1}, Table 1). The mean DO concentration in the wet season (12.43 ± 2.45 mg·L^{-1}) was significantly higher (p < 0.001) than that in the dry

Table 1. Summary of basic characteristics in both dry and wet seasons.

	Maximum	Minimum	Median	Average	SD
Dry					
DOC (mg·L^{-1})	5.69	0.58	2.74	2.97	1.64
DIC (mg·L^{-1})	25.25	3.02	17.07	16.31	7.26
pH	8.82	7.66	8.10	8.10*	0.32
DO (mg·L^{-1})	13.80	6.24	9.53	9.26**	2.05
EC (μs·cm^{-1})	1056.00	85.88	698.90	596.07	329.86
TDN (mg·L^{-1})	2.42	0.06	0.85	0.92*	0.68
TDP (mg·L^{-1})	0.06	0.00	0.03	0.03	0.02
Wet					
DOC (mg·L^{-1})	12.82	0.47	3.08	4.29	3.89
DIC (mg·L^{-1})	32.10	4.05	20.13	20.46	7.09
pH	8.53	7.32	7.81	7.81*	0.27
DO (mg·L^{-1})	16.05	8.79	12.36	12.43**	2.45
EC (μs·cm^{-1})	926.00	74.53	485.80	436.09	234.16
TDN (mg·L^{-1})	2.59	0.70	1.29	1.63*	0.57
TDP (mg·L^{-1})	0.18	0.00	0.05	0.06	0.05

[a] Note: SD, standard deviation; Seasonal variation: * p < 0.05, ** p < 0.001.

season (9.26 ± 2.05 mg·L^{-1}). DOC and DIC concentrations followed similar seasonal patterns, with greater variability observed in the wet season (0.47–12.82 mg·L^{-1} for DOC and 4.05–32.10 mg·L^{-1} for DIC, Table 1) than in the dry season (0.58–5.69 mg·L^{-1} for DOC and 3.02–25.25 mg·L^{-1} for DIC, Table 1).

3.2. Spatial and temporal variations in DOM optical parameters by UV–Vis absorbance and fluorescence

The values of $SUVA_{254}$, E2:E3, E3:E4, FI, BIX, and HIX are presented in Figs. 2 and 3 and Table S5. Significant seasonal variability was observed for E2:E3 (p < 0.05), FI (p < 0.001), BIX (p < 0.001), and HIX (p < 0.001). The mean values of E2:E3, FI, and BIX in the dry season were 1.23, 1.04, and 1.10 times higher than those in the wet season, respectively, whereas the mean HIX value in the wet season was 2.39 times higher than that in the dry season. These DOM optical properties also showed significant spatial differences among the three rivers. The mean $SUVA_{254}$ value in the LZX river was the highest during both the dry and wet seasons. The mean values of E2:E3 and E3:E4 in the dry season decreased in the order THX > LZX > ZXH, while in the wet season, the order was THX > ZXH > LZX. For the fluorescence parameters, the BIX value in LZX during the dry season was the lowest among the three rivers (p < 0.001). The HIX values ranged from 0.46 to 2.72, with the highest values observed in THX (p < 0.05). During the wet season, variations among the three rivers decreased. BIX and HIX values were similar among the three rivers (p > 0.05), whereas the FI values differed significantly, following the order THX > ZXH > LZX (p < 0.05).

3.3. PARAFAC components of the DOM

Typical EEM components of DOM are presented in Fig. 4 and Table S6. Three PARAFAC fluorescent components, including one protein-like (C2) and two humic-like (C1, C3) components, were identified across both seasons.

Component 1 (C1) exhibited excitation/emission (Ex/Em) peaks at 240(310)/410 nm in the dry season and 242(318)/418 nm in the wet season. These peaks corresponded to terrestrial humic-like peak A (associated with high-molecular-weight aromatic compounds) and marine humic-like peak M (derived from bacterial sources) [33,34]. Component 2 (C2) had identical excitation wavelengths at 228(280) nm in both seasons, with emission peaks at 330 nm in the dry season and 334 nm in the wet season. These characteristics resemble protein-like peaks T1 and T2, commonly associated with tryptophan-like substances [35]. Component 3 (C3) showed peaks at 266(364)/474 nm in the dry season, and at 268(364)/478 nm in the wet season. Its long emission wavelengths (474–478 nm) indicate the presence of high-molecular-weight aromatic terrestrial organic matter [36].

Validation of the PARAFAC component stability was performed using an additional model based on all 34 EEM samples from both seasons together (Fig. S1 and Table S7). The combined model also converged on a three-component solution. The spectral characteristics of these components were highly consistent with those from the separate seasonal models. Specifically, C1 showed Ex/Em peaks at 242(318)/414 nm, which is comparable to the dry-season peaks of 240(310)/410 nm and wet-season peaks of 242(318)/418 nm. C2 showed Ex/Em peaks at 228(280)/330 nm, which is nearly identical to the dry and wet season (330 nm and 334 nm, respectively). C3 showed Ex/Em peaks at 242(364)/478 nm, which is close to the dry-season peaks of 266(364)/474 nm and wet-season peaks of 268(364)/478 nm. These close correspondences confirm that the same three fluorescent components were consistently identified regardless of whether samples were analyzed separately by season or collectively.

The relative abundances of the three components (C1, C2, C3) across seasons are shown in Fig.S2 and Table S8. Significant seasonal differences were observed (p < 0.01). Humic-like C1 and C3 were more abundant in the wet season, whereas the proportion of the protein-like C2 decreased from 51.40% in the dry season to 36.24% in the wet season.

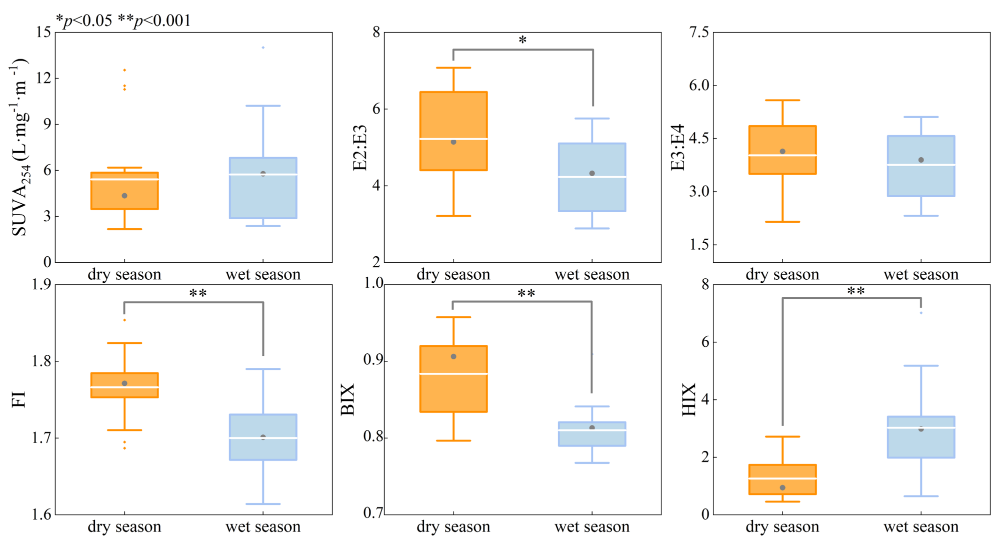

Fig. 2. Seasonal variations in $SUVA_{254}$, E2:E3, E3:E4, FI, BIX, and HIX (the grey points and white lines, along with the lower and upper edges, bars, and dots in or outside the boxes, represent median and mean values, 25th and 75th, 5th and 95th, and < 5th and > 95th percentiles of all data, respectively). Seasonal differences for all indices were evaluated using paired t-tests based on matched samples collected from the same sampling sites in the dry and wet seasons. (*p < 0.05, **p < 0.001).

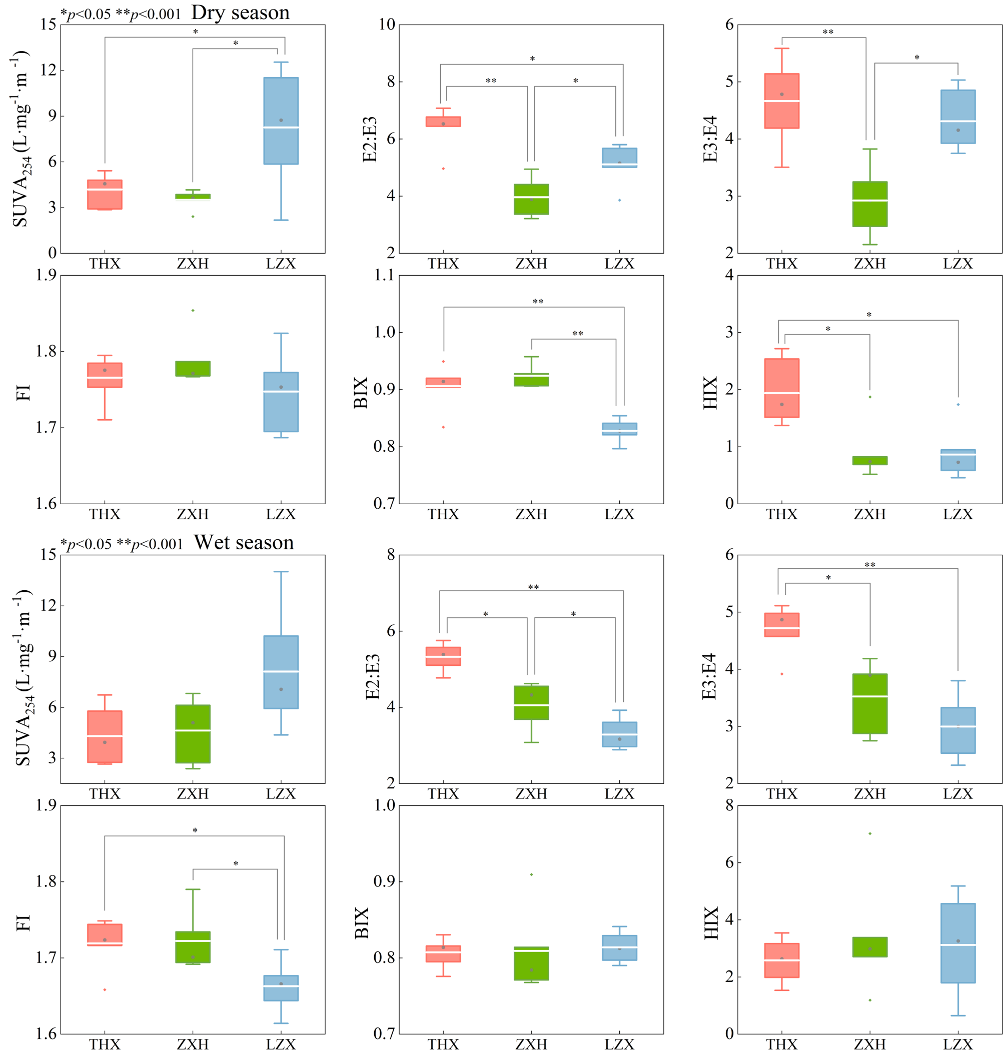

Fig. 3. Spatial variations in $SUVA_{254}$, E2:E3, E3:E4, FI, BIX, and HIX, with symbols similar to Fig. 2.

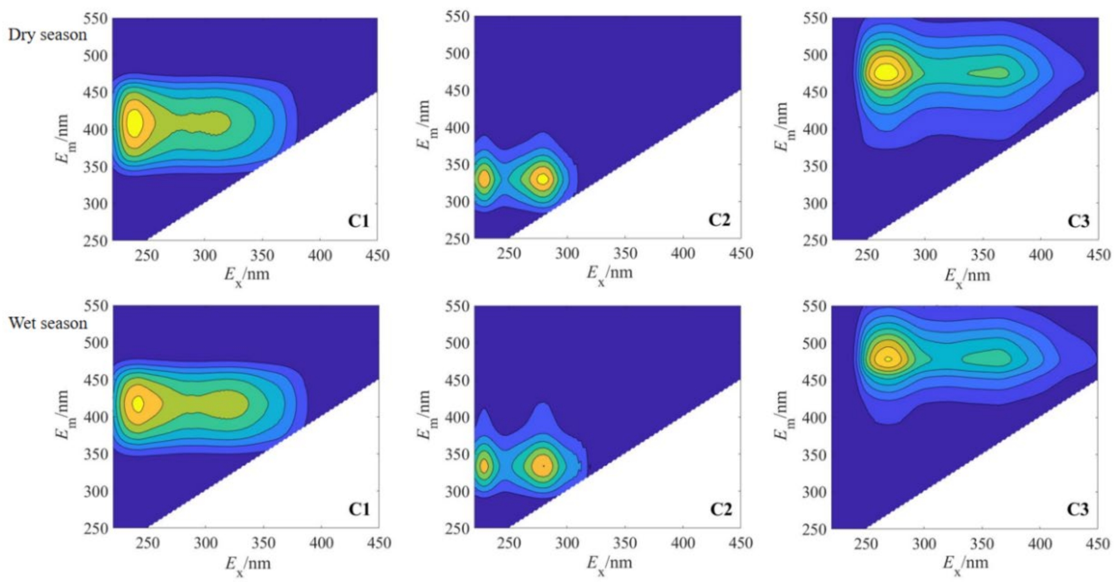

Fig. 4. Contour plots of EEM–PARAFAC components of DOM in the dry and wet seasons.

3.4. Relationship between DOM characteristics, water quality and LULC types

Water quality parameters and LULC types exhibited strong associations with DOM characteristics in both the dry and wet seasons, with the relationships being more pronounced during the dry season (Fig. 5). $SUVA_{254}$ was significantly and negatively correlated with DOC and DIC concentra-

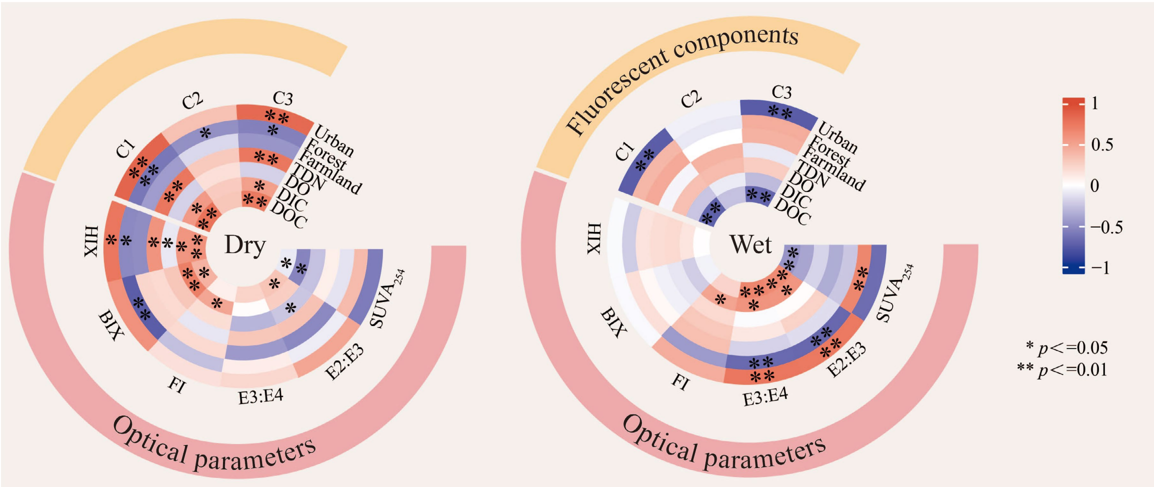

Fig. 5. Correlation analysis of water quality indicators, LULC types, optical parameters, and fluorescent components (C1, C2, C3) of DOM in both dry and wet seasons.

tions ($p < 0.05$). E2:E3 and E3:E4 showed significant negative correlations with DO concentration and positive correlations with DOC, DIC and TDN concentrations ($p < 0.05$). During the dry season, all three fluorescent components correlated positively with the concentrations of DOC, DIC, and TDN levels, with humic-like components (C1, C3) exhibiting significant relationships ($p < 0.05$). In contrast, these correlations were markedly weaker during the wet season ($p > 0.05$).

For different LULC types, farmland areas showed significant positive correlations with DIC and DO concentrations in both seasons ($p < 0.05$). During the dry season, forest cover was strongly negatively correlated with most DOM properties ($p < 0.05$), except for $SUVA_{254}$. Urban land cover showed positive correlations with DOM optical properties in the dry season. In contrast, during the wet season, it exhibited significant negative correlations with humic-like components ($p < 0.05$).

To further quantify the combined effects of hydrological season and LULC type on DOM optical properties, a two-way PERMANOVA was conducted (Table 2). The results revealed significant interaction effects between season and LULC for E2:E3, E3:E4, and BIX ($p < 0.01$), indicating that the influence of land use on DOM characteristics varies under different hydrological conditions. In addition, LULC had significant effects on most DOM indices (e.g., $SUVA_{254}$, E2:E3 and E3:E4; $p < 0.001$), while hydrological season significantly influenced E2:E3, FI, BIX, and HIX ($p < 0.001$).

4. Discussion

4.1. LULC-driven spatial variations in riverine DOM

The $SUVA_{254}$ value was highest in the LZX catchment (Fig. 3), suggesting a larger proportion of aromatic, high-molecular-weight DOM. Consistent with previous studies [37,38], this finding suggested that areas with dense forest and grassland cover are likely to facilitate the input of allochthonous organic matter. Such DOM is generally derived from the decomposition of terrestrial vegetation and animals, and is generally considered to be rich in tannin-like or humic-like substances [39,40].

THX exhibited lower molecular weight DOM and stronger endogenous signals, which can be largely attributed to the extensive urban land cover (Fig. 3). Human-induced changes in LULC may be associated with enhanced heterotrophic microbial activity [41]. Dense urban development along the THX riverbanks has also raised nutrient inputs from domestic, industrial, and livestock sources, which may promote the production of autochthonous organic matter [42,43]. This enrichment of nutrients has been suggested to stimulate microbial activity, which may contribute to the increased proportion of protein-like DOM components observed in this catchment [33]. Previous research has reported that highly urbanized watersheds tend to support higher bacterial productivity in soils, streams, and benthic communities [44]. Due to the decreased forest cover, the water surface in THX is exposed to more sunlight, and this may enhance DOM photodegradation. This process lowers molecular weight and enriches the DOM pool with protein-like components [37,45].

Urbanization, along with the increase of impervious surfaces, limits the input of natural humic-like DOM while increasing the contribution of anthropogenic fulvic acid-like DOM [41]. These factors may be responsible for the fact that E3:E4 ratios of THX are significantly higher than the other two rivers

Table 2. Results of two-way ANOVA showing the effects of hydrological season, LULC types, and their interaction on DOM characteristics.

Parameter	F value			P value		
	LULC type	hydrological season	Interaction effect	LULC type	hydrological season	Interaction effect
$SUVA_{254}$	9.557	0.129	0.181	p<0.001	p>0.05	p>0.05
E2:E3	32.251	22.531	6.769	p<0.001	p<0.001	p<0.01
E3:E4	17.908	1.713	7.663	p<0.001	p>0.05	p<0.01
FI	5.348	25.466	0.744	p<0.05	p<0.001	p>0.05
BIX	6.465	44.939	8.182	p<0.01	p<0.001	p<0.01
HIX	0.163	18.767	2.097	p>0.05	p<0.001	p>0.05

during two seasons as mentioned before ($p < 0.05$). Such a shift toward labile and low-molecular-weight DOM may indicate that urbanization not only influences the DOM turnover, but may also potentially affect carbon cycling processes in the river system.

Notably, although THX is characterized by stronger protein-like and autochthonous DOM signals, it also exhibits relatively high HIX values. This apparent inconsistency may be explained by the fact that HIX reflects the degree of humification rather than exclusively indicating terrestrial sources. In urban-impacted rivers, elevated HIX values may also be related to anthropogenic inputs, such as wastewater-derived organic matter, as well as the degradation products of algal biomass [41]. In particular, during the dry season, relatively longer water residence time may favor algal growth, and the subsequent degradation of algal-derived organic matter can contribute to humic-like fluorescence signals, thereby increasing HIX values [46,47]. This interpretation is further supported by the relatively higher FI values observed in THX during the dry season, indicating a stronger contribution of autochthonous DOM. Therefore, the elevated HIX in THX more likely reflects the combined influence of anthropogenic inputs and in-situ production processes.

DOM in ZXH was derived from both recent autochthonous and allochthonous sources (Fig. 3). Although the proportions of farmland in the ZXH and THX watersheds are comparable, the THX basin has a substantially higher proportion of urban land, which may introduce additional anthropogenic inputs through urban runoff and domestic wastewater, thereby influencing DOM composition. Previous studies have shown that urbanized catchments often exhibit increased nutrient inputs and enhanced microbial processing, which can promote the production of protein-like or microbially derived DOM components [41]. As a river flowing across a mainly agricultural catchment, ZXH is highly impacted by intensive farming, with the extensive use of organic fertilizers [48]. These activities influence nutrient cycling, and elevate the production of macromolecules such as proteins and lipids [49]. Such processes are consistent with an enhanced protein-like DOM signal driven by nutrient enrichment in agricultural systems [45]. Besides, the flow paths in agricultural watersheds are often shallower, raising the chance of surface soils being washed into the river channels [10]. These soils are generally rich in organic matter, particularly humic substances and high-molecular-weight compounds from the decomposition of terrestrial plants.

In general, the results suggest that LULC is a primary driver for the spatial variations in DOM characteristics. It modulates DOM sources and the related transformation processes in different ways: in rivers that are strongly influenced by anthropogenic activities, DOM composition is mainly controlled by wastewater inputs and microbial activities. By contrast, in rivers surrounded by natural vegetation, DOM shows a terrestrial-dominated signature maintained through continuous transfer along the "litter–soil–water" pathway.

4.2. Seasonal hydrological rhythms drive temporal variations in riverine DOM

Compared to the dry season, DOM in the wet season exhibited higher molecular weight, stronger terrestrial signatures, and greater humification (Fig. 2, Table S5). These patterns are likely associated with the subtropical monsoon climate of the study area, which brought abundant precipitation and intensified leaching, thereby enhancing terrestrial DOM inputs [50]. Meanwhile, reduced light availability may limit photosynthetic activity and microbial metabolism in phytoplankton and algae, thereby suppressing autochthonous DOM production. Together with increased terrestrial inputs, this may contribute to the accumulation of more aromatic, humic-like compounds [51]. Although BIX decreased during the wet season, the mean value (0.81; Fig. 2 and Table S5) remained relatively high, suggesting that recently produced biological DOM still contributes substantially to the overall DOM pool [52]. This pattern may reflect active microbial processing of organic matter under the warm and humid conditions typical of the monsoon season. Increased runoff during the wet season transports terrestrially derived organic matter from soils and vegetation into river systems, providing additional substrates for microbial activity. As a result, microbial reworking of organic matter may continue to generate recently produced biological DOM even under conditions of enhanced terrestrial inputs. Nevertheless, the overall DOM composition during the wet season was still characterized by higher proportions of humic-like components and higher humification indices, indicating that terrestrially derived DOM remained the dominant component of the DOM pool.

During the wet season, heavy rainfall may dilute the DOM pools. Runoff-driven flushing may also influence plankton community structure [53]. At the same time, higher temperature and solar radiation may promote microbial activity and the decomposition of aquatic vegetation, both of which may contribute to changes in DOM quality [17]. Together, these processes likely contributed to seasonal variations in sources and molecular characteristics of DOM, revealing how internal and external inputs respond to varying hydrographic conditions. These processes may also explain why the correlations between fluorescence components and water quality parameters were weaker during the wet season. Increased runoff can introduce DOM from multiple sources, including soil organic matter, plant litter, and potential anthropogenic inputs from surrounding catchments. The mixing of these different DOM sources may result in a more heterogeneous DOM pool, thereby weakening the relationships between specific fluorescence components and water quality parameters under wet-season hydrological conditions. In addition, higher discharge during the wet season can enhance hydrological transport and reduce water residence time, which may limit in-stream DOM processing and further alter DOM composition during downstream transport, thereby weakening the observed correlations [54,55]. The combined effects of dilution and microbial activity suggest that the wet season may represent an important period for DOM turnover, which may increase DOM reactivity and influence downstream carbon transport [16]. In addition, the relatively large variability in DOC concentrations during the wet season may reflect spatial differences among the three rivers. Increased runoff during the wet season can enhance the mobilization and transport of terrestrial organic matter from surrounding catchments, and the magnitude of these inputs varies among rivers with different LULC characteristics [56].

Variations in excitation/emission (Ex/Em) wavelengths during the wet season suggest changes in the structural composition of organic matter [57]. The red-shifted fluorescence peaks of C1 and C3 (Fig. 4 and Table S6) suggest higher proportions of aromatic and high-molecular-weight compounds [58]. The dry season showed higher proportions of C2, reflecting more tryptophan-like substances. Conversely, wet-season samples showed increased C1 and C3, indicating greater humic-like inputs (Fig. S2 and Table S8). These seasonal changes are mainly associated with the subtropical monsoon climate in southwestern China [59]. The region experiences both intense rainfall and high temperatures [60]. In the dry season, limited rainfall and minimal external inputs may favor autochthonous production, resulting in higher proportions of protein-like C2 [61]. In response to the arrival of the monsoon, warmer conditions may enhance the activity of microbial extracellular enzymes, which may accelerate the release and degradation of protein-like DOM [45,62]. Meanwhile, the increase in runoff and the biological carbon pump also may promote the inputs of endogenous and exogenous humic-like substances [63], enriching C1 and C3. Overall, these findings suggest that DOM characteristics are closely related to watershed runoff, leaching, and metabolism of aquatic organisms in response to hydrological rhythms.

4.3. Linkages and controls of DOM variability and dynamics

Microbial oxygen consumption may increase with higher DO concentrations, further modulating the composition and structure of DOM [64]. In this study, the correlation between DO and DOM optical properties suggests that relatively high DO concentrations may stimulate the production of autochthonous DOM and the microbial degradation of humic-like substances [65]. TDN exhibited positive correlations with HIX, C1, and C3 during the dry season (Fig. 5). This suggests that nitrogen enrichment may enhance DOM humification and promote the accumulation of humic-like components. These processes may be related to nitrogen transport and transformation within river systems [66]. Elevated nitrogen levels have been reported to stimulate primary productivity of algae and phytoplankton, and may thereby accelerate the mineralization and humification of organic matter and strengthen the association between TDN and humic-like substances [67]. In contrast, during the wet season, increased precipitation brings more terrestrial organic matter (soil-derived material, decaying vegetation and anthropogenic pollutants) into stream systems, which likely dilutes the contribution of TDN to the production of humic-like substances, resulting in weakened correlations [68].

The positive correlations between E2:E3, E3:E4 and urban land use strengthened from the dry to the wet season (Fig. 5), suggesting that rainfall-enhanced anthropogenic inputs may facilitate the generation of low-molecular-weight, fulvic acid-like substances [58]. Forest cover exhibits distinct seasonal effects on DOM characteristics. In the dry season, increased forest coverage was negatively correlated with DOM fluorescent components (Fig. 5), likely due to improved soil stability and reduced surface runoff, which may limit the input of organic matter into river systems [69]. Conversely, for the wet season, forested catchments presented positive correlations with humic-like C1 and C3, suggesting that more terrestrially derived humic substances may be transported to the river network by rainfall-induced runoff [70]. Furthermore, the effects were much more significant in forested catchments during the wet season. This result is consistent with numerous previous reports that indicated significant allochthonous DOM inputs during storm events [71].

The results of the PERMANOVA further support the combined effects of hydrological season and LULC on DOM characteristics. In particular, the significant interaction effects observed for E2:E3, E3:E4, and BIX provide direct statistical evidence that these two factors do not operate independently but jointly regulate DOM composition. This suggests that seasonal hydrological processes, such as precipitation-driven runoff during the wet season, may enhance the transport of terrestrially derived organic matter in forested catchments, while simultaneously amplifying anthropogenic inputs in urban and agricultural areas. These interactions highlight the importance of considering both land use and hydrological variability when interpreting DOM dynamics in river systems.

The outcomes suggest that land use and seasonal regulation of hydrology play important roles in shaping riverine DOM sources and composition in the TGR region, which may in turn influence biogeochemical processes maintaining riverine carbon cycling (Fig. 6). Seasonal hydrological signals, particularly monsoon-driven runoff, are associated with a shift in DOM from protein-like, autochthonous materials in the dry season to humic-like, high-molecular-weight materials in the wet season (Fig. 2, Fig. S2 and Table S5). Land use in the catchment also influences the composition of characteristic DOM components. Forests tend to act as reservoirs of aromatic, humic-like DOM, while agricultural and urban areas are associated with increased export of protein-like DOM, presumably derived from microbial activity (Fig. 3 and Fig. 5). These spatiotemporal signals may influence DOM transformation and reactivity, and thus control DOM function in riverine carbon cycling [72]. By integrating seasonal hydrology, land use and biogeochemical processes, we highlight the importance of terrestrial–aquatic connectivity for carbon dynamics (Fig. 6). This study further demonstrated that lowering anthropogenic disturbances and adopting management measures according to climate variability may help maintain the carbon balance of rivers and support the general health of the ecosystem.

It should be noted that this study primarily relies on optical indices and conventional water quality parameters to characterize DOM composition and infer its sources and transformation processes. Although these approaches are widely used and provide valuable insights into DOM dynamics, they provide indirect evidence and may not fully capture the underlying microbial and molecular-level mechanisms. Future studies integrating microbial community analyses and high-resolution molecular techniques (e.g., high-resolution mass spectrometry) would help to further constrain DOM sources and transformation pathways, and provide a more comprehensive understanding of the mechanisms controlling DOM dynamics.

5. Conclusion

In this study, the composition and characteristics of riverine DOM under different LULC types in the TGR region were investigated using spectroscopic methods, PARAFAC modeling and correlation analysis. Pronounced spatial and temporal variations were observed in DOM optical properties, composi-

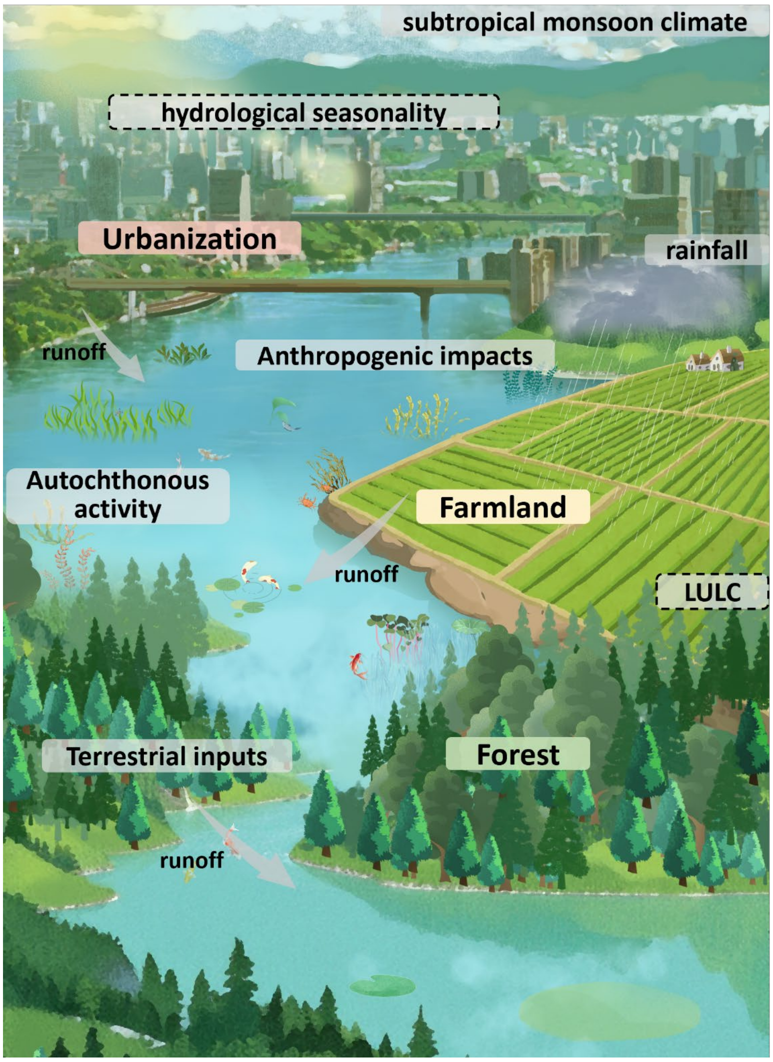

Fig. 6. Schematic diagram of the effects of land use change and seasonal hydrological variability on riverine DOM characteristics.

tion, and sources. During the dry season, DOM was dominated by protein-like and autochthonous components. While during the wet season, DOM primarily consisted of terrestrially derived humic-like substances characterized by higher molecular weight and aromaticity. The relative contributions of autochthonous and allochthonous DOM were affected by DO and TDN concentrations. Intensified human activities and elevated temperature and humidity during the wet season may enhance microbial metabolism of DOM, and then change the composition, concentration, and reactivity. Spatially, DOM aromaticity was higher in the catchments with greater forest cover. While in the urban and agricultural catchments, DOM showed stronger autochthonous signatures. In summary, the results in this study indicate that water quality variation, precipitation and LULC types are key drivers of DOM dynamics. These findings enhance our understanding of DOM composition and its environmental drivers. DOM is crucial for maintaining riverine carbon cycling. In addition, the results in this study offer scientific references for further biogeochemical studies and ecological conservation in monsoon areas.

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Conflicts of Interest

Xuewu Zhang is currently employed by CCTEG CHONGQING ENGINEERING (GROUP) CO., LTD. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

All data needed to support the conclusions in the paper are presented in the manuscript and the Supplementary Materials.

Electronic Supplementary Material (ESM)

The online version contains supplementary material available at https://doi.org/10.26599/ECS.2026.9600039.

References

[1] Monteith, D. T., Stoddard, J. L., Evans, C. D., de Wit, H. A., Forsius,

M.; Høgåsen, T.; Wilander, A.; Skjelkvåle, B. L., Jeffries, D. S., Vuorenmaa, J. et al. Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry. *Nature*, 2007, 450: 537–540.

[2] Cole, J. J., Prairie, Y. T., Caraco, N. F., McDowell, W. H., Tranvik, L. J., Striegl, R. G., Duarte, C. M., Kortelainen, P.; Downing, J. A., Middelburg, J. J., et al. Plumbing the global carbon cycle: Integrating inland waters into the terrestrial carbon budget. *Ecosystems*, 2007, 10(1): 171–184.

[3] Kamjunke, N.; Herzsprung, P.; von Tümpling, W.; Matoušů, A.; Znachor, P.; Sanders, T.; Brix, H.; Bussmann, I.; Weitere, M.; Lechtenfeld, O. J. Longitudinal dynamics and transformation of riverine dissolved organic matter from source to sea. *Water Res.*, 2026, 288: 124613.

[4] Yang, Q.; Wu, F. Z.; Wu, Q. Q.; Peñuelas, J.; Sardans, J.; Peng, Y.; Li, Z. M.; Heděnec, P.; Li, Z. J.; Yue, K. Global patterns and hierarchical controls of metabolism from headwaters to large rivers. *J. Hydrol.*, 2025, 663: 134268.

[5] Battin, T. J., Lauerwald, R.; Bernhardt, E. S., Bertuzzo, E.; Gener, L. G., Hall, R. O., Hotchkiss, E. R., Maavara, T.; Pavelsky, T. M., Ran, L. S. et al. River ecosystem metabolism and carbon biogeochemistry in a changing world. *Nature*, 2023, 613: 449–459.

[6] Gunaalan, K.; Fabbri, E.; Capolupo, M. The hidden threat of plastic leachates: A critical review on their impacts on aquatic organisms. *Water Res.*, 2020, 184: 116170.

[7] Derrien, M.; Yang, L. Y.; Hur, J. Lipid biomarkers and spectroscopic indices for identifying organic matter sources in aquatic environments: A review. *Water Res.*, 2017, 112: 58–71.

[8] Rodeles, A. A.; Barquín, J.; Peñas, F. J. River metabolism regimes across large environmental gradients. *Limnol. Oceanogr.*, 2025, 70: 2718–2732.

[9] Graeber, D.; Gelbrecht, J.; Pusch, M. T., Anlanger, C.; von Schiller, D. Agriculture has changed the amount and composition of dissolved organic matter in Central European headwater streams. *Sci. Total Environ.*, 2012, 438: 435–446.

[10] Chen, S.; Du, Y. X.; Das, P.; Lamore, A. F., Dimova, N. T., Elliott, M.; Broadbent, E. N., Roebuck, J. A., Jaffé, R.; Lu, Y. H. Agricultural land use changes stream dissolved organic matter *via* altering soil inputs to streams. *Sci. Total Environ.*, 2021, 796: 148968.

[11] Lin, X. W.; Wu, X. D.; Chen, B. F.; Ge, X. G.; Wu, C.; Gu, X. C.; Zhu, S. M.; Gao, Z. N. Deciphering the impacts of main inflowing rivers on dissolved organic matter in Lake Daye using isotopes, optical spectroscopy, and FT-ICR MS during non-flood season. *J. Hydrol.*, 2025, 663: 134090.

[12] Fellman, J. B., Hood, E.; Spencer, R. G. M. Fluorescence spectroscopy opens new windows into dissolved organic matter dynamics in freshwater ecosystems: A review. *Limnol. Oceanogr.*, 2010, 55(6): 2452–2462.

[13] Gad, M.; Khomami, N. T. S., Krieg, R.; Schor, J.; Philippe, A.; Lechtenfeld, O. J. Environmental drivers of dissolved organic matter composition across Central European aquatic systems: A novel correlation-based machine learning and FT-ICR MS approach. *Water Res.*, 2025, 273: 123018.

[14] Wang, X.; Wang, J. Y.; Yan, J. X.; Dong, Y.; Wang, W. Z.; Gao, Q.; Huang, X. J.; Zhang, Z. Q.; Lu, J. S. Sources and transformations of dissolved organic matter in urban impervious surface sediments: Insights from optical signatures and environmental drivers. *Water Res.*, 2025, 285: 124117.

[15] Zhu, L. J.; Zhao, Y.; Bai, S. C.; Zhou, H. X.; Chen, X. M.; Wei, Z. M. New insights into the variation of dissolved organic matter components in different latitudinal lakes of Northeast China. *Limnol. Oceanogr.*, 2020, 65(3): 471–481.

[16] Ma, Y. M.; Mao, R.; Li, S. Y. Hydrological seasonality largely contributes to riverine dissolvedorganicmatter chemical composition: Insights from EEM-PARAFAC and optical indicators. *J. Hydrol.*, 2021, 595: 125993.

[17] Tang, G.; Zheng, X.; Hu, S. W.; Li, B. R.; Chen, S. L.; Liu, T.; Zhang, B. W.; Liu, C. X. Microbial metabolism changes molecular compositions of riverine dissolved organic matter as regulated by temperature. *Environ. Pollut.*, 2022, 306: 119416.

[18] He, N.; Guo, W. X.; Lan, J. Q.; Yu, Z. Q.; Wang, H. X. The impact of human activities and climate change on the eco-hydrological processes in the Yangtze River basin. *J. Hydrol. Reg. Stud.*, 2024, 53: 101753.

[19] Huang, Q.; Liu, L. Z.; Huang, J. C.; Chi, D. W.; Devlin, A. T.; Wu, H. W. Seasonal dynamics of chromophoric dissolved organic matter in Poyang Lake, the largest freshwater lake in China. *J. Hydrol.*, 2022, 605: 127298.

[20] Yu, X. B.; Hawley-Howard, J.; Pitt, A. L., Wang, J. J.; Baldwin, R. F., Chow, A. T. Water quality of small seasonal wetlands in the Piedmont ecoregion, South Carolina, USA: Effects of land use and hydrological connectivity. *Water Res.*, 2015, 73: 98–108.

[21] Ni, M. F.; Li, S. Y.; Luo, J. C.; Lu, X. X. CO_2 partial pressure and CO_2 degassing in the Daning River of the Upper Yangtze River, China. *J. Hydrol.*, 2019, 569: 483–494.

[22] Zhao, L. Y.; Gong, D. D.; Zhao, W. H.; Lin, L.; Yang, W. J.; Guo, W. J.; Tang, X. Q.; Li, Q. Y. Spatial-temporal distribution characteristics and health risk assessment of heavy metals in surface water of the Three Gorges Reservoir, China. *Sci. Total Environ.*, 2020, 704: 134883.

[23] Xiang, R.; Wang, L. J.; Li, H.; Tian, Z. B.; Zheng, B. H. Water quality variation in tributaries of the Three Gorges Reservoir from 2000 to 2015. *Water Res.*, 2021, 195: 116993.

[24] Wang, K.; Pang, Y.; He, C.; Li, P. H.; Xiao, S. B.; Sun, Y. G.; Pan, Q.; Zhang, Y. H.; Shi, Q.; He, D. Optical and molecular signatures of dissolved organic matter in Xiangxi Bay and mainstream of Three Gorges Reservoir, China: Spatial variations and environmental implications. *Sci. Total Environ.*, 2019, 657: 1274–1284.

[25] Zhang, Y.; Wang, H.; Ma, Y. M.; Du, J. J.; Long, J. X.; Lang, J. R.; Ni, M. F. Deciphering riverine CO_2 dynamics and driving factors coupled with dissolved organic carbon and nutrient status. *J. Lake Sci.*, 2024, 36: 794–806.

[26] Tang, W.; Xu, Y. J., Ma, Y. M.; Maher, D. T., Li, S. Y. Hot spot of CH_4 production and diffusive flux in rivers with high urbanization. *Water Res.*, 2021, 204: 117624.

[27] Weishaar, J. L.; Aiken, G. R.; Bergamaschi, B. A.; Fram, M. S.; Fujii, R.; Mopper, K. Evaluation of specific ultraviolet absorbance as an indicator of the chemical composition and reactivity of dissolved organic carbon. *Environ. Sci. Technol.*, 2003, 37: 4702–4708.

[28] Zhou, S. L.; Zhang, Y. R.; Huang, T. L.; Liu, Y. F.; Fang, K. K.; Zhang, C. H. Microbial aerobic denitrification dominates nitrogen losses from reservoir ecosystem in the spring of Zhoucun reservoir. *Sci. Total Environ.*, 2019, 651: 998–1010.

[29] Lavonen, E. E.; Kothawala, D. N.; Tranvik, L. J.; Gonsior, M.; Schmitt-Kopplin, P.; Köhler, S. J. Tracking changes in the optical properties and molecular composition of dissolved organic matter during drinking water production. *Water Res.*, 2015, 85: 286–294.

[30] Ohno, T. Fluorescence inner-filtering correction for determining the humification index of dissolved organic matter. *Environ. Sci. Technol.*, 2002, 36: 742–746.

[31] Huguet, A.; Vacher, L.; Relexans, S.; Saubusse, S.; Froidefond, J. M., Parlanti, E. Properties of fluorescent dissolved organic matter in the Gironde Estuary. *Org. Geochem.*, 2009, 40: 706–719.

[32] Bro, R.; Smilde, A. K. Centering and scaling in component analysis. *J. Chemom.*, 2003, 17: 16–33.

[33] Baker, A.; Curry, M. Fluorescence of leachates from three contrasting landfills. *Water Res.*, 2004, 38: 2605–2613.

[34] Zhang, Y. L.; van Dijk, M. A., Liu, M. L.; Zhu, G. W.; Qin, B. Q. The contribution of phytoplankton degradation to chromophoric dis-

solved organic matter (CDOM) in eutrophic shallow lakes: Field and experimental evidence. *Water Res.*, 2009, 43: 4685–4697.
[35] Zhang, Y. L.; Zhang, E. L.; Yin, Y.; van Dijk, M. A., Feng, L. Q.; Shi, Z. Q.; Liu, M. L.; Qina, B. Characteristics and sources of chromophoric dissolved organic matter in lakes of the Yungui Plateau, China, differing in trophic state and altitude. *Limnol. Oceanogr.*, 2010, 55: 2645–2659.
[36] Zhao, Y.; Song, K. S.; Wen, Z. D.; Li, L.; Zang, S. Y.; Shao, T. T.; Li, S. J.; Du, J. Seasonal characterization of CDOM for lakes in semiarid regions of Northeast China using excitation–emission matrix fluorescence and parallel factor analysis (EEM–PARAFAC). *Biogeosciences*, 2016, 13: 1635–1645.
[37] Williams, C. J., Yamashita, Y.; Wilson, H. F., Jaffé, R.; Xenopoulos, M. A. Unraveling the role of land use and microbial activity in shaping dissolved organic matter characteristics in stream ecosystems. *Limnol. Oceanogr.*, 2010, 55: 1159–1171.
[38] Niu, G. X.; Yin, G. G.; Mo, X. H.; Mao, Q. G.; Mo, J. M.; Wang, J. J.; Lu, X. K. Do long-term high nitrogen inputs change the composition of soil dissolved organic matter in a primary tropical forest? *Environ.Res. Lett.*, 2022, 17(9): 095015.
[39] Tao, Y.; Zhang, J.; Zhang, Y. H.; Du, S. L.; Wu, H.; Cao, J. L.; Liang, H. Y. Analysis of the fluorescence spectral characteristics of dissolved organic matter in the Linjiang River watershed. *J. Agro-Environ. Sci*, 2023, 42(12): 2711–2720.
[40] Wang, M.; Liao, C.; Tian, Q. X.; Wang, D. Y.; Wu, Y.; Tang, Y. N.; Liu, F. Dissolved organic matter characteristics and important site factors in a subtropical mountain forest in Central China. *For. Sci.*, 2020, 66: 49–57.
[41] Hosen, J. D., McDonough, O. T., Febria, C. M., Palmer, M. A. Dissolved organic matter quality and bioavailability changes across an urbanization gradient in headwater streams. *Environ. Sci. Technol.*, 2014, 48: 7817–7824.
[42] Gücker, B.; Brauns, M.; Solimini, A. G.; Voss, M.; Walz, N.; Pusch, M. T. Urban stressors alter the trophic basis of secondary production in an agricultural stream. *Can. J. Fish. Aquat. Sci.*, 2011, 68: 74–88.
[43] Chen, Z. Y.; Li, S. Y. Seasonal variation of DOM spectral characteristics of rivers with different urbanization levels in the Three Gorges Reservoir area. *Environ. Sci.*, 2021, 42(1): 195–203.
[44] Obernosterer, I.; Reitner, B.; Herndl, G. J. Contrasting effects of solar radiation on dissolved organic matter and its bioavailability to marine bacterioplankton. *Limnol. Oceanogr.*, 1999, 44: 1645–1654.
[45] Ma, Y. M.; Ni, M. F.; Gu, S. J.; Zhang, L. Q.; Li, S. Y. Autochthonous sources and biogeochemical processes drive the spatiotemporal variation of DOM composition and optical indicators in a karst river. *J. Hydrol.*, 2023, 623: 129825.
[46] Zhang, Q. Y.; Sun, W.; Du, Y. X.; Gong, X. L. Biodegradation of algae-derived organic matter (I-DOM) from lake Taihu. *Huanjing Kexue*, 2021, 42: 1870–1878.
[47] Fu, P. Q. Dissolved organic matter in natural aquatic environments and its complexation with metal ions: a study based on fluorescence spectroscopy. University of Chinese Academy of Sciences (Institute of Geochemistry, Chinese Academy of Sciences), Guiyang, China, 2004.
[48] Wilson, H. F., Xenopoulos, M. A. Effects of agricultural land use on the composition of fluvial dissolved organic matter. *Nat. Geosci.*, 2009, 2: 37–41.
[49] Hu, X. S.; Zhou, Y. Q.; Zhou, L.; Zhang, Y. L.; Wu, L.; Xu, H.; Zhu, G. W.; Jang, K. S.; Spencer, R. G. M., Jeppesen, E. et al. Urban and agricultural land use regulates the molecular composition and biolability of fluvial dissolved organic matter in human-impacted southeastern China. *Carbon Res.*, 2022, 1: 19.
[50] Raymond, P. A., Oh, N. H. An empirical study of climatic controls on riverine C export from three major U. *S. watersheds. Glob. Biogeochem. Cycles*, 2007, 21: 2006GB002783.
[51] Jiang, T.; Wang, D. Y.; Wei, S. Q.; Yan, J. L.; Liang, J.; Chen, X. S.; Liu, J.; Wang, Q. L.; Lu, S.; Gao, J. et al. Influences of the alternation of wet-dry periods on the variability of chromophoric dissolved organic matter in the water level fluctuation zone of the Three Gorges Reservoir area, China. *Sci. Total Environ.*, 2018, 636: 249–259.
[52] Birdwell, J. E., Engel, A. S. Characterization of dissolved organic matter in cave and spring waters using UV–Vis absorbance and fluorescence spectroscopy. *Org. Geochem.*, 2010, 41: 270–280.
[53] Clark, J. M., Lane, S. N., Chapman, P. J., Adamson, J. K. Export of dissolved organic carbon from an upland peatland during storm events: Implications for flux estimates. *J. Hydrol.*, 2007, 347: 438–447.
[54] Battin, T. J., Kaplan, L. A., Findlay, S.; Hopkinson, C. S., Marti, E.; Packman, A. I., Newbold, J. D., Sabater, F. Biophysical controls on organic carbon fluxes in fluvial networks. *Nat. Geosci.*, 2008, 1: 95–100.
[55] Lambert, T.; Teodoru, C. R.; Nyoni, F. C.; Bouillon, S.; Darchambeau, F.; Massicotte, P.; Borges, A. V. Along-stream transport and transformation of dissolved organic matter in a large tropical river. *Biogeosciences*, 2016, 13: 2727–2741.
[56] Boyer, E. W., Hornberger, G. M., Bencala, K. E., McKnight, D. M. Response characteristics of DOC flushing in an Alpine catchment. *Hydrol. Process.*, 1997, 11: 1635–1647.
[57] He, D.; Li, P. H.; He, C.; Wang, Y. T.; Shi, Q. Eutrophication and watershed characteristics shape changes in dissolved organic matter chemistry along two river-estuarine transects. *Water Res.*, 2022, 214: 118196.
[58] Coble, P. G. Characterization of marine and terrestrial DOM in seawater using excitation-emission matrix spectroscopy. *Mar. Chem.*, 1996, 51: 325–346.
[59] Yuan, D. N.; Li, S. Y.; Ye, C.; Liu, W. Z.; Xu, J. Dissolved organic matter (DOM) rather than warming and eutrophication directly affects partial pressure of CO_2 (pCO_2) in mesocosm systems. *Water Res.*, 2024, 267: 122448.
[60] Peng, Y. J.; Zhang, D. D.; Xu, G. H.; Wang, W. G.; Guo, W.; Lin, T. T. Water surface evaporation prediction of Three Gorges Reservoir based on VMD-LSTM model. *Yangtze River*, 2024, 55(10): 110–118.
[61] Meng, F. G.; Huang, G. C.; Yang, X.; Li, Z. Q.; Li, J.; Cao, J.; Wang, Z. G.; Sun, L. Identifying the sources and fate of anthropogenically impacted dissolved organic matter (DOM) in urbanized rivers. *Water Res.*, 2013, 47: 5027–5039.
[62] Cruz-Paredes, C.; Tájmel, D.; Rousk, J. Can moisture affect temperature dependences of microbial growth and respiration? *Soil Biol. Biochem.*, 2021, 156: 108223.
[63] Xia, F.; Liu, Z. H.; Zhao, M.; Li, Q.; Li, D.; Cao, W. F.; Zeng, C.; Hu, Y. D.; Chen, B.; Bao, Q. et al. High stability of autochthonous dissolved organic matter in karst aquatic ecosystems: Evidence from fluorescence. *Water Res.*, 2022, 220: 118723.
[64] Baxa, M.; Musil, M.; Kummel, M.; Hanzlík, P.; Tesařová, B.; Pechar, L. Dissolved oxygen deficits in a shallow eutrophic aquatic ecosystem (fishpond)–Sediment oxygen demand and water column respiration alternately drive the oxygen regime. *Sci. Total Environ.*, 2021, 766: 142647.
[65] Yuan, H. D. Temporal and spatial patterns of dissolved organic matter and its biodegradation characteristics in typical karst rivers. M.S. Thesis, Guizhou Minzu University, Guiyang, China, 2023.
[66] Zhang, Y. L.; Liu, X. H.; Wang, M. Z.; Qin, B. Q. Compositional differences of chromophoric dissolved organic matter derived from phytoplankton and macrophytes. *Org. Geochem.*, 2013, 55: 26–37.
[67] Zhou, Y. Q.; Zhang, Y. L.; Jeppesen, E.; Murphy, K. R., Shi, K.; Liu, M.

L.; Liu, X. H.; Zhu, G. W. Inflow rate-driven changes in the composition and dynamics of chromophoric dissolved organic matter in a large drinking water lake. *Water Res.*, 2016, 100: 211–221.

[68] Shi, Y.; Zhang, L. Q.; Li, Y. P.; Zhou, L.; Zhou, Y. Q.; Zhang, Y. L.; Huang, C. C.; Li, H. P.; Zhu, G. W. Influence of land use and rainfall on the optical properties of dissolved organic matter in a key drinking water reservoir in China. *Sci. Total Environ.*, 2020, 699: 134301.

[69] Felgate, S. L., Barry, C. D. G., Mayor, D. J., Sanders, R.; Carrias, A.; Young, A.; Fitch, A.; Mayorga-Adame, C. G., Andrews, G.; Brittain, H. et al. Conversion of forest to agriculture increases colored dissolved organic matter in a subtropical catchment and adjacent coastal environment. *J. Geophys. Res. Biogeosci.*, 2021, 126: e2021JG006295.

[70] Tian, P.; Tian, X. J.; Geng, R.; Zhao, G. J.; Yang, L.; Mu, X. M.; Gao, P.; Sun, W. Y.; Liu, Y. L. Response of soil erosion to vegetation restoration and terracing on the Loess Plateau. *CATENA*, 2023, 227: 107103.

[71] Lambert, T.; Bouillon, S.; Darchambeau, F.; Morana, C.; Roland, F. A. E., Descy, J. P.; Borges, A. V. Effects of human land use on the terrestrial and aquatic sources of fluvial organic matter in a temperate river basin (The Meuse River, Belgium). *Biogeochemistry*, 2017, 136: 191–211.

[72] Zhang, K.; Su, Y. M.; Xu, D. S. Study on water environment management in integrated planning of Zhuxihe basin. *Water Resour. Plan. Des*, 2024, 2: 68–71.