Received: 27 September 2024 | Revised: 25 December 2024 | Accepted: 19 March 2025
DOI: 10.1002/wer.70064

RESEARCH ARTICLE

water
ENVIRONMENT RESEARCH

Fluorescence characteristics of dissolved organic matter (DOM) in bottled drinking water of different countries: A potential risk to public health

Nahin Mostofa Niloy[1,2] | Mashura Shammi[1] | Shafi M. Tareq[1]

[1]Hydrobiogeochemistry and Pollution Control Laboratory, Department of Environmental Sciences, Jahangirnagar University, Dhaka, Bangladesh

[2]Centre for Coastal Biogeochemistry, School of Environment, Science and Engineering, Southern Cross University, Lismore, New South Wales, Australia

Correspondence
Shafi M Tareq, Hydrobiogeochemistry and Pollution Control Laboratory, Department of Environmental Sciences, Jahangirnagar University, Dhaka 1342, Bangladesh.
Email: smtareq@juniv.edu

Abstract

Bottled drinking water of numerous brands from different countries, including Bangladesh, Malaysia, Australia, India, Singapore, Norway, Japan, Vietnam, and Taiwan, were studied using three-dimensional fluorescence (excitation–emission matrix, EEM) spectroscopy and multivariate parallel factor analysis (PARAFAC) model. Fluorescent-dissolved organic matter (DOM) components such as microbial processed tyrosine-, fulvic acid (M)-, and tryptophan-like had maximum intensity/concentration at 70.8%, 16.7%, and 12.5% bottled drinking water samples, respectively. The total intensity of all fluorescing DOM components was minimum and maximum in one of the brands from Australia and Vietnam, respectively. Unlike in Japan, the concentrations of DOM components in bottled drinking water were comparable to or higher than groundwater, freshwater, and marine water in Bangladesh, Malaysia, India, and Taiwan. The concentration of *Escherichia coli* was quantified from its significant correlation equation with the microbial-processed tryptophan-like component. Apart from 60% and 20% of bottled water samples from Malaysia and Bangladesh, the remaining samples of studied countries were medium to very high-risk because of *E. coli* signatures. The adverse health impacts from previously identified over-acceptable-limit mineral concentrations in bottled drinking water are discussed. DOM components at such concentrations in bottled drinking water also strengthened doubts about the efficiency of conventional water treatment techniques and biofilm control. Economic indicators of the studied countries affirmed that willingness and proper management knowledge are necessary to ensure safe bottled drinking water besides budget and labor wages.

PRACTITIONER POINTS

- Higher protein-like components intensity than humic-like affirmed microbial abundance

- Risks for *E. coli* availability was medium to very high in maximum samples
- Adverse health impacts for overlimit Pb, Al, and PO_4^{3-} minerals in Bangladeshi brands
- Inefficiency of drinking water treatment techniques in DOM and biofilm control
- Importance of labor wage, willingness, and knowledge for drinking water treatment

KEYWORDS

DOM components, *E. coli* risk, EEM model, fluorescence spectroscopy, PARAFAC analysis

INTRODUCTION

Bottled drinking water is considered one of the quickest-growing beverages because its production and consumption have increased worldwide (Felipe-Sotelo et al., 2015). The global market value of bottled drinking water was estimated at 270 billion US$ in 2021 and is projected to reach 500 billion US$ by 2030 (Bouhlel et al., 2023). Bottled water is considered a healthier option because of its therapeutic and medicinal benefits, better taste and less odor than tap water (Djam et al., 2020; I. M. M. Rahman et al., 2017). Multiple purification techniques such as boiling, deionization, filtration, reverse osmosis, ozonation and chlorination are followed to ensure the quality of bottled drinking water (Djam et al., 2020; I. M. M. Rahman et al., 2017). However, several concerns, including over-acceptable level mineral concentration and physicochemical properties, contamination during production, transportation and storage, refilling in used bottles illegally, and the possibility of pathogenic abundance, have posed severe doubt on the quality of bottled drinking water (I. M. M. Rahman et al., 2017). Considering the growing demands, different studies have been conducted on disinfection by-products, mycotoxins, volatile organic compounds, endocrine disruptors, pharmaceuticals, minerals, pesticides, and microorganic presence in bottled drinking water (Carstea et al., 2016; Mata et al., 2015; Otero et al., 2015; Shammi et al., 2022).

Dissolved organic matter (DOM) in drinking water is a significant emerging concern because it disrupts aesthetic, chemical, and biological stability and affects treatment techniques and encourages pathogenic development (Croft, 2012). DOM can originate from soil, living and dead animals, terrestrial and aquatic plants, microorganisms and their decayed products, and various anthropogenic sources (Chow et al., 1999). DOM components are carbon sources for the metabolism of living organisms. DOM can also influence biogeochemical and ecological functions, including photochemical reactions, proton binding, and transportation and aggregation of organic and inorganic substrates (Bridgeman et al., 2011). The presence of DOM can change the color of drinking water, disrupting taste and causing odor. DOM can act as substrates that promote microbial growth and activity (Leenheer & Croue, 2003). DOM can also impose unwavering doubts on conventional drinking water treatment techniques and their efficiencies by clogging the pores in activated carbon, fouling membranes, competing for adsorption sites with other compounds, and demanding more coagulant and disinfectant chemicals (Croue et al., 2000). Coagulant and disinfectant chemicals in excessive amounts can further react with DOM and generate disinfection byproducts (DBPs) in drinking water (Matilainen et al., 2011). The promotion of microbial growth and production of DBPs cause severe and deadly health problems in the human body, including cancer (Li & Mitch, 2018).

Pathogenic health impacts because of DOM presence include dysentery, diarrhea, typhoid fever, hepatitis, cholera, cryptosporidiosis, vomiting, nausea, headache, amoebiasis, anorexia, polio, and colitis (WHO, 2017). Moreover, DBPs can cause bladder cancer, miscarriages, and the birth of small children because of gestational age (Li & Mitch, 2018). Approximately 1 million people die from contaminated drinking water each year worldwide (Ritchie et al., 2019). Around 7.2 million illnesses, 600,800 emergency department (ED) visits, 120,000 hospitalizations, and 6600 deaths were recorded because of waterborne infections in the United States in 2014, of which 1.13 million illnesses, 31,600 ED visits, 47,700 hospitalizations, and 3300 deaths were associated with drinking water (Gerdes et al., 2023). Mostly norovirus and nontuberculous mycobacteria were responsible for illness, hospitalization, and death cases, and about \$1.39 billion cost for health care annually because of drinking contaminated water in the United States (Gerdes et al., 2023). According to The World Counts, yearly, around 3.6 million people die from water-related diseases, of whom 2.2 million are children. The World Counts also informed about ~6% of total annual deaths worldwide because of waterborne disease.

Fluorescence spectroscopy is a widely used organic matter characterization technique in terrestrial, aquatic, and atmospheric environments (Coble, 2007; Hudson et al., 2007). Such a technique portrays a three-dimensional excitation–emission matrix (EEM) sketch with distinct excitation/emission wavelength positions for particular fluorescing components (Stedmon & Bro, 2008). Parallel factor analysis (PARAFAC), an advanced multivariate analytical tool, can comprehensively separate each component from EEM according to its distinct excitation/emission wavelength position with fluorescent intensity/concentration (Stedmon & Bro, 2008). The technique is simple, prompt, sensitive, and specific, and it hardly requires any sample preparation, pre-treatment, or component extraction (Hudson et al., 2007; Stedmon & Markager, 2005). Because of such advantages, fluorescence spectroscopy was considered for the study over other time-consuming and complex high-performance size exclusion chromatography (HPSEC) and liquid chromatography–mass spectrometry (LC–MS) techniques.

Studies on bottled drinking water quality, including DOM distribution, are minimal. Mineral concentration, microbial abundance, and the database of waterborne diseases, illnesses, and deaths utterly demand frequent and extensive study on bottled water quality. Moreover, according to the United States Environmental Protection Agency (USEPA), worldwide climate change can significantly deteriorate drinking water quality in the future. Therefore, using fluorescence spectroscopy, this study characterized and quantified significant emerging contaminants, that is, DOM components in bottled drinking water of various countries. Risk levels due to microbial contamination were further assessed following DOM concentrations. This study also discussed efficiency differences in various bottled water manufacturing techniques, adverse effects of overlimit mineral concentrations, and role of economic indicators on bottled water purification methods.

MATERIALS AND METHODS

Sampling and water-quality measurement

The study considered 24 bottled drinking water brands from nine different countries, including five from Bangladesh: B1, B2, B3, B4, and B5; five from Malaysia: M1, M2, M3, M4, and M5; three from Australia: A1, A2, and A3; three from India: I1, I2, and I3; three from Taiwan: T1, T2, and T3; two from Vietnam: V1 and V2; and one from each of Singapore: S1, Japan: J1, and Norway: N1. Bottled drinking water was preserved at 4°C temperature in a portable cooler box for transportation to the laboratory, followed by starting water sample analysis immediately. The information mentioned in the bottle labelling, such as mineral content, water source, and treatment technique, were noted. Physicochemical parameters, including temperature, pH, conductivity, dissolved oxygen (DO), and turbidity of the bottled water, were measured using a YSI sonde multiparameter.

Measurement of fluorescence properties of bottled drinking water

The three-dimensional fluorescence (EEM) properties of the collected bottled drinking water were measured using a fluorescence spectrophotometer. Samples were placed in a 5-cm long quartz cuvette for the measurement. Scanning excitation (Ex) and emission (Em) wavelengths in fluorescence spectrophotometer were set at 225–400 nm and 250–500 nm with 5- and 1-nm intervals, respectively. Further parameters in the fluorescence spectrophotometer were set as silt width at 5 nm for excitation and emission bands, scanning speed at 1200 nm/min, and photomultiplier tube voltage at 700 V during sample measurement. Ultrapure Milli-Q water was used as a blank during sample measurement in the fluorescence spectrophotometer.

EEM and PARAFAC modeling with samples

The collected data from the fluorescence spectrophotometer were processed by subtracting blank Milli-Q and removing Raman and Rayleigh spectra from each sample. The arbitrary unit of fluorescence data was converted to the Raman unit (RU) using the Raman wavelength position of Milli-Q water (Lawaetz & Stedmon, 2009). The processed data of each sample was later considered for fluorescence EEM and PARAFAC analysis. DOMFluor (v1.7) toolbox in MATLAB (v.2016a) was used for such three-dimensional modeling (Stedmon & Bro, 2008). Data calibration and validation were meticulously performed during PARAFAC modeling to identify the exact number of fluorescing components in the sample (Stedmon & Bro, 2008).

Quality control and assurance in the study

Research quality was adequately controlled and assured during the study. The fluorescence spectrophotometer was calibrated properly before sample measurement. The apparatuses used during sample analysis and measurement were entirely rinsed using acids and Milli-Q water before usage. The laboratory environment was ensured to follow WHS standards, and the samples were carefully secured from any dust or miscellaneous contamination.

RESULTS AND DISCUSSION

Physicochemical properties in bottled water

Bottled drinking water of different brands in various countries showed unlike physicochemical properties (Table 1). The properties such as temperature, pH, conductivity, specific conductivity, DO (%), DO, and turbidity varied between 23.9–27.3°C (26.1 ± 0.9), 5.9–7.7 (6.7 ± 0.5), 4.6–284.3 μS/cm (93.5 ± 87.9), 4.4–277.9 μS/cm (92.3 ± 86.7), 56.2–85.6% (71.0 ± 7.0), 4.7–6.8 mg/l (5.7 ± 0.5), and 0.1–0.2 NTU (0.1 ± 0.04) in bottle drinking water except B4 (Table 1). pH, conductivity, and DO in B4 were found at 7.4, 96.4 μS/cm and 5.4 mg/l (I. M. M. Rahman et al., 2017). Apart from pH and turbidity at 6.5–8.5 and 0.5 NTU, respectively, other physicochemical parameters, including temperature, conductivity, and DO, still lack any standard acceptable limit in drinking water (WHO, 2022). However, there are suggestive limits for such parameters to maintain the best and most health-effective drinking water quality. The advised limits of conductivity, DO, and DO (%) are 50–800 μS/cm, 6.5–8.0 ppm, and 80–110% in healthy drinking water (Atlas Scientific, 2022; Wisewell, 2022). pH in M2, M5, I2, I3, V1 S1, A1, A2, and J1 were lower than the acceptable limit (Table 1). Low pH causes corrosion in drinking water (WHO, 2022). Conductivity, specific conductivity, and turbidity were within the accepted limit in all drinking bottled water (Table 1). However, DO in the bottled water was lower than the recommended limit except A1 and A3

TABLE 1 Physicochemical properties of bottled drinking water at various countries.

Sample ID	Temperature (°C)	pH	Conductivity (μS/cm)	Specific conductivity (μS/cm)	DO (%)	DO (mg/l)	Turbidity (NTU)	Reference
B1	25.1	7.1	143.2	142.4	75.0	6.1	0.1	This study
B2	26.2	6.7	27.7	26.9	72.8	5.9	0.2	
B3	25.6	7.1	168.3	166.4	64.7	5.3	0.1	
B4	-	7.4	96.4	-	-	5.4	-	(I. M. M. Rahman et al., 2017)
B5	27.3	7.4	283.9	271.9	68.6	5.5	0.2	This study
M1	24.5	6.6	79.3	80.4	68.8	5.7	0.1	
M2	24.3	6.3	198.7	201.4	59.6	4.9	0.1	
M3	25.2	6.6	66.7	67.3	63.9	5.3	0.1	
M4	25.7	6.6	117.6	115.9	78.9	6.3	0.2	
M5	23.9	5.9	216.8	221.1	56.2	4.7	0.1	
A1	27.2	6.3	37.9	36.4	85.6	6.8	0.1	
A2	27.2	6.3	89.9	86.5	76.3	5.9	0.1	
A3	27.2	6.8	46.7	44.8	83.6	6.5	0.1	
I1	26.6	7.1	49.2	47.7	64.8	5.3	0.2	
I2	26.8	6.2	8.6	8.3	69.9	5.5	0.1	
I3	27.1	6.4	8.5	8.2	65.7	5.2	0.2	
V1	26.4	6.2	4.6	4.4	70.7	5.6	0.1	
V2	26.2	7.7	284.3	277.9	67.7	5.5	0.1	
S1	26.9	6.3	5.6	5.4	70.3	5.6	0.1	
N1	26.3	7.4	28.9	28.2	74.2	5.9	0.2	
T1	25.8	7.3	6.4	6.3	70.6	5.7	0.1	
T2	27.2	7.4	41.6	40.0	73.6	6.4	0.1	
T3	25.5	6.9	164.5	162.9	74.1	5.9	0.1	
J1	25.6	6.3	72.4	71.7	77.7	6.4	0.1	

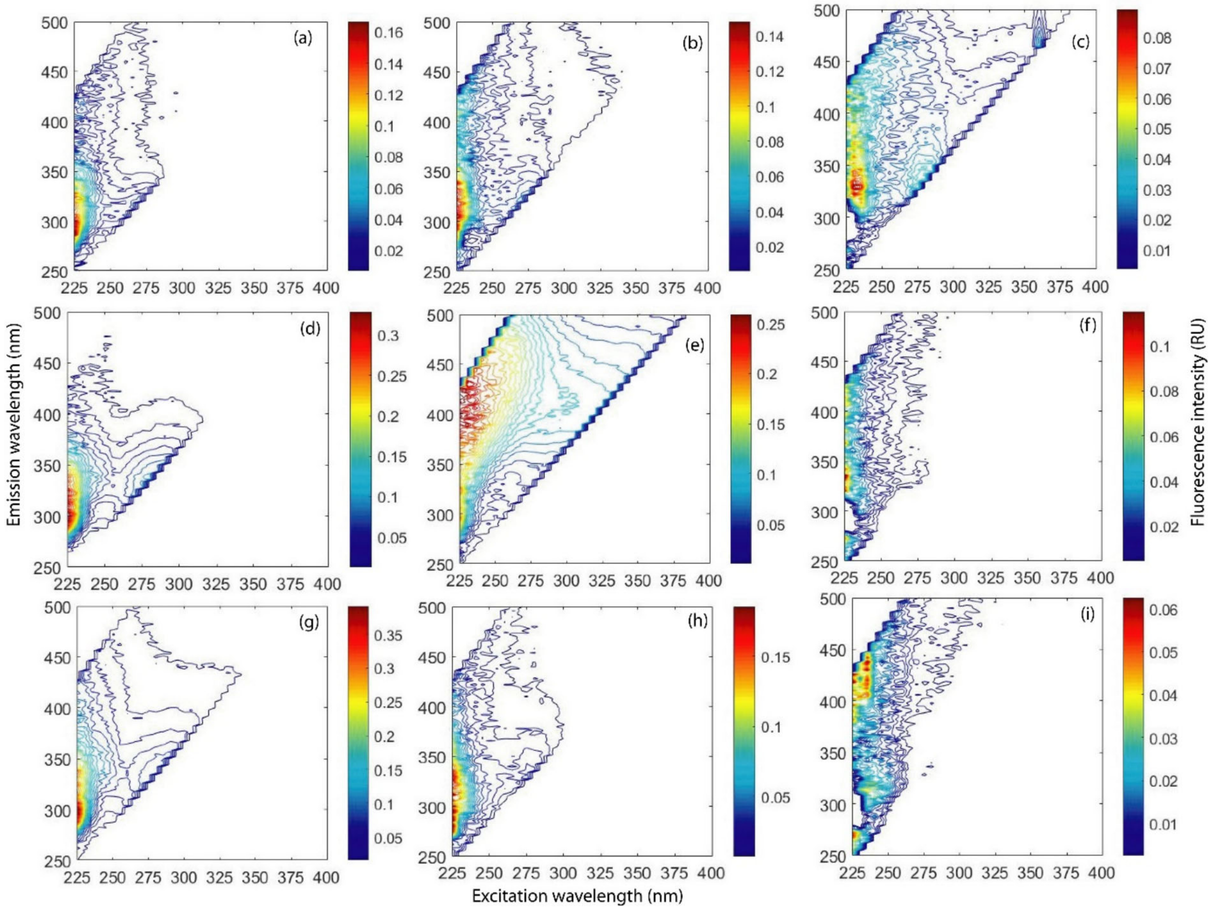

FIGURE 1 Three-dimensional fluorescence EEM of bottled drinking water samples: (a) B3, (b) M5, (c) A2, (d) I3, (e) V2, (f) S1, (g) N1, (h) T3, and (i) J1. EEM, excitation–emission matrix.

(Table 1). DO at low concentrations can promote microbial conversion of sulfate to sulfide and nitrate to nitrite (WHO, 2022). pH and DO were lowest at Malaysian bottled water M5 among the studied samples (Table 1).

EEM and PARAFAC model with bottled drinking water samples

EEM model identified various humic- and protein-like fluorophores in drinking bottle water samples (Figure 1). EEM model found fluorophores including Ex/Em = 225–230/294–318 nm (tyrosine-like) at 50%, 230–240/334–340 nm (tryptophan-like) at 8.3%, 225–230/288–310 nm (tyrosine-like) and 225–235/328–332 (tryptophan-like) at 12.5%, 230/410 nm (fulvic acid [M-like]) at 4.2%, 225–245/270–318 nm (tyrosine-like) and 225–235/410–434 nm (fulvic acid [M-like]) at 12.5%, 225–230/264–300 nm (tyrosine-like), 225–235/336–376 nm (tryptophan-like), and 225–235/398–420 nm (fulvic acid [M-like]) at 12.5% samples (Figure 1). Comparatively higher intensity of tyrosine-like in total 84.5% samples indicated its frequent presence in bottle drinking water (Figure 1).

PARAFAC model identified four fluorescing DOM components in bottled drinking water (Figure 2). Component 1 (C1) had a fluorescence peak at Ex/Em = 225/302 nm, indicating its character as tyrosine-like (Fellman et al., 2010; Santín et al., 2009). Component 2 (C2) showed peaks at Ex/Em = 230/400 and 285/400 nm, indicating its nature as autochthonous fulvic acid (M)-like (Fu et al., 2010). Component 3 (C3) can be characterized as fulvic acid (C)-like as it showed fluorescence peaks at 260/456 and 325/456 nm (Fu et al., 2010). Component 4 (C4) showed a fluorescence peak at 240/338 nm, specifying its character as tryptophan-like (Dubnick et al., 2010).

Among the four fluorescing DOM components, C1 had the highest intensity in 70.8% samples, while C2 and C4 occupied the highest intensity in the remaining 16.7% and 12.5% samples (Figure 3). C2 had the highest intensity among four DOM components in all Vietnam and Japanese bottled water brands V1, V2, and J1, and one Australian brand A2 (Figure 3). C4 had the highest

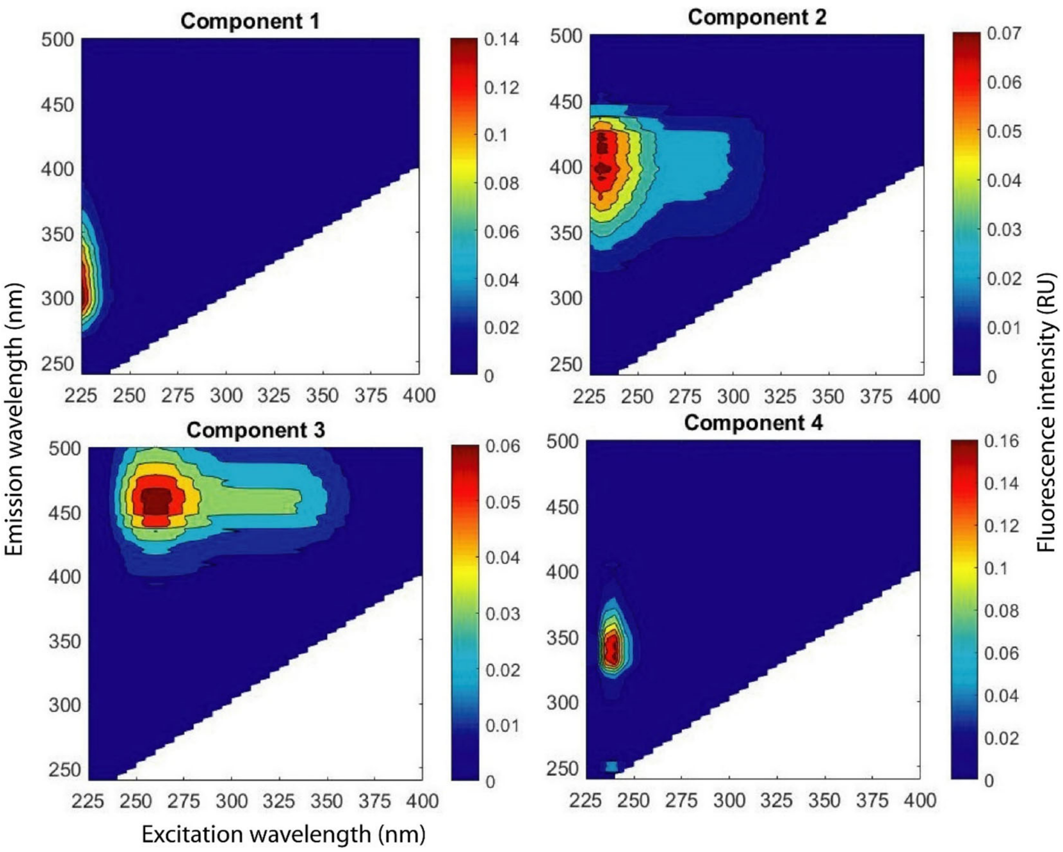

FIGURE 2 Fluorescent DOM components in bottled drinking water identified by PARAFAC modeling. DOM, dissolved organic matter.

intensity in two Australian brands, that is, A1 and A3, and one Taiwan brand, T2 (Figure 3). The fluorescent intensities ranged between 0.002–0.4 RU (0.12 ± 0.12), 0–0.25 RU (0.03 ± 0.05), 0.0004–0.17 RU (0.016 ± 0.03), and 0–0.39 RU (0.04 ± 0.08) in C1–C4, respectively (Figure 3). Maximum intensity of C1 and C4 were identified in M3 and T2, respectively (Figure 3). C2 and C3 had their maximum intensity in V2 (Figure 3). Intensities of C1 in I2 and N1 were in the comparable ranges with its maximum intensity containing brand M3 (Figure 3). Fluorescence intensity of DOM components in total was maximum in V2 (Figure 3). Integrated intensity of components at I3, M3, N1 and T2 were in the similar ranges with V2 (Figure 3). Minimum intensities of C1–C4 were identified in A1, B1, B4, and M3, respectively (Figure 3). C2 was absent in B4 and T1, while C4 was absent in M1, M2, and B4 (Figure 3).

By country, C1 ranged between 0.05–0.15 RU (0.08 ± 0.04), 0.15–0.4 RU (0.21 ± 0.11), 0.002–0.03 RU (0.01 ± 0.02), 0.06–0.3 RU (0.19 ± 0.14), 0.02–0.18 RU (0.1 ± 0.11), and 0.03–0.19 RU (0.1 ± 0.09) in Bangladesh, Malaysia, Australia, India, Vietnam, and Taiwan, respectively, having minimum and maximum intensity in Australia and Malaysia, respectively (Figure 3). C2 was found within the ranges between 0 and 0.04 RU (0.02 ± 0.02), 0.02–0.04 RU (0.03 ± 0.007), 0.005–0.05 RU (0.02 ± 0.02), 0.01–0.03 RU (0.02 ± 0.01), 0.02–0.25 RU (0.13 ± 0.16), and 0–0.02 RU (0.02 ± 0.01) in Bangladesh, Malaysia, Australia, India, Vietnam, and Taiwan, respectively, showing minimum and maximum intensity in Taiwan and Vietnam, respectively (Figure 3). C3 varied between 0.0004–0.02 RU (0.008 ± 0.008), 0.007–0.02 RU (0.01 ± 0.004), 0.001–0.02 RU (0.009 ± 0.01), 0.005–0.008 RU (0.006 ± 0.002), 0.006–0.17 RU (0.09 ± 0.12), and 0.001–0.008 RU (0.005 ± 0.003) in Bangladesh, Malaysia, Australia, India, Vietnam, and Taiwan, respectively, possessing minimum and maximum intensity in Taiwan and Vietnam, respectively (Figure 3). C4 showed intensities between 0 and 0.04 RU (0.02 ± 0.01), 0–0.01 RU (0.004 ± 0.006), 0.01–0.04 RU (0.02 ± 0.02), 0.006–0.09 RU (0.04 ± 0.04), 0.006–0.02 RU (0.01 ± 0.009), and 0.01–0.39 RU (0.14 ± 0.22) in Bangladesh, Malaysia, Australia, India, Vietnam, and Taiwan, respectively, having the minimum and maximum intensity in Malaysia and Taiwan, respectively (Figure 3). Component intensities in total ranged between 0.06–0.21 RU (0.13 ± 0.07), 0.19–0.45 RU (0.25 ± 0.11), 0.02–0.15 RU (0.07 ± 0.07), 0.12–0.47 RU (0.26 ± 0.18), 0.05–0.61 RU (0.33 ± 0.4), and 0.1–0.44 RU (0.26 ± 0.17) in Bangladesh, Malaysia, Australia, India,

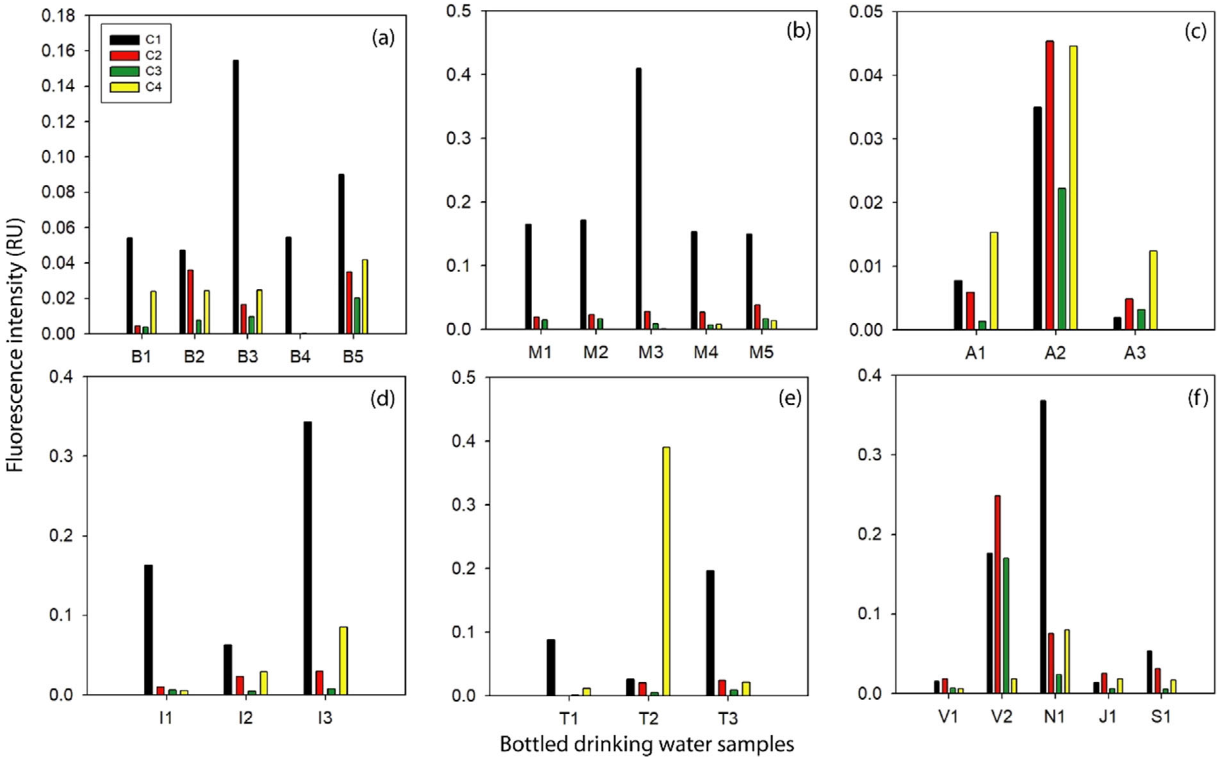

FIGURE 3 Fluorescent intensities of DOM components identified by the PARAFAC model at various bottled drinking water of different countries: (a) Bangladesh, (b) Malaysia, (c) Australia, (d) India, (e) Taiwan, (f) Vietnam, Norway, Japan, and Singapore. DOM, dissolved organic matter.

Vietnam, and Taiwan, respectively, showing minimum and maximum intensity in Australia and Vietnam, respectively (Figure 3). Protein-like components dominated in bottled drinking water and possessed >50% of total intensity in all samples of studied countries except Vietnam (Figure 3). Integrated intensity of entirely anthropogenic sourced and microbial processed protein-like C1 and C4 possessed >70% of total intensity in 80%, 100%, 33%, 100%, and 100% samples in Bangladesh, Malaysia, Australia, and Taiwan (Figure 3). In contrary, integrated intensity of natural and microbial derived humic-like components C2 and C3 had 53–68% of total intensity in all studied bottled drinking water samples of Vietnam (Figure 3).

The intensity/concentration of fulvic-like substances (C2 and C3) in Malaysian bottled waters were although lower than Cikapundung River, protein-like components (C1 and C4) were up to 41 times higher than the river water (Sururi et al., 2021). The identified sources of microbial-derived protein-like components in the Cikapundung River water were animal manure, domestic waste, tourism, residential waste, and plantation (Sururi et al., 2021). In Bangladesh, the intensities of humic- and protein-like components in bottled drinking water were lower than in groundwater except C1 in B3 and B5 (Tareq et al., 2013). C1 in bottled water was similar and higher than groundwater in B5 and B3, respectively (Tareq et al., 2013). Moreover, intensities of C2 in B2, B3 and B5, and C3 and C4 in B1, B2, B3, and B5 were either similar or higher than their intensities in most of the months in the upstream Ganges River, Bangladesh (Niloy et al., 2021). Intensities of C1 in B3 and C2 in B2, B3, and B5 were in the comparable ranges with upstream and downstream Brahmaputra River, Bangladesh (Niloy et al., 2022). Such studies on river water identified the sources and production of C1, C2, and C4 from microbial processing and C3 through photochemical activities (Niloy et al., 2021, 2022). In India, C1, C2, and C3 in I1, I2 and I3, and C4 in I2 and I3 were higher than in the southwestern Bay of Bengal water in the Indian portion (Chari et al., 2013). Sources of the components in the southwestern Bay of Bengal were identified as bacterial degraded allochthonous, autochthonous, and anthropogenic substances (Chari et al., 2013). C1 in I1 and I3 was higher than groundwater (Wilson et al., 2023). C1 was comparable to groundwater and surface water in I2 and I3, respectively (Wilson et al., 2023). Moreover, C4 in I3 was higher than groundwater (Wilson et al., 2023). Microbial-derived slurry or waste materials were identified as sources of such protein-like components C1 and

C4 (Wilson et al., 2023). The identified intensities of humic- and protein-like components in the bottled water were comparable to or higher than shallow aquifers in the western Bengal Basin in India (Schittich et al., 2018). In Japan, intensities of humic- and protein-like components in bottled water were lower than in the Ohta, Kurose, Yodo, Yamato, and Kokubu rivers water (Ayeni et al., 2022; Mostofa et al., 2005). In Taiwan, integrated intensities of C1 and C4 in T1, T2, and T3 were higher than in estuarine water (Yang et al., 2013). Microbial metabolites, sewerage, miscellaneous anthropogenic inputs, and autochthonous production were identified as sources of protein-like components in Taiwan estuaries (Yang et al., 2013). The intensity of C4 in T2 was also found higher than in the Taiwan Strait throughout the year and the Jiulong River Estuary (Guo et al., 2012; Lin et al., 2016). Sources of C4 were identified as microbial-processed allochthonous and autochthonous substances (Guo et al., 2012; Lin et al., 2016).

Humic substances can cause an endemic and peripheral vascular disease called "Blackfoot disease" (F. J. Lu, 1990b). The presence of As_2O_3 accelerates the oxidation and polymerization of protocatechuic acid and thus promotes the production of humic substances (F. J. Lu, 1990b). In a 20–32 days study, 50% Balb/c mice became crippled, had ulceration, phlegmasia, gangrene and necrosis in the extremities, and experienced black turned leg and tail when they were fed 5 mg of humic substance per 20 g of body weight daily (F. J. Lu, 1990b). Such blackfoot disease can also cause kidney, bladder, liver, and lung cancers; diabetes mellitus; erythematous swelling; hypertension; cardiovascular anomalies; cerebral apoplexy; ulcers; goiter; amputation of affected limbs; and blood coagulation in the human body (F. Lu, 1990a; F. J. Lu, 1990b). Humic-metal complex, especially with As, was also found to inhibit human plasmin activity up to 80% (Hseu et al., 2001). The mortality rate was significantly higher in the blackfoot disease-affected zones compared to the unaffected areas (Chen et al., 1994). Intensities of both humic substances C2 and C3 were maximum in one of the bottled drinking water brands from Vietnam V2 (Figure 3). Intensities of C2 and C3 in V2 were 3.3–56.9 times and 7.3–469.4 times higher than their intensities in other bottled water brands (Figure 3) and thus stimulate the possibility of occurring blackfoot disease through the drinking of bottled water.

Microbial growth and activity linkage with protein-like components

Tryptophan- and tyrosine-like components predominantly originate from microbial intracellular and extracellular activities, including metabolism, cell multiplication, structural fragments, and particular functional proteins of microbes (Carstea et al., 2016; Fox et al., 2017). The tryptophan-like component was ubiquitously identified in the supernatant, lysed, and resuspended cells of cultured bacteria such as *Escherichia coli*, *Bacillus subtilis,* and *Pseudomonas aeruginosa* (Fox et al., 2017). The presence of a tryptophan-like component in the environment was found to correlate strongly with microbial population size and thus is widely affirmed to exploit such fluorescing component for the measurement of microbial activities in the system (Baker et al., 2015; Fox et al., 2017).

Tryptophan- and tyrosine-like components were mainly found in industrial effluent, sewage wastewater, and urban and agricultural runoff (Yang et al., 2012; Ye et al., 2019). Moreover, the influx of sewage into surface water from residential runoff stimulates algal growth, which was identified as another source of protein-like components (Yang et al., 2012). Anthropogenic and microbial-induced protein-like components are labile, comparatively less aromatic, smaller in molecular size and weight, and contain higher $\delta^{13}C$ value and lower double bond equivalents and stability than mostly natural humic-like components (Ye et al., 2019). Hydrophilic protein substances were less likely to be removed than hydrophobic humic in the alum-used coagulation process (Soh et al., 2008). Biodegradable dissolved organic carbon (BDOC) that supports microbial growth is usually found with higher concentration in hydrophilic protein than in hydrophobic humic substance (Soh et al., 2008). Moreover, despite poor trihalomethane formation potentiality, inadequate removal of hydrophilic protein than hydrophobic humic substance in coagulation significantly contributes to carcinogenic DBP formation (Bieroza et al., 2010; Soh et al., 2008).

Microbial risk assessment using concentration of tryptophan-like fluorophore

A significant correlation ($r = 0.74, 0.85$) was identified between *E. coli* enumeration and concentration of tryptophan-like component in groundwater and polluted river water in a previous study (Baker et al., 2015; Nowicki et al., 2019). Tryptophan was absent in B4, M1, and M2 and, therefore, was excluded from microbial enumeration and risk assessment. *E. coli* concentration ranged from 1.79 to 22112.07 CFU/100 ml and was minimum and maximum at Malaysian bottled drinking water M3 and Taiwan bottled water T2, respectively (Table 2). M3 was the only bottled water brand to affirm low risk for *E. coli* abundance (Table 2). M4, M5, A3, I1, V1, and T1 bottled water were in the medium-high risk category, and the remaining drinking water was in the high/very high-risk category because of *E. coli* availability (Table 2). Among the countries with multiple bottled water brands in this study, 0%, 33.3%, 33.3%, 50%, and 33.3% bottled water were in medium-high, and 80%, 66.7%, 66.7%, 50%, and 66.7% bottled drinking water were in high/very high-risk category in Bangladesh, Australia, India, Vietnam, and Taiwan, respectively (Table 2). In contrast, in Malaysia, 20% and 40% of bottled water were found in low and medium/high-risk categories, respectively, and hardly any bottled water had a very high risk for *E. coli* contamination (Table 2). Moreover, in Singapore, Norway, and Japan, bottled drinking water was in the high/very high-risk category (Table 2). C4 was though absent in B4, M1, and M2, the presence of another microbial-derived anthropogenic component, C1, indicated the predominance of other types of microorganisms apart from *E. coli* in such bottled drinking waters (Figure 3).

Concentration of minerals in bottled drinking water and related consequences on health

Minerals such as Na, K, Ca, Mg, and SO_4 in bottled drinking water were within the permissible limit in Bangladesh, Malaysia, Australia, Norway, and Singapore in terms of brand-specific and on average (Tables 3, 4 and S1). Concentration of Na, Mg, and Ca in I2 and I3, and K, Ca, and Mg in V2 were also within the permissible limit (Tables 3, 4, and S1). HCO_3^- concentration in M2, M5, N1, V2, and Singapore and Australian bottle drinking water also followed the guideline values (Tables 3, 4,

TABLE 2 Microbial activity assessment from the concentration of tryptophan-like component (C4).

			According to (Baker et al., 2015)		
Sample ID	Fluorescence intensity (RU)	Concentration (ppb)	*E. coli* amount (CFU/100 ml)	Risk category for *E. coli* concentration	Risk category for *E. coli* concentration (according to [Nowicki et al., 2019])
B1	0.024	5.32	239.02	High	Very high
B2	0.024	5.4	244.87	High	Very high
B3	0.025	5.5	252.27	High	Very high
B4	0	0	0	N/A	N/A
B5	0.042	9.29	590.37	High	Very high
M1	0	0	0	N/A	N/A
M2	0	0	0	N/A	N/A
M3	0.001	0.26	1.79	Low	Low
M4	0.008	1.66	36.14	Medium	High
M5	0.013	2.88	88.34	Medium	High
A1	0.015	3.39	115.08	High	High
A2	0.045	9.89	653.44	High	Very high
A3	0.012	2.75	81.96	Medium	High
I1	0.006	1.26	23.11	Medium	High
I2	0.029	6.38	320.94	High	Very high
I3	0.086	18.99	1882.64	High	Very high
V1	0.006	1.39	27.1	Medium	High
V2	0.018	4.06	154.18	High	High
S1	0.017	3.67	130.88	High	High
N1	0.079	17.73	1684.25	High	Very high
T1	0.012	2.6	74.83	Medium	High
T2	0.39	86.72	22112.07	High	Very high
T3	0.021	4.69	194.82	High	Very high
J1	0.018	4.01	151.11	High	High

TABLE 3 Concentration of minerals mentioned in the labeling of bottled drinking water in various countries.

Sample ID	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	HCO_3^- (mg/l)
B5	<8	-	-	-	-	-	-
M2	4.5	1.8	18.3	1.2	0.55	3.2	62
M5	7.6	2.5	27	3.1	<2	13	110
I3	3	-	-	1	-	-	-
N1	3	0.5	4.5	1.7	5	4	15
S1	2	-	-	-	-	-	-
Acceptable limits (WHO, 2022)	<200	12	<100–300	<100–300	200–300	<250	<100

TABLE 4 Concentration of minerals in bottled drinking water found at various studies in different countries (Kumar et al., 2021; Que et al., 2021; I. M. M. Rahman et al., 2017; M. A. Rahman et al., 2013).

Mineral name	B1	B2	B3	B4	B5	I2	I3	V2	WHO Permissible limit (WHO, 2022)
Na (mg/l)	23.9	-	7.8	16.3	-	55	58	-	<200
K (mg/l)	0.4	-	0.9	0.03	-	-	-	2–3	12
Ca (mg/l)	1.6	-	14.6	0.06	-	65	70	11–17	<100–300
Mg (mg/l)	1.5	-	1.7	5.3	-	25	30	3–6	<100–300
Cl^- (mg/l)	-	-	-	-	-	-	-	-	200–300
SO_4^{2-} (mg/l)	20.5	-	17.9	9.5	-	-	-	-	<250
HCO_3^- (mg/l)	-	-	-	-	-	-	-	280–330	<100
Al (mg/l)	0.6	-	0.7	0.8	-	-	-	-	<0.1
B (mg/l)	0.07	-	0.04	0.06	-	-	-	-	<2.4
Ba (μg/l)	2.7	-	2.3	-	-	-	-	-	<1300
Cd (μg/l)	-	-	0.5	0.07	-	-	-	-	<3
Cu (μg/l)	6.4	-	8.2	8.2	-	-	-	-	<2000
Li (μg/l)	2.3	-	3.4	-	-	-	-	-	-
Pb (μg/l)	12.2	-	54.9	1.6		-	-	-	<10
Sr (μg/l)	10.7	-	78.2	-	-	-	-	-	-
Fe (μg/l)	-	-	-	-	-	-	-	-	<300
Zn (μg/l)	-	-	-	-	-	-	-	-	<4000
Cr (μg/l)	-	-	-	-	-	-	-	-	<50
Mn (μg/l)	-	-	-	-	-	-	-	-	<100
Ni (μg/l)	-	-	-	-	-	-	-	-	<70
As (μg/l)	-	-	-	-	-	-	-	-	<10
F^- (mg/l)	-	-	-	-	-	-	-	<0.5	<1.5
NO_3^- (mg/l)	12.8	-	72.9	8.3	-	-	-	-	<50
I^- (mg/l)	-	-	-	-	-	-	-	<0.01	-
PO_4^{3-} (mg/l)	7.3	-	9.7	5.9	-	-	-	-	0.1

and S1). Concentration of B, Ba, Cd, Cu, NO_3 were within the acceptable limits in drinking bottled water in Bangladesh (Table 4 and S1). However, the concentration of Al exceeded the permissible limits in brand-specific and, on average, bottled drinking water in Bangladesh (Table 4 and S1). Pb in B1, B3, and B5; NO_3 in B3; and PO_4^{3-} in B1, B3, and B4 also exceeded the acceptable limits in bottled drinking water in Bangladesh (Table 4).

In Malaysian bottled drinking water, average concentrations of Cd, Cu, Cr, Fe, Zn, Mn, Ni, As, Pb, F^-, and NO_3^- were within the permissible limits (Table S1). The concentration of Cl^- according to bottle labelling and, on average, in Malaysia and Norway followed the acceptable guideline limit (Table 3 and S1).

Overlimit of Pb concentration in drinking water can damage the brain and kidney; cause problems in teeth, bones, hearing, joints and muscles, immune system, reproductive organs, biological functions and liver, and disrupt red blood cell production that carries oxygen in every part of human body (Mulvihill, 2023; WHO, 2022). Elevated levels of Pb in the human body can also cause headache, anemia, appetite loss, disturbance in sleep and concentration, tingling sensation in the skin, convulsion, seizures, and even coma and death (Environmental Health, 2024). Young children, infants, and pregnant women can be highly affected as low intelligence quotients (IQ) containing brains in children were found to link with elevated Pb consumption (Larsen & Sánchez-Triana, 2023). A low concentration of Pb can affect patients with high blood pressure and kidney problems more likely than healthy persons (Environmental Health, 2024). The stored Pb in bones in the mother's body can also be transferred into the infant during pregnancy and thus can affect brain development in newborns (Cangelosi et al., 2017; Levallois et al., 2018). The presence of Pb in paints, pipes, faucets, solders, and miscellaneous materials in plumbing, water distribution and treatment systems, and bottled water packaging areas can be the possible sources of overlimit Pb in bottled drinking water in Bangladesh (Levallois et al., 2018). Dust and fume contamination, corrosion, and water temperature increase can also elevate Pb concentration in drinking water (Environmental Health, 2024; Levallois et al., 2018).

Bangladesh is a South Asian lower middle-income country according to the World Bank region and income classification. Pb was found at 6.8 μg/dl in adult and children's blood, which was enough to reduce 6.9 per child and 20 million total IQ points in 2019 in Bangladesh (Sarah, 2023). Moreover, 85 per 100,000 population and in total 138,045 people died from cardiovascular disease because of Pb exposure in 2019 in Bangladesh (Sarah, 2023). The death rate in Bangladesh was 5.54‰ in 2019, and such death because of Pb-induced cardiovascular disease was ~15% of total deaths (Sarah, 2023). Costs because of cardiovascular disease mortality and IQ loss were estimated at US$17,736 million and US$10,897 million, which equated to 5.86% and 3.6% of GDP in Bangladesh (Sarah, 2023). No research has been conducted on Pb concentration in bottled drinking water to date in the countries of this study except Bangladesh. Pb concentration in human blood was found maximum in South Asia, followed by Middle East and North Africa, Sub-Saharan Africa, Latin America and the Caribbean, East Asia and Pacific, and Europe and Central Asia (Larsen & Sánchez-Triana, 2023). Such study also revealed that children with <5 years of age lost 765 million IQ points, and 545,000 adults died from cardiovascular disease worldwide because of Pb exposure in 2019 (Larsen & Sánchez-Triana, 2023). Moreover, IQ loss and death from cardiovascular disease followed the descending order Sub-Saharan Africa > South Asia > East Asia and Pacific > Middle East and North Africa > Latin America and Caribbean > Europe and Central Asia and East Asia and Pacific > South Asia > Europe and Central Asia > Sub-Saharan Africa > Middle East and North Africa > Latin America and Caribbean (Larsen & Sánchez-Triana, 2023). 23% less income in future than present job evaluation because of IQ loss in children and 77% monetary cost for welfare purposes in cardiovascular disease mortality summed up to US$6.0 trillion in 2019 because of Pb exposure, which equated to 6.9% global gross domestic products (GDP) (Larsen & Sánchez-Triana, 2023). Europe and Central Asia were identified as the maximum cost bearer because of IQ loss and mortality in cardiovascular disease, equating to 15.2% of its GDP (Larsen & Sánchez-Triana, 2023). Such costs in East Asia and Pacific, Middle East and North Africa, South Asia, Sub-Saharan Africa, Latin America and the Caribbean were 10.5%, 9.7%, 9.1%, 8.9%, and 6.7% of their corresponding GDP, respectively (Larsen & Sánchez-Triana, 2023).

Excessive Al might come from hydrolyzing salts such as aluminum sulfate (VI) and sodium aluminate or pre-hydrolyzed polyaluminum chlorides used in coagulation during water treatment (Krupińska, 2020). Hydrolyzed aluminum salts were identified to increase monomer soluble Al concentration more efficiently than pre-hydrolyzed salts (Krupińska, 2020). Overlimit Al > 0.1 mg/l in drinking water was identified to strongly correlate with dementia and Alzheimer's disease with relative risk of 1.99 and 2.14, respectively (Rondeau et al., 2000). The toxicity causing descending order $[Al(H_2O)_6]^{3+} > [Al(OH)^{2+}] > [Al(OH)_2{}^{+}]$ ensured infuse into blood plasma and causes vomiting, nausea, mouth ulcers, diarrhea, arthritic pain, skin rashes, skin ulcers, nervous system damage, neurofibril degeneration, atrophy of neurons, T lymphocyte functioning disorders, and lymphopenia (Krupińska, 2020; Sosnowski, 2023; WHO, 2003). Al is ionized and can be easily absorbed in both acidic and alkaline conditions, causing harm to living organisms (Krupińska, 2020). The presence of phosphate and organic matter can influence Al solubility in water (Krupińska, 2020). Phosphate in Bangladeshi bottled drinking water exceeded the threshold limit and was identified at a very high concentration (Table 4). Concentrations of humic and protein-like DOM components identified in this study were either comparable or sometimes higher than groundwater and the Ganges and Brahmaputra River water (Niloy et al., 2021, 2022). After the complexation of Al and ligands in organic matter, the bioavailability of Al and coagulation effects were found to decrease (Wang et al., 2010). Such Al-organic matter complexation was so stable that removing Al from drinking water was found difficult in the treatment process (Wang et al., 2010). Such high concentrations of phosphate and organic matter may strongly influence Al solubility in Bangladeshi bottled drinking water and increase the possibility of severe Al-induced toxicity and damage in the human body.

Efficiency assessment of water treatment processes mentioned in the bottle label

The particular water treatment process was mentioned in the labelling of some of the studied bottled drinking water (Table S2). According to such information, B4 and M3 were treated through reverse osmosis, where B5, I1, I3, and S1 were purified following ultrafiltration, multistage purification, ozonation, and advanced purification, respectively (Table S2). I2 hardly mentions any particular treatment process (Table S2). Fluorescence intensities including all DOM components at such seven drinking water brands followed descending order as I3 > M3 > B5 > I1 > I2 > S1 > B4 (Figure 3). Intensities of I3 and M3 were in comparable ranges and were far higher than the rest bottled waters (Figure 3). Such higher intensities in I3 and M3 nevertheless of using reverse osmosis and ozonation in water treatment affirmed the failure of such advanced techniques in DOM and microbial growth control. Moreover, despite the similar treatment techniques, much higher intensity than B4 affirmed the shortcoming in the reverse osmosis purification process of M3 (Figure 3). Component C4 was low in concentration at M3 (Figure 3). However, the presence of another microbial-derived DOM component C1 at high amount affirmed the excessive presence of other microbial species rather than *E coli* in M3 (Figure 3). Except B4, high risk of *E. coli* and other microbial contamination in rest of the bottled drinking water affirmed the inefficiency of the claimed water treatment processes in DOM and biofilm control.

Correlations between economic parameters and bottled drinking water quality

Economic indicators in the studied countries were assessed for any correlation with DOM intensities in bottled drinking water to identify country-specific purification strategies and market value adjustment. Such assessment inferred that economic indicators such as gross domestic product (GDP), GDP per capita, gross national income (GNI) per capita, % population with <6.85 $PPP/day income, and %population living under the poverty line had insignificant correlation ($p > 0.05$) with summed intensities of DOM components C3 and C4 and total DOM intensity (Table S3). Such an insignificant correlation affirmed that drinking water production companies still do not consider the presence of DOM and microbial activities gravely. However, total DOM intensity had an inverse and nearly significant correlation ($r = -0.689,\ p = 0.059$) with minimum paid wages in the studied countries (Table S3). The top wage-paid countries, such as Australia and Japan, had the lowest average DOM intensities in bottled drinking water among the studied brands (Figure 3). Conversely, Taiwan and Singapore are moderate wage-paid countries (Table S3). However, despite the similar range paid wages, DOM intensity in Taiwan bottled drinking water brands, especially in T2 and T3, were significantly higher than in Singapore bottled water S1 (Figure 3). Among the other four countries, despite the lowest paid rate, the average DOM intensity in Bangladeshi bottled drinking water were around 50% less than Malaysia, India, and Vietnam (Figure 3 and Table S3). The average intensity in Bangladeshi bottled water was similar to Singapore's, although the paid wage in Singapore was almost eight times higher than in Bangladesh (Figure 3 and Table S3). The average DOM intensity in bottled water in Malaysia, India, and Vietnam was comparable, although paid wages in India and Vietnam were almost 50% less than in Malaysia (Figure 3 and Table S3). The minimum wage here functioned as a secondary indicator. Such comparison of paid wages with DOM intensity reflected that budget and economic health could affect water treatment processes, but they are not the only controlling factors. Instead, willingness, consciousness, and proper knowledge and management contribute more than the budget for DOM and microbial control in bottled drinking water.

CONCLUSION

This study focused on characterizing and quantifying DOM components in bottled drinking water of numerous brands from different countries, including Bangladesh, Malaysia, Australia, India, Singapore, Norway, Japan, Vietnam, and Taiwan, using three-dimensional fluorescence spectroscopy and multivariate PARAFAC model. Anthropogenic sourced and microbial-processed tyrosine- and tryptophan-like components were found with maximum intensities in 83.3% of samples, affirming the presence of frequent microbial activity in bottled drinking water. Bottled drinking water was in the medium to very high-risk category in 84% of samples because of *E. coli* abundance. Comparatively higher intensity of humic substances in one of the bottled drinking water brands in Vietnam than other brands posited the possibility of organometallic complex formation with As, thus causing peripheral vascular blackfoot disease. Discussed health impacts because of over acceptable-limit minerals such as Pb, Al, and PO_4^{3-} at Bangladeshi bottled drinking waters indicated that such unrestrained minerals concentration can cause biological organ and productive system damage, IQ loss, red blood cell production disruption, dementia and Alzheimer's disease, death, and economic loss individually or in complexation with DOM components. Unlike in Japan, DOM intensities in bottled drinking water were comparable and higher than those found in groundwater, freshwater, and marine water, thus confirming the inefficiency of conventional drinking water treatment techniques. The economic indicators of the studied countries inferred that besides budget and labor wages, willingness, proper knowledge of treatment techniques, and consciousness play significant roles in drinking water treatment. Such extensive pioneer and novel studies on DOM characterization and concentrations, microbial abundance, adverse health, and economic impacts of overlimit mineral contents in bottled drinking water will surely help relevant authorities and governments of the studied countries to become more concerned and secure proper steps to develop drinking treatment techniques and adequate monitoring, and ensure safe quality before consumption.

AUTHOR CONTRIBUTIONS

Nahin Mostofa Niloy: Writing – original draft, Methodology, Investigation, and Formal analysis. **Mashura Shammi:** Writing – review and editing, Methodology, and Investigation. **Shafi M. Tareq:** Writing – review and editing, Validation, Supervision, Software, Resources, Methodology, and Conceptualization.

ACKNOWLEDGMENTS

Open access publishing facilitated by Southern Cross University, as part of the Wiley - Southern Cross University agreement via the Council of Australian University Librarians.

CONFLICT OF INTEREST STATEMENT

None of the authors have a conflict of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Nahin Mostofa Niloy https://orcid.org/0000-0003-0254-7563

REFERENCES

Atlas Scientific. (2022). What Is The Typical Water Conductivity Range? https://atlas-scientific.com/blog/water-conductivity-range/

Ayeni, T. T., Iwamoto, Y., Takeda, K., Sakugawa, H., & Mostofa, K. M. G. (2022). Optical properties of dissolved organic matter in Japanese rivers and contributions to photoformation of reactive oxygen species. *Science of the Total Environment*, *826*, 153671. https://doi.org/10.1016/j.scitotenv.2022.153671

Baker, A., Cumberland, S. A., Bradley, C., Buckley, C., & Bridgeman, J. (2015). To what extent can portable fluorescence spectroscopy be used in the real-time assessment of microbial water quality? *Science of the Total Environment*, *532*, 14–19. https://doi.org/10.1016/j.scitotenv.2015.05.114

Bieroza, M. Z., Bridgeman, J., & Baker, A. (2010). Fluorescence spectroscopy as a tool for determination of organic matter removal efficiency at water treatment works. *Drinking Water Engineering and Science*, *3*(1), 63–70. https://doi.org/10.5194/dwes-3-63-2010

Bouhlel, Z., Köpke, J., Mina, M., & Smakhtin, V. (2023). *Global Bottled Water Industry: A Review of Impacts and Trends*. http://inweh.unu.edu/publications/

Bridgeman, J., Bieroza, M., & Baker, A. (2011). The application of fluorescence spectroscopy to organic matter characterisation in drinking water treatment. *Reviews in Environmental Science and Biotechnology*, *10*(3), 277–290. https://doi.org/10.1007/s11157-011-9243-x

Cangelosi, V., Ruckthong, L., & Pecoraro, V. L. (2017). Lead (II) binding in natural and artificial proteins. In *Lead: Its effects on environment and health* (Vol. 17) (pp. 271–317). Walter de Gruyter GmbH. https://doi.org/10.1515/9783110434330-010

Carstea, E. M., Bridgeman, J., Baker, A., & Reynolds, D. M. (2016). Fluorescence spectroscopy for wastewater monitoring: A review. In *Water research* (Vol. 95) (pp. 205–219). Elsevier Ltd. https://doi.org/10.1016/j.watres.2016.03.021

Chari, N. V. H. K., Rao, S., & Sarma, N. S. (2013). Fluorescent dissolved organic matter in the continental shelf waters of western Bay of Bengal. *Journal of Earth System Science*, *122*(5), 1325–1334. https://doi.org/10.1007/s12040-013-0349-0

Chen, S.-L., Dzeng, S. R., & Yang, M.-H. (1994). Arsenic species in groundwaters of the blackfoot disease area, Taiwan. *Environmental Science & Technology*, *28*, 877–881. https://pubs.acs.org/sharingguidelines, https://doi.org/10.1021/es00054a019

Chow, C. W. K., Van Leeuwen, J. A., Drikas, M., Fabris, R., Spark, K. M., & Page, D. W. (1999). The impact of the character of natural organic matter in conventional treatment with alum. *Water Science and Technology*, *40*(9), 97–104. https://doi.org/10.1016/S0273-1223(99)00645-9

Coble, P. G. (2007). Marine optical biogeochemistry: The chemistry of ocean color. *Chemical Reviews*, *107*(2), 402–418. https://doi.org/10.1021/cr050350+

Croft, J. (2012). *Natural organic matter characterization of different source and treated waters; implications for membrane fouling control*. University of Waterloo.

Croue, J.-P., Korshin, G. V., Leenheer, J., & Benjamin, M. (2000). Isolation, fractionation and characterization of natural organic matter in drinking water. https://www.researchgate.net/publication/238199485

Djam, S., Najafi, M., Ahmadi, S. H., & Shoeibi, S. (2020). Bottled water safety evaluations in IRAN: Determination of bromide and oxyhalides (chlorite, chlorate, bromate) by ion chromatography. *Journal of Environmental Health Science and Engineering*, *18*(2), 609–616. https://doi.org/10.1007/s40201-020-00486-9

Dubnick, A., Barker, J., Sharp, M., Wadham, J., Grzegorz, L., Telling, J., Fitzsimons, S., & Jackson, M. (2010). Characterization of dissolved organic matter (DOM) from glacial environments using total fluorescence spectroscopy and parallel factor analysis. *Annals of Glaciology*, *51*(56), 111–122. https://doi.org/10.3189/172756411795931912

Environmental Health. (2024). *Lead exposure in children and adults*. NSW Health. https://www.health.nsw.gov.au/environment/factsheets/Pages/lead-exposure-children.aspx

Felipe-Sotelo, M., Henshall-Bell, E. R., Evans, N. D. M., & Read, D. (2015). Comparison of the chemical composition of British and Continental European bottled waters by multivariate analysis. *Journal of Food Composition and Analysis*, *39*, 33–42. https://doi.org/10.1016/j.jfca.2014.10.014

Fellman, J. B., Spencer, R. G. M., Hernes, P. J., Edwards, R. T., D'Amore, D. V., & Hood, E. (2010). The impact of glacier runoff on the biodegradability and biochemical composition of terrigenous dissolved organic matter in near-shore marine ecosystems. *Marine Chemistry*, *121*(1–4), 112–122. https://doi.org/10.1016/j.marchem.2010.03.009

Fox, B. G., Thorn, R. M. S., Anesio, A. M., & Reynolds, D. M. (2017). The in situ bacterial production of fluorescent organic matter; an investigation at a species level. *Water Research*, *125*, 350–359. https://doi.org/10.1016/j.watres.2017.08.040

Fu, P., Mostofa, K. M. G., Wu, F., Liu, C.-Q., Li, W., Liao, H., Wang, L., Wang, J., & Mei, Y. (2010). Excitation-emission matrix characterization of dissolved organic matter sources in two eutrophic lakes (southwestern China plateau). *Geochemical Journal*, *44*, 99–112. https://doi.org/10.2343/geochemj.1.0047

Gerdes, M. E., Miko, S., Kunz, J. M., Hannapel, E. J., Hlavsa, M. C., Hughes, M. J., Stuckey, M. J., Francois Watkins, L. K., Cope, J. R., Yoder, J. S., Hill, V. R., & Collier, S. A. (2023). Estimating waterborne infectious disease burden by exposure route, United States, 2014. *Emerging Infectious Diseases*, *29*(7), 1357–1366. https://doi.org/10.3201/eid2907.230231

Guo, W., Yang, L., Yu, X., Zhai, W., & Hong, H. (2012). Photoproduction of dissolved inorganic carbon from dissolved organic matter in contrasting coastal waters in the southwestern Taiwan Strait, China. *Journal of Environmental Sciences (China)*, *24*(7), 1181–1188. https://doi.org/10.1016/S1001-0742(11)60921-2

Hseu, Y.-C., Chang, W.-C., & Yang, H.-L. (2001). Inhibition of human plasmin activity using humic acids with arsenic. *The Science of the Total Environment*, *273*, 93–99. https://doi.org/10.1016/S0048-9697(00)00846-9

Hudson, N., Baker, A., & Reynolds, D. (2007). Fluorescence analysis of dissolved organic matter in natural, waste and polluted waters—A review. *River Research and Applications*, *23*, 631–649. https://doi.org/10.1002/rra.1005

Krupińska, I. (2020). Aluminium drinking water treatment residuals and their toxic impact on human health. *Molecules*, *25*(3), 641. https://doi.org/10.3390/molecules25030641

Kumar, A., Ain, S., Ain, Q., Gupta, R., Rai, A., & Ikram. (2021). A comparative study of mineral contents of bottled water and tap water in the western Uttar Pradesh. *World Journal of Pharmacy and Pharmaceutical Sciences*, *10*(12), 418–428. https://doi.org/10.20959/wjpps202112-20520

Larsen, B., & Sánchez-Triana, E. (2023). Global health burden and cost of lead exposure in children and adults: A health impact and economic modelling analysis. *The Lancet Planetary Health*, *7*(10), e831–e840. https://doi.org/10.1016/S2542-5196(23)00166-3

Lawaetz, A. J., & Stedmon, C. A. (2009). Fluorescence intensity calibration using the Raman scatter peak of water. *Applied Spectroscopy*, *63*(8), 936–940. https://doi.org/10.1366/000370209788964548

Leenheer, J., & Croue, J.-P. (2003). Characterizing dissolved aquatic organic matter. *Environmental Science & Technology*, *37*, 19A–26A. https://pubs.acs.org/sharingguidelines, https://doi.org/10.1021/es032333c

Levallois, P., Barn, P., Valcke, M., Gauvin, D., & Kosatsky, T. (2018). Public health consequences of lead in drinking water. In *Current environmental health reports* (Vol. 5, Issue 2) (pp. 255–262). Springer. https://doi.org/10.1007/s40572-018-0193-0

Li, X. F., & Mitch, W. A. (2018). Drinking water disinfection byproducts (DBPs) and human health effects: Multidisciplinary challenges and opportunities. *Environmental Science and Technology*, *52*(4), 1681–1689. https://doi.org/10.1021/acs.est.7b05440

Lin, H., Cai, Y., Sun, X., Chen, G., Huang, B., Cheng, H., & Chen, M. (2016). Sources and mixing behavior of chromophoric dissolved organic matter in the Taiwan Strait. *Marine Chemistry*, *187*, 43–56. https://doi.org/10.1016/j.marchem.2016.11.001

Lu, F. (1990a). Fluorescent humic substances and blackfoot disease in Taiwan. *Applied Organometallic Chemistry*, *4*(3), 191–195. https://doi.org/10.1002/aoc.590040304

Lu, F. J. (1990b). Blackfoot disease: Arsenic or humic acid? *The Lancet*, *336*, 115–116. https://doi.org/10.1016/0140-6736(90)91629-O

Mata, A. T., Ferreira, J. P., Oliveira, B. R., Batoréu, M. C., Barreto Crespo, M. T., Pereira, V. J., & Bronze, M. R. (2015). Bottled water: Analysis of mycotoxins by LC-MS/MS. *Food Chemistry*, *176*, 455–464. https://doi.org/10.1016/j.foodchem.2014.12.088

Matilainen, A., Gjessing, E. T., Lahtinen, T., Hed, L., Bhatnagar, A., & Sillanpää, M. (2011). An overview of the methods used in the characterisation of natural organic matter (NOM) in relation to drinking water treatment. *Chemosphere*, *83*(11), 1431–1442. https://doi.org/10.1016/j.chemosphere.2011.01.018

Mostofa, K. M. G., Honda, Y., & Sakugawa, H. (2005). Dynamics and optical nature of fluorescent dissolved organic matter in river waters in Hiroshima Prefecture, Japan. *Geochemical Journal*, *39*(3), 257–271. https://doi.org/10.2343/geochemj.39.257

Mulvihill, K. (2023). Causes and Effects of Lead in Water. https://www.nrdc.org/stories/causes-and-effects-lead-water

Niloy, N. M., Haque, M., & Tareq, S. M. (2021). Characteristics, sources, and seasonal variability of dissolved organic matter

(DOM) in the Ganges. *Environmental Processes*, *8*, 1–13. https://doi.org/10.1007/s40710-021-00499-y

Niloy, N. M., Shammi, M., Haque, M. M., & Tareq, S. M. (2022). Investigating dissolved organic matter dynamics in the downstream reaches of the Ganges and Brahmaputra Rivers using fluorescence spectroscopy. *Frontiers in Earth Science*, *10*, 1–14. https://doi.org/10.3389/feart.2022.821050

Nowicki, S., Lapworth, D. J., Ward, J. S. T., Thomson, P., & Charles, K. (2019). Tryptophan-like fluorescence as a measure of microbial contamination risk in groundwater. *Science of the Total Environment*, *646*, 782–791. https://doi.org/10.1016/j.scitotenv.2018.07.274

Otero, P., Saha, S. K., Moane, S., Barron, J., Clancy, G., & Murray, P. (2015). Improved method for rapid detection of phthalates in bottled water by gas chromatography-mass spectrometry. *Journal of Chromatography B: Analytical Technologies in the Biomedical and Life Sciences*, *997*, 229–235. https://doi.org/10.1016/j.jchromb.2015.05.036

Que, V. N. X., Van Tuan, D., Huy, N. N., & Phu, V. L. (2021). Design and performance of small-scale reverse osmosis desalination for brackish water powered by photovoltaic units: A review. *IOP Conference Series: Earth and Environmental Science*, *652*(1), 012024. https://doi.org/10.1088/1755-1315/652/1/012024

Rahman, I. M. M., Barua, S., Barua, R., Mutsuddi, R., Alamgir, M., Islam, F., Begum, Z. A., & Hasegawa, H. (2017). Quality assessment of the non-carbonated bottled drinking water marketed in Bangladesh and comparison with tap water. *Food Control*, *73*, 1149–1158. https://doi.org/10.1016/j.foodcont.2016.10.032

Rahman, M. A., Salam, M. A., Salam, A., Roy, M., Ara, N. J., & Alam, A. S. (2013). Mineral content of different bottled water available in Bangladesh: Assessment of their compliance with current regulations. *Journal of the Asiatic Society of Bangladesh, Science*, *38*(1), 7–15. https://doi.org/10.3329/jasbs.v38i1.15316

Ritchie, H., Spooner, F., & Roser, M. (2019). Clean Water. https://ourworldindata.org/clean-water#article-citation

Rondeau, V., Commenges, D., Jacqmin-Gadda, H., & Dartigues, J.-F. (2000). Relation between aluminum concentrations in drinking water and Alzheimer's disease: An 8-year follow-up study. In. *American Journal of Epidemiology*, *152*(1), 59–66.https://doi.org/10.1093/aje/152.1.59

Santín, C., Yamashita, Y., Otero, X. L., Álvarez, M. Á., & Jaffé, R. (2009). Characterizing humic substances from estuarine soils and sediments by excitation-emission matrix spectroscopy and parallel factor analysis. *Biogeochemistry*, *96*, 131–147. https://doi.org/10.1007/s10533-009-9349-1

Sarah. (2023). *Bangladesh: New studies reveal alarming findings on lead pollution, need for urgent multi-sectoral actions*. https://www.pureearth.org/bangladesh-new-studies-reveal-alarming-findings-on-lead-pollution-need-for-urgent-multi-sectoral-actions/

Schittich, A. R., Wünsch, U. J., Kulkarni, H. V., Battistel, M., Bregnhøj, H., Stedmon, C. A., & McKnight, U. S. (2018). Investigating fluorescent organic-matter composition as a key predictor for arsenic mobility in groundwater aquifers. *Environmental Science and Technology*, *52*(22), 13027–13036. https://doi.org/10.1021/acs.est.8b04070

Shammi, M., Rahman, M. M., Ali, M. I., Khan, A. S. M., Siddique, M. A. B., Ashadudzaman, M., Bodrud-Doza, M., Alam, G. M. M., & Tareq, S. M. (2022). Application of short and rapid strategic environmental assessment (SEA) for biomedical waste management in Bangladesh. *Case Studies in Chemical and Environmental Engineering*, *5*, 100177.

Soh, Y. C., Roddick, F., & Van Leeuwen, J. (2008). The impact of alum coagulation on the character, biodegradability and disinfection by-product formation potential of reservoir natural organic matter (NOM) fractions. *Water Science and Technology*, *58*(6), 1173–1179. https://doi.org/10.2166/wst.2008.475

Sosnowski, S. (2023). Aluminum in Drinking Water-Everything You Need to Know. https://mytapscore.com/blogs/tips-for-taps/aluminium-in-drinking-water-everything-you-need-to-know

Stedmon, C. A., & Bro, R. (2008). Characterizing dissolved organic matter fluorescence with parallel factor analysis: A tutorial. *Limnology and Oceanography: Methods*, *6*(11), 572–579. https://doi.org/10.4319/lom.2008.6.572

Stedmon, C. A., & Markager, S. (2005). Tracing the production and degradation of autochthonous fractions of dissolved organic matter by fluorescence analysis. *Limnology and Oceanography*, *50*(5), 1415–1426. https://doi.org/10.4319/lo.2005.50.5.1415

Sururi, M. R., Dirgawati, M., Roosmini, D., & Notodarmodjo, S. (2021). Characterization of fluorescent dissolved organic matter in an affected pollution raw water source using an excitation-emission matrix and parafac. *Environment and Natural Resources Journal*, *19*(6), 459–467. https://doi.org/10.32526/ennrj/19/2021008

Tareq, S. M., Maruo, M., & Ohta, K. (2013). Characteristics and role of groundwater dissolved organic matter on arsenic mobilization and poisoning in Bangladesh. *Physics and Chemistry of the Earth*, *58–60*, 77–84. https://doi.org/10.1016/j.pce.2013.04.014

Wang, W., Yang, H., Wang, X., Jiang, J., & Zhu, W. (2010). Effects of fulvic acid and humic acid on aluminum speciation in drinking water. *Journal of Environmental Sciences*, *22*(2), 211–217. https://doi.org/10.1016/S1001-0742(09)60095-4

WHO. (2003). *Aluminium in Drinking-water: Background document for development of WHO Guidelines for Drinking-water Quality*.

WHO. (2017). *Guidelines for Drinking-water Quality*.

WHO. (2022). *Guidelines for drinking-water quality: Fourth edition incorporating the first and second addenda*.

Wilson, G. J. L., Lu, C., Lapworth, D. J., Kumar, A., Ghosh, A., Niasar, V. J., Krause, S., Polya, D. A., Gooddy, D. C., & Richards, L. A. (2023). Spatial and seasonal controls on dissolved organic matter composition in shallow aquifers under the rapidly developing city of Patna, India. *Science of the Total Environment*, *903*, 166208. https://doi.org/10.1016/j.scitotenv.2023.166208

Wisewell. (2022). *Which water temperature is best for drinking?* https://www.wisewell.com/blogs/news/which-water-temperature-is-best-for-drinking

Yang, L., Hong, H., Chen, C. T. A., Guo, W., & Huang, T. H. (2013). Chromophoric dissolved organic matter in the estuaries of populated and mountainous Taiwan. *Marine Chemistry*, *157*, 12–23. https://doi.org/10.1016/j.marchem.2013.07.002

Yang, L., Hong, H., Guo, W., Huang, J., Li, Q., & Yu, X. (2012). Effects of changing land use on dissolved organic matter in a subtropical river watershed, Southeast China. *Regional Environmental Change*, *12*(1), 145–151. https://doi.org/10.1007/s10113-011-0250-9

Ye, Q., Zhang, Z. T., Liu, Y. C., Wang, Y. H., Zhang, S., He, C., Shi, Q., Zeng, H. X., & Wang, J. J. (2019). Spectroscopic and molecular-level characteristics of dissolved organic matter in a highly polluted urban river in South China. *ACS Earth and Space Chemistry*, *3*(9), 2033–2044. https://doi.org/10.1021/acsearthspacechem.9b00151

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Niloy, N. M., Shammi, M., & Tareq, S. M. (2025). Fluorescence characteristics of dissolved organic matter (DOM) in bottled drinking water of different countries: A potential risk to public health. *Water Environment Research*, *97*(4), e70064. https://doi.org/10.1002/wer.70064