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Faecal contamination and its relationship with some environmental variables of four urban rivers in inner Hanoi city, Vietnam

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ABSTRACT

Coliform bacteria are essential variables for assessing riverine water quality. In this study, the faecal indicator bacteria (FIB) in relationship with some physico-chemical variables were investigated during the period 2020-2022 for four urban rivers (To Lich, Lu, Set, and Kim Nguu) in the inner Hanoi city to provide the updated water quality of these rivers. The results demonstrated severe faecal coliforms contamination in riverine waters compared to the permissible values of the Vietnam technical regulation for surface water quality, QCVN08-MT:2015/BTNMT column B1. Nutrients (ammonium and phosphate) concentrations and dissolved oxygen (DO) values exceeded the permissible values, whereas pH was within the standard. The Pearson analysis demonstrated the significant positive correlation between total coliforms (TC) and *Escherichia coli* (EC) densities and ammonium concentration in the riverine water. Besides, these variables were higher in the dry season than the rainy one for all sites observed. All these reflect the critical role of the point sources, notably domestic wastewater inputs in the four river basins. Considering these rivers' deteriorating condition, developing an effective wastewater treatment system is necessary for the rivers in Hanoi.

Keywords: Total coliforms, faecal coliforms, Hanoi city, water quality, point sources, wastewater.

1. Introduction

Rivers in urban areas play vital roles, including water supply for multiple purposes, rainwater storage, flood prevention, and habitats for plants and animals. However, numerous studies have demonstrated that rivers, whether situated in or flowing through urban areas, are subjected to a higher degree of faecal coliforms contamination (Goto et al., 2011; Paule-Mercado et al., 2016; Nguyen et al., 2016a; Kubera, 2021). As faecal pollution may introduce various pathogens, the degradation of rivers represents an increased infection risk for humans (Arnold et al., 2017; Kauppinen et al., 2017). Thus, assessing the level of faecal bacteria pollution and

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understanding how faecal bacteria enter urban rivers are vital for effective remediation implementation by water management authorities (Walker et al., 2015; Tillett et al., 2018).

Numerous studies on faecal coliforms contamination were carried out to assess the water quality of different rivers across the world, such as in Asia (e.g. the Cagayan de Oro, Philippines (Lubos et al., 2013), the Kok and Kham rivers, Thailand (Chotinantakul et al., 2022), the Larut River, Malaysia (Bong et al., 2022)); in Africa: the Crocodile river, Mozambique (Maphanga et al., 2022), the Mohale river, Lesotho (Gwimbi et al., 2019); in America: the Mad and the Great Miami rivers, United State (MDC, 2018), the Bogotá River, Colombia (Castro Fernández et al., 2022); and in Europe: the Seine river (Servais et al., 2007b), the Enan and Handölan rivers, Sweden (Maes et al., 2022)… Besides, faecal coliforms density and its relationship with environmental factors have been paid attention for better modelling development to predict microbial contamination in the hydro-system (Servais et al., 2007 a, b; Nguyen et al., 2016b).

In Vietnam, total coliforms (TC) and *Escherichia coli* (*E. coli,* or EC) have been observed in some rivers in different locations. For example, they were investigated for the large Red River (Nguyen et al., 2014; Nguyen et al., 2016a) and its coastal zone (Le et al., 2023), or some urban rivers from the North to the South (e.g., in Bac Kan (Bac Kan CRET., 2022), Hai Phong city (Hai Phong DONRE., 2021), Ho Chi Minh city (Hochiminh DONRE., 2021), Tien Giang and Long An provinces (Tien Giang DONRE., 2020; Long An DONRE., 2020; Tran et al., 2021), and Dong Thap province (Le et al., 2020).

Hanoi city is the capital of Vietnam, where human activities significantly impact the water quality of rivers and lakes. The four main rivers in inner Hanoi, including the To Lich, Lu, Set, and Kim Nguu, have been highly polluted due to receiving sizeable amounts of untreated wastewater (Duong et al., 2022). Many researchers have studied the different variables of the riverine water quality, such as heavy metals (Thuong et al., 2013) or organic substances (Le et al., 2021; Do et al., 2023). However, there are few reports on microbial contamination of these main rivers in Hanoi, except for the earlier studies providing the monitoring data before 2016 (Luong et al., 2016).

This study presents the updated assessment of faecal coliforms contamination in the surface water of four rivers in inner Hanoi city during 2020-2022. The results may provide a scientific basis for better protection and management of urban river systems in a large city in South Asia like Hanoi.

2. Sites studied and methodology

2.1. Sites studied

The water quality of four urban rivers (To Lich, Lu, Set, and Kim Nguu) in inner Hanoi city was investigated in this study. The To Lich, Lu, Set and Kim Nguu lengths are about 14.8, 12.2, 5.8, and 6.7 km, respectively. Their mean water depths were from 1-4 m, whereas their highest water discharges were 30, 15, 6, and 8 $m^3.s^{-1}$, respectively. These four rivers are located in 12 districts of the inner Hanoi centre where very high population density (mean value: 12,069 inhabitants.km^{-2}) was reported (Hanoi-GSO 2022). In Hanoi city (total surface area of 3,360 km^2), the climate is divided into the rainy/wet season (from May to October) and the dry one (from November to next April). Rainfall in the wet season was higher than that of the dry one. Air temperature varied from 16.9 to 31.7°C, averaging 25.3°C during 2020-2021 (Hanoi-GSO 2021; 2022). Some essential characteristics of the four rivers are presented in Table 1.

Table 1. Sampling sites of four rivers studied and their basin characteristics (Hanoi-GSO, 2021; Luong et al., 2016)

River name	Sampling sites	Basin area, km^2	Population density*, 10^3 $Inhab.km^{-2}$	Agricultural land* (ha)	Livestock numbers*	
					Poultry (head)	Cattle (head)
To Lich	TL1: 21°02'45.5"N; 105°48'19.0"E TL2: 20°57'47.2"N; 105°49'04.6"E	68.2	12.1	< 5000	< 500	< 8000
Lu	L1: 21°00'25.3"N; 105°49'56.1"E L2: 20°58'24.5"N; 105°49'42.3"E	5.6	10.5	< 2000	< 500	< 3000
Set	S1: 20°59'35.8"N; 105°50'35.4"E S2:20°58'27.9"N; 105°51'03.3"E	5.8	16.5	–	–	–
Kim Nguu	KN1: 21°00'11.2"N; 105°51'41.4"E KN2: 20°58'57.1"N; 105°51'49.5"E	18	9.8	< 2000	< 500	< 800

*: relative estimations basing on data by different districts belonging to river basins in Hanoi city

Surface water samples (0-30 cm) were taken at the upstream (TL1, L1, S1, and KN1) and the downstream (TL2, L2, S2 and KN2) sites of each river (the To Lich, the Lu, the Set and the Kim Nguu, respectively) (Fig. 1) during 6 sampling campaigns including the dry (Feb., Mar. 2020 and Apr. 2022) and the rainy (Sept. and Oct. 2020 and Jun. 2022) seasons. Water samples were then stored by the Vietnamese standard TCVN-6663-3:2008 (ISO-5667-3:2003). Some physico-chemical variables, including pH, water temperature, dissolved oxygen (DO), total dissolved solids (TDS), and conductivity, were measured with a water quality checker (TOA, Japan) in the field.

Figure 1. Sampling sites of four rivers in Hanoi city

2.2. Laboratory analysis

The direct count method using 3M Petrifilm™ *E.coli*/Coliform Count Plate was used to determine TC and EC densities on the unfiltered water samples (APHA, 2012; Harmon, 2014). The details for TC and EC analysis were introduced in the previous studies (Nguyen et al., 2016a; Le et al., 2023). All samples were triplicate analysed, and the mean values were presented here (CFU.100 mL^{-1}).

Dissolved nutrients (NH_4^+, and PO_4^{3-}) were spectrophotometrically analysed on filtered water samples by spectrophotometry (Jasco V630, Japan) methods (APHA, 2017). Total suspended solids (TSS) and particulate organic carbon (POC) were determined on filter papers (Whatman GF/F, pore size: 0.7 µm) after being dried at 105°C for 1 hour and then 550°C for 4 hours (Servais et al., 1995).

2.3. Statistical analysis

The seasonal (rainy *vs.* dry) and spatial (upstream *vs.* downstream) differences of all variables (pH, DO, water temperature, conductivity, TDS, TC, EC, TSS, POC, and nutrients (NH_4^+, PO_4^{3-})) in water samples were tested by using student-t-tests. The probabilities (p) < 0.05, were considered significant.

The relationship between TC and EC densities with the values of different water quality variables was calculated by the Statistical software XLSTAT (XLSTAT Addinsoft, 2019), expressed by the Pearson correlation coefficients. Besides, the relationships among 11 water quality variables were also checked using Principal Component Analysis (PCA).

3. Results and discussions

3.1. Results of water quality of four urban rivers

3.1.1. TC and EC densities

TC density in water of the four rivers varied from 16×10^4 to 312×10^4 CFU.100mL^{-1}, averaging 89.5×10^4 CFU.100mL^{-1}, which far exceeded the allowed value of the Vietnam technical regulation for surface water quality QCVN-08-MT:2015/BTNMT column B1 (7.500 CFU.100mL^{-1}) from 21 to 416 times (Table 2). Similarly, EC density fluctuated from 4×10^4 to 240×10^4 CFU.100mL^{-1}, averaging 58.9×10^4 CFU.100mL^{-1}, much higher than the allowed value from 400 to 24,000 times (Table 2).

Table 2. TC and EC densities (mean (min-max) values) in surface water of four rivers in inner Hanoi city

River name	Site name	TC 10^4 CFU.100mL^{-1}	EC 10^4 CFU.100mL^{-1}
To Lich	TL1	81(69–102)	53(28.5–81.5)
	TL2	87(60.5–117)	63(36–88)
Lu	L1	120(65.5–285.5)	72(16.5–168)
	L2	126(53–312)	88(14–240)
Set	S1	99(46.5–186.5)	55(24–96)
	S2	81(58–106.5)	57(23–93)
Kim Nguu	KN1	92(39–212.5)	69(29–144.5)
	KN2	32(16–48.5)	14(4–28.5)
All four rivers	**All sites**	**89.5(16–312)**	**58.9(4–240)**
QCVN 08-MT:2015/BTNMT column B1*		***7500***	***100***

*: Values are in CFU.100mL^{-1} for TC and EC in QCVN-08-MT:2015/BTNMT column B1 whereas all observation values are in 10^4 CFU.100mL^{-1}

Within four rivers, TC and EC values of the Lu River were the highest, whereas the Kim Nguu had the lowest values. Higher TC and EC values were observed for all sites in the dry season (p<0.05) (Fig. 2). No evident spatial variation of TC and EC from the upstream to the downstream was detected in this study (Fig. 2).

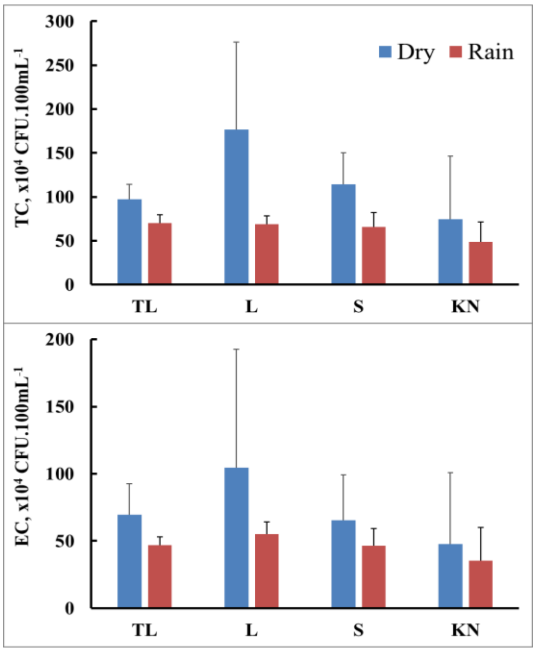

Figure 2. Seasonal variations of TC and EC densities of four Hanoi rivers

3.1.2. Other variables

The mean concentrations of other water quality variables, including water temperature, pH, conductivity, TDS, DO, NH_4^+, PO_4^{3-}, TSS, and POC of the four rivers were presented in Fig. 3. The values of these variables were as follows: pH values fluctuated from 5.6 to 8.3, averaging 7.4±0.9; water temperature: 20.1–30.8, (26.6±3.0)°C; conductivity: 0.5–1.2, (0.9±0.2) $mS.cm^{-1}$; TDS: 0.3–0.8, (0.6±0.1) $g.L^{-1}$; DO: 0.6–6.7, (2.7±1.8) $mg.L^{-1}$; NH_4^+ : 4.2–19.5, (10.3±3.9) $mgN.L^{-1}$; PO_4^{3-}: 0.2–4.3, (1.5±0.7) $mgP.L^{-1}$, TSS: 14.3–138.4, (35.0±24.0) $mg.L^{-1}$, and POC : 1.2–6.0, (3.4±1.0) $mgC.L^{-1}$.

Compared with the values proposed by the Vietnam technical regulation QCVN-08-MT:2015/BTNMT, the average pH value was within the permissible value. In contrast, three variables (DO, NH_4^+, and PO_4^{3-}) have their average values exceeding the allowable ones (1.5, 11.4, and 5 times, respectively) (Fig. 3). Seasonal variations were found for some variables such as pH, DO, TDS, conductivity, and NH_4^+ ($p < 0.05$) (Fig. 4). However, no evident spatial variation of different variables was detected in this study ($p > 0.05$).

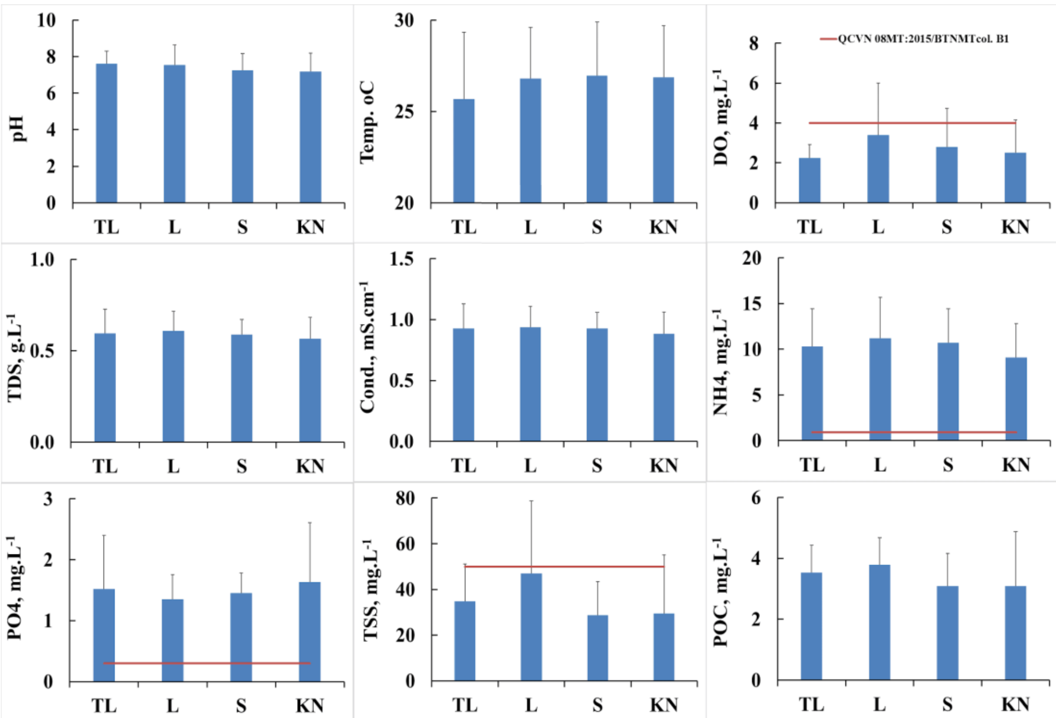

Figure 3. Mean values of some physical chemical variables of surface water of four Hanoi rivers

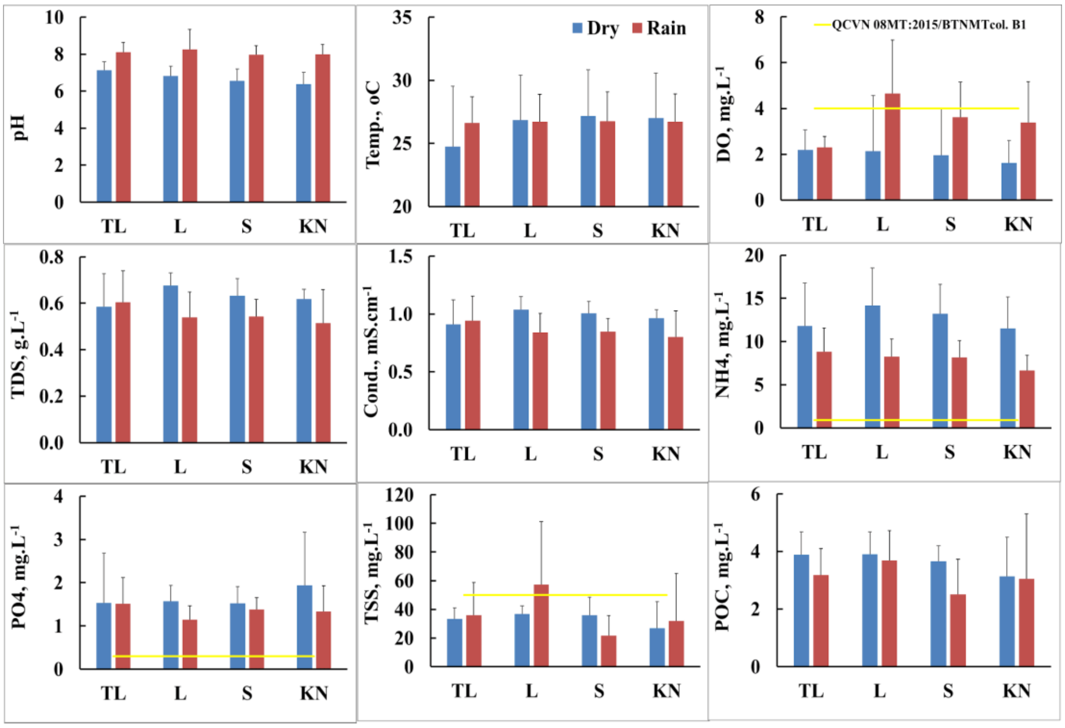

Figure 4. Seasonal variations of some physical chemical variables in surface water of four Hanoi rivers

3.1.3. Statistical results

The Principal Component Analysis (PCA) indicated that the first two axes occupied for 49.73% of the variance, and the two distinct circumstances were seen. The dry season was characterised by the variables such as PO_4^{3-}, POC, NH_4^+, EC, and TC, located on the right side of PCA (black ellipse), whereas the rainy season by pH and DO, located on the left side (red ellipse) (Fig. 5). In parallel, the results from the Pearson correlation analysis of 11 water quality variables demonstrated that TC and EC were positively correlated with NH_4^+ concentrations (R^2>0.7), whereas they showed a negative correlation with DO (R^2 ~ 0.34) (Table 3).

Table 3. Pearson's correlation between different water quality variables of Hanoi urban rivers

	pH	Temperature	DO	TDS	Conductivity	NH_4^+	PO_4^{3-}	TC	EC	POC	TSS
pH	1										
Temperature	0.016	1									
DO	**0.495****	-0.054	1								
TDS	-0.255	-0.059	-0.168	1							
Conductivity	-0.263	-0.066	-0.178	**0.982****	1						
NH_4^+	**-0.356***	-0.181	**-0.461****	**0.523****	**0.513****	1					
PO_4^{3-}	0.001	**0.441****	-0.282	**0.431****	**0.410****	**0.406****	1				
TC	**-0.393****	-0.260	**-0.338***	0.253	0.241	**0.710****	0.040	1			
EC	-0.258	-0.213	**-0.358***	0.140	0.134	**0.712****	0.112	**0.917****	1		
POC	-0.255	0.119	-0.197	**0.336***	**0.344***	0.252	0.238	**0.351***	**0.375****	1	
TSS	0.160	-0.056	0.100	0.171	0.180	0.069	0.080	0.164	0.190	**0.731****	1

Values in bold are different from 0 with a significance level alpha = 0.05

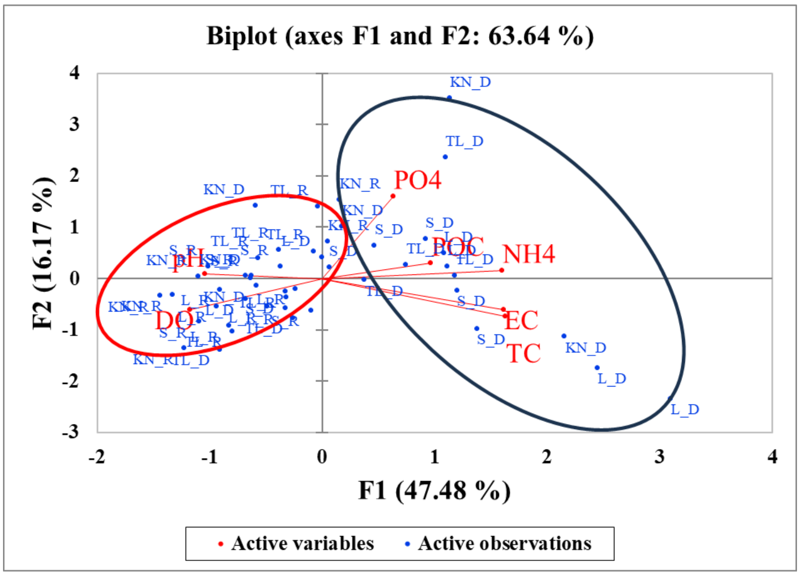

Figure 5. PCA results of 11 different water quality variables of four Hanoi rivers

3.1.4. Comparison with coliform densities of other rivers in the world

TC (89.5×10^{4} CFU.100mL^{-1}) and EC (58.9×10^{4} CFU.100mL^{-1}) in this study were higher than the observed values for the rivers in Hanoi in 2015 by Luong et al. (2016). Still, they closed with some rivers and canals in inner Hochiminh city, Vietnam (TC: 12×10^{3}–98×10^{4}, averaged $20.9\times10^{4}\pm31.5\times10^{4}$ CFU.100mL^{-1}) (Hochiminh DONRE, 2021), or the 19 surface water sampling points in Soc Trang province, Vietnam (TC: 1.5×10^{2}-5.1×10^{5} CFU.100mL^{-1}) (Soc Trang DONRE, 2021) or some other rivers in the World (e.g. the Larut River, Malaysia: TC: 1.0×10^{5}–4.7×10^{5}, EC: 1.0×10^{5}–4.1×10^{5} (Bong et al., 2022)) where wastewater strongly affected riverine water quality (Table 4).

The coliform densities in the rivers in Hanoi city were still far lower than some values reported for the Dhaleshwari River, Bangladesh (TC: 11.05×10^{8}–19×10^{23}, EC: 5×10^{5}-6×10^{13}) (Real et al., 2017), or the downstream of the Yamuna River, India (TC: 27×10^{5} CFU.100mL^{-1} and EC: 11×10^{5} CFU.100mL^{-1}) (Bhardwaj, 2005), where the rivers received untreated wastewater and poor quality of wastewater discharged from treatment plants, leading to be severely polluted river. Similarly, in another case, a long-term survey for the Bogotá River, Colombia, showed that very high coliform densities (TC: $6.7\times10^{9}\pm25.8\times10^{9}$; EC: $12.5\times10^{6}\pm17.8\times10^{6}$ CFU.100mL^{-1}) were impacted by the various activities including unregulated discharges of domestic, industrial, and commercial wastewater discharges (Castro Fernández et al., 2022) (Table 4).

These values of four Hanoi rivers, however, were much higher in comparison with the large rivers, for example, the Red River, Vietnam (TC:23-13,000, averaged 1,765 MPN.100mL^{-1}; EC:0-1,600, averaged 191 MPN.100mL^{-1}) (Nguyen et al., 2014) or the Crocodile River, Mozambique (Maphanga et al., 2022) where high riverine discharge and turbidity affected the bacteria growth. The values found in this study far exceeded the ones of streams (Bac Kan CRET., 2022) or mountainous rivers (e.g. the Enan and Handölan rivers, Sweden (Maes et al., 2022)) where human activities were much less than in populated urban areas (Table 4).

Table 4. TC and EC densities in some rivers in the world

River	Sampling time	TC CFU.100mL^{-1} (or MPN.100mL^{-1}) min-max (mean±SD)	EC CFU.100mL^{-1} (or MPN.100mL^{-1}) min-max (mean±SD	References
To Lich, Set, Lu rivers, Hanoi city, Vietnam	Apr. 2016	36,000–93,000 (50,667±20,661)	120–260 (224±69)	Luong et at., 2016
La Buong river, Dong Nai province, Vietnam	2010–2017	Dry season: 11,497±14,534 Rainy season: 14,485±11,468	Dry season: 1,623±2,491 Rainy season: 1,943±2,137	Tran et al., 2021
16 sites of rivers and canals, Ho Chi Minh city, Vietnam	2021	12,000–980,000 (209,000±315,000)	–	Hochiminh DONRE, 2021
Tien Giang river, Dong Thap province, Vietnam	2016–2018 2015–2019	3,286–254,333 nd–11,000	448–178,333	Le et al., 2020 Tien Giang DONRE, 2020
Rivers/canals, Tien Giang province, Vietnam	2015–2019	20–46,000	–	Tien Giang DONRE, 2020
Rivers and cannals, Long An province, Vietnam	2016–2020	0–30,269	–	Long An DONRE, 2020
39 sites of rivers, Bac Kan province, Vietnam	2022	860–5,000	–	Bac Kan CRET, 2022
19 sites in Soc Trang province, Vietnam	2021	1.5×10^2–5.1×10^5	–	Soc Trang DONRE, 2021
20 sites of streams/canals, Ha Giang province, Vietnam	2022	12–5,800	–	Ha Giang DONRE, 2022
Urban rivers, Hai Phong city, Vietnam	2021	200–94,000	11–170	Hai Phong DONRE, 2021
Kok and Kham rivers, Thailand	2021–2022	Kok: 14.78×10^3–109×10^3 Kham: 6.56×10^3–37.33×10^3	–	Chotinantakul et al., 2022
Dhaleshwari river, Bangladesh	2015	11.05×10^{10}–19×10^{25}	5×10^7–6×10^{15}	Real et al., 2017
Rupsha and Bhairab rivers Khulna city, Bangladesh	2018	-	2.3×10^3–5.4×10^4	Islam et al., 2022
Crocodile River, Mozambique	2016–2021	-	45-72	Maphanga et al., 2022
Mohale river, Lesotho Highlands	May 2018	-	Protected spring: <30-4.2×10^3 Unprotected spring: 4.5×10^3–4.35×10^7 Stream: 1.15×10^4–1.18×10^4	Gwimbi et al., 2019
Mad and Great Miami rivers, United State	May-Oct. 2018	-	20–24,196 10–24,200	MDC, 2018
Bogotá River, Colombia	2019	2.4×10^3–1.0×10^{11}	1.0×10^2–5.5×10^7	Castro Fernández et al., 2022
Enan and Handölan rivers, Sweden	2020	Enan river: 0–70 Handölan river: 0–470	Enan river: 0–56 Handölan river: 0–79	Maes et al., 2022

3.2. Discussions

3.2.1. Sources and controls of microbial contamination in Hanoi urban rivers

Previous studies demonstrated that TC and EC densities in riverine water were directly affected by different human activities, including the point sources (e.g. domestic and industrial wastewater) and diffuse sources (e.g. leaching from agricultural land, grazing land, or atmospheric deposition) as well as environmental factors such as temperature, pH, nutrient concentrations, turbidity, salinity, climatic and hydrological regimes (Servais et al., 2007 a, b; Ouattara et al., 2011; Sunagawa et al., 2015; Vasemägi et al., 2017; Weller et al., 2021; Kodera et al., 2023).

The whole of Hanoi city had a total population of 8.25×10^6 in 2020 and 8.33×10^6 inhabitants in 2021 (Hanoi-GSO, 2021; 2022). These four rivers are in 12 districts of the inner Hanoi centre, where the mean population density was 12,069 inhabitants.km^{-2} (Hanoi-GSO, 2022). Domestic wastewater in the whole city was estimated at 1.2×10^6 m^3.day^{-1} of which about 79.4% was untreated (MONRE, 2019). The four observed rivers in this study are considered the city's common drainage canals and have not received water from the headwaters. Our monitoring results in 2020-2022 revealed higher values of TC and EC densities in the dry season for all four urban rivers (Fig. 2). This agrees with the previous observation that higher water quality pollution in inner-Hanoi-city rivers in the dry seasons was found (Nguyen et al., 2018). That may reflect the significant influence of point sources, notably domestic wastewater, for these rivers, especially in the dry season. In the rainy season, in addition to the impact of local domestic wastewater, river water may be smoothly affected by leaching and erosion from agricultural land and livestock grazing. Still, due to the dilution by rainwater, coliform densities in the water of the four rivers decreased (Fig. 2). Hanoi city covered a surface area of 3,360 km^2, of which agricultural production land was 58.9% in 2021 (GSO-Hanoi, 2022). However, agricultural land is located in the suburban of Hanoi centre, and the livestock numbers were small (Table 1). Moreover, Servais et al. (2007a, b) suggested that EC pollution due to the point source was hundreds of times higher than the diffuse sources, even when the wastewater of the entire population in the basin was treated. Thus, our study emphasised that microbial pollution of river water in inner Hanoi city was caused by domestic wastewater, especially in the dry season.

Nutrient markers such as ammonium have also been utilised to identify faecal contamination incidences (Cabral et al., 2006; Mallin et al., 2012). In natural waters, NH_4^+ concentrations are usually low because microorganisms (autotrophic algae, heterotrophic bacteria, and autotrophic nitrifying bacteria) use it very rapidly (Andersson et al., 2006; Spataru, 2022). High ammonia concentrations in water usually indicate domestic wastewater pollution. In addition, a previous study revealed that NH_4^+ could be used in combination with FIB to aid the identification of the biological source of faecal contamination, and it also potentially presents a more efficient alternate approach to faecal pollution monitoring (Lim et al., 2017). In our study, higher values of NH_4^+ concentrations and coliform densities were found in the dry season, and their significant positive correlation may reflect the same pollution source. In more detail, high NH_4^+ levels indicated human faecal pollution in urban rivers in Hanoi city. Our results were similar to those found in other river systems, such as the Dublin urban stream, Ireland (Reynolds et al., 2021) or the adjacent waters of Rushan bay, China (He et al., 2018).

DO is also an environmental factor related to FIB development. The observations made by Baez and Shiloach (2017) proved that a high level of DO in river water can reduce EC growth and accelerate higher removal rates of coliform bacteria. In contrast, an increased FIB can lead to a rise in oxygen demand and, subsequently, a decline in DO concentration in water, as observed in the case of the Geum-Hak stream in South Korea (Paule-Mercado et al., 2016). Besides, other studies demonstrated that an increase in organic matters accelerated microbes and their metabolism and thus decreased DO concentrations in water as found for the cases of the U.S. rivers (Mulholland et al., 2005), or the Pearl Estuary, China (Liu et al., 2015). Indeed, excessive inputs of fermentable organic matters were observed with the increased faecal bacteria and decreased DO during their decomposition process in the Bukavu urban rivers, Democratic Republic of Congo (Bisimwa et al., 2022). In our study, in the dry season, lower DO levels, higher FIB numbers, and nutrient and POC concentrations in the Hanoi rivers (Figs. 2, 4) demonstrate the significant inputs of domestic wastewater, which lead to oxygen depletion due to the decomposition of organic matters.

Previous studies have reported that water temperature is vital in bacterial metabolism (Martiny et al., 2016) and significantly correlates with bacteria in the world's urban rivers (Abia et al., 2015; Bisimwa et al., 2022). The favorable water temperature for FIB growth is 17.9–26.1°C (Larif et al., 2013; Bisimwa et al., 2022). For example, Paule-Mercado et al. (2016) reported that warm temperature significantly correlated with FIB growth in the Geum-Hak stream in South Korea. Similar results were also reported for other rivers, e.g., the Bukavu River, Democratic Republic of Congo (Bisimwa et al., 2022), or the Betna River, Bangladesh (Islam et al., 2017). Our present study did not demonstrate the positive relationship between these variables (Table 4). However, with water temperature from 20.1 to 30.8°C during the sampling period, FIB can grow in the Hanoi rivers, like other tropical urban rivers (Liang et al., 2015).

3.2.2. Implications

The EC presence in river water revealed that the water source was contaminated with faecal waste since EC only comes from human and warm-blooded animal feces. High EC density in the Hanoi rivers indicated high pollution from human and warm-blooded animal feces. Therefore, effective measures are needed to manage and treat domestic wastewater before discharging it into the urban river system.

Besides, a part of the Hanoi riverine water is used for irrigation. According to Nguyen (2012), there are about 194.51 ha (rice paddy, fish ponds, and aquatic plants) of field area involving 201 farmer households in the basin studied. This land is irrigated by the downstream To Lich water through different pumping stations. Thus, such high TC and EC densities in the riverine water, which may present harmful coliform groups, may pose a potential risk to public health. Our results emphasised the need for regular observation of harmful coliform groups in urban river water, especially for agricultural irrigation or fish culture.

4. Conclusions

The observation results for four rivers in Hanoi city during six sampling campaigns in the period from 2020–2022 showed that both TC and EC densities far exceeded the allowable values of the Vietnam technical regulation for surface water quality QCVN 08-MT:2015/BTNMT column B1. High values of physico-chemical variables (NH_4^+, PO_4^{3-}, and POC) favoured the multiplication of FIB densities, especially in the dry than in the rainy/wet season, and reflected the vital contribution of domestic wastewater in Hanoi city to the four urban rivers. Very high TC and EC densities in the surface water of the

Hanoi rivers may pose a potential risk to public health due to the use of river water for agricultural irrigation. This study highlights the need to monitor urban river water quality, especially microbiological variables, regularly. Our results also pointed out that domestic wastewater in Hanoi city must be treated before discharging into the rivers to protect riverine water quality.

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