Assessment of the River Water Pollution Levels in Kuantan, Malaysia, Using Ion-Exclusion Chromatographic Data, Water Quality Indices, and Land Usage Patterns

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ABSTRACT: Water qualities of three suburban rivers, namely, Kuantan, Belat, and Galing rivers, in Kuantan, Malaysia, were examined effectively by using ion-exclusion/cation-exchange chromatography with water quality indices and land usage data. Specifically, we have focused on evaluating and grasping the effect of sewage/household wastewater discharged from housing areas in the Kuantan district on the river water quality. Based on this study, the following beneficial information were obtained effectively: (1) the pollution levels in the three rivers (Kuantan River: Classes I–III, Belat River: Classes I–III, and Galing River: Classes I–V) are linked with the urbanization level of the river basin area; (2) differences in the biological reactions in the different pollution level rivers are understood; (3) Galing River is among the most polluted rivers not only in Kuantan but also in the Peninsular Malaysia, owing to poor water treatment of the sewage/household wastewater discharged from the river basin area.

KEYWORDS: ion-exclusion/cation-exchange chromatography, water quality index, land usage, urban rivers water pollution, effective water quality assessment, Malaysia

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Introduction

Water pollution and eutrophication of lakes, rivers, and oceans have been caused by the increased influx of wastewater due to rapid economic, industrial, and agricultural development without the construction of applicable water infrastructure and treatment facilities.[1,2] Water pollution is a particularly severe problem in developing countries, and adequate water quality monitoring is required to identify the suitability for usage and assist with water quality management or improvement. In the 1980s, 42 tributaries in Malaysia were identified as being highly polluted.[3] In the 1990s and 2000s, almost 60% of the major rivers were regulated for domestic, agricultural, and industrial purposes, owing to water quality degradation by the wastewater from housing, industrial, and business/servicing sectors.[4,5]

As shown in Figure 1, three rivers, namely Kuantan, Belat, and Galing, flow through Kuantan city located at the east coast of Peninsular Malaysia. Kuantan is the state capital of Pahang and the 17th largest city in Malaysia.[6] The National Physical Plan 2005 identified Kuantan as one of the future growth centers and a hub for trade, commerce, transportation, and tourism in the east coast of Peninsular Malaysia, owing to its strategic location. By following the *Kuantan District Locality Plan 2004–2015*, the Kuantan area has rapidly developed over the last 10 years, leading to environmental degradation.[7–10] As shown in Figures 2 and 3, the east coast area of Kuantan city are dramatically urbanized and its agricultural and forest regions have been used for housing and business/servicing purposes (housing area: 0.498%, business/servicing area: 0.0268%, agricultural area: 11.7, forest area: 16.3%), while a lot of forest and agricultural areas still remain (housing area: 30.5%, business/servicing area: 5.38%, agricultural area: 20.2%, forest areas: 74.7%) in the west area of Kuantan and different situations of river water pollution are expected.

Therefore, our research group focused on the Kuantan, Belat, and Galing rivers in this research. Kuantan River is one of the largest rivers of the Peninsular Malaysia that flows from northwest to east coast in Kuantan. It flows through four administrative regions that include forests and agricultural areas (K-1–K-4); forests, agricultural areas, and small villages (K-5–K-6); and the main urban area of Kuantan city

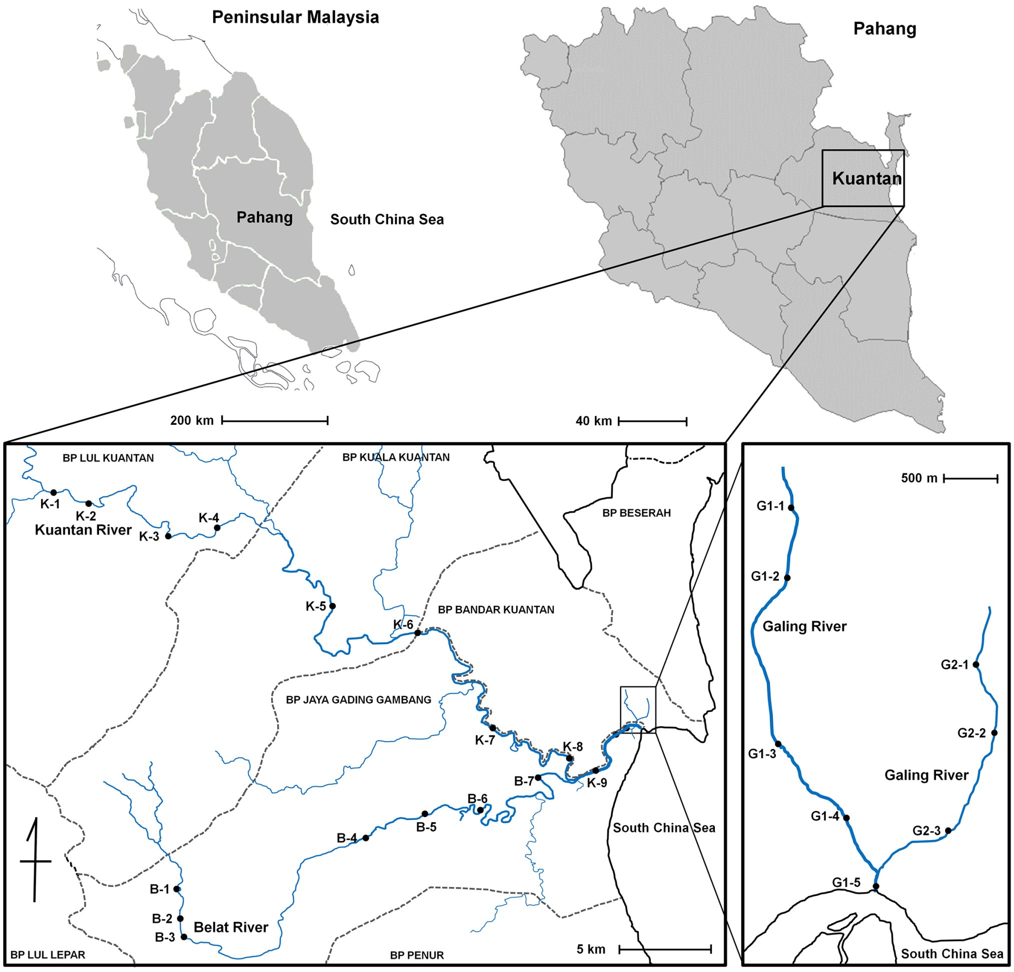

Figure 1. Maps of the sampling locations.
Notes: The Kuantan, Belat, and Galing river water samples were collected from nine, seven, and eight different sites along these rivers, respectively, in the daytime. All the river water samples were collected at the center of the river in the surface water layer (0–15 cm from the surface).

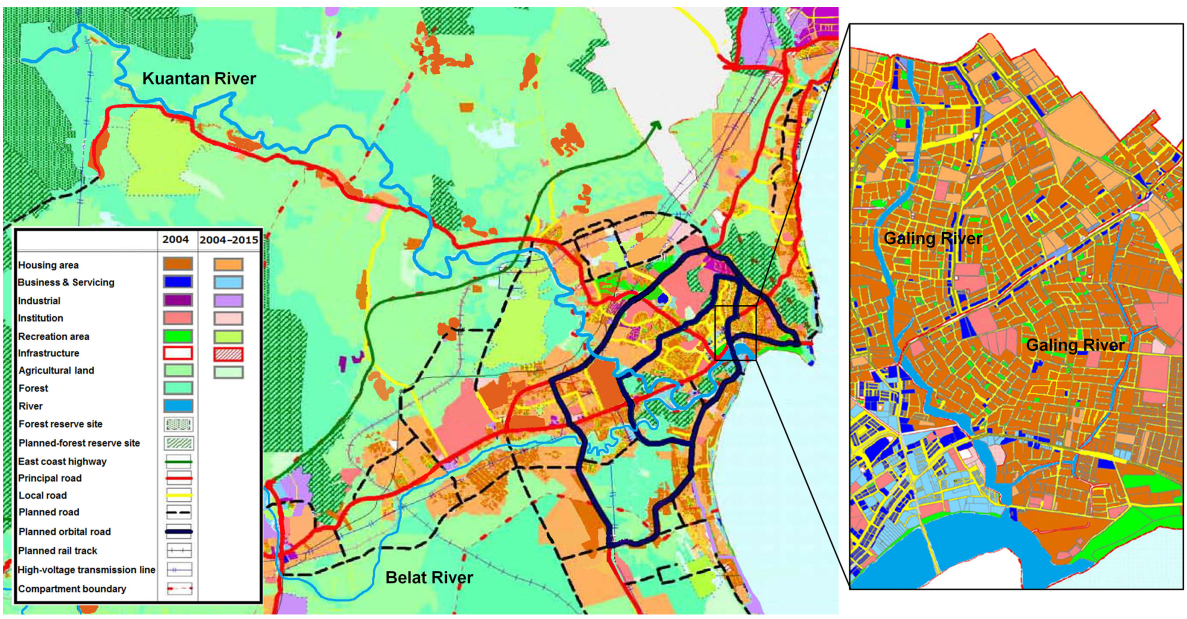

Figure 2. Land use map for Kuantan.
Note: This figure was constructed based on the data obtained from the JPBD Pahang Town and Country Planning Department.[7]

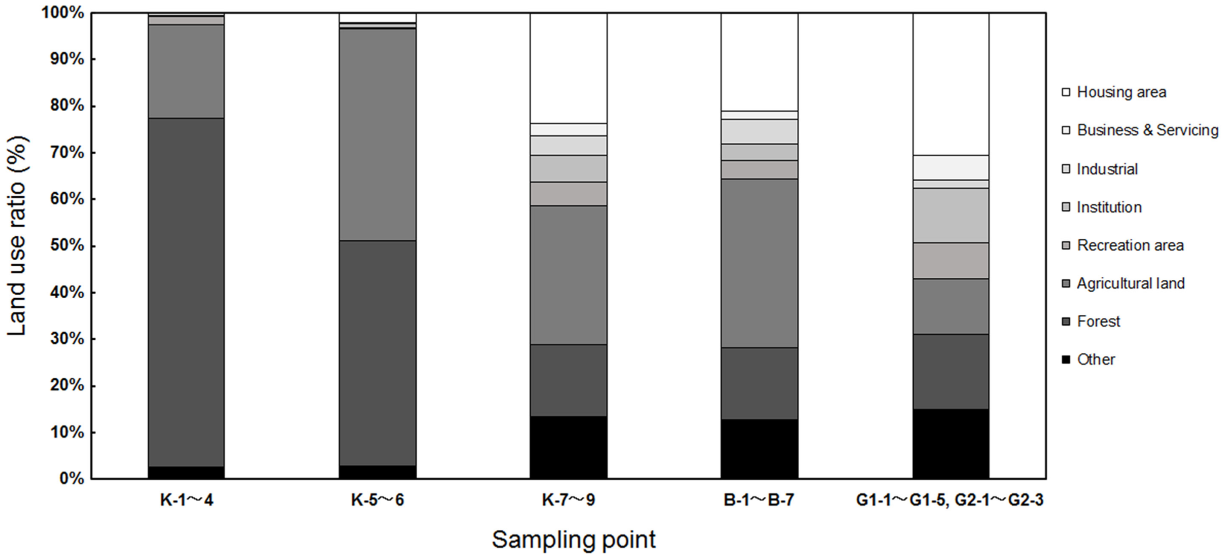

Figure 3. Land use percentages of the sampled areas of the rivers.
Note: This figure was constructed based on the data obtained from the JPBD Pahang Town and Country Planning Department.[7]

(K-7–K-9), as shown in Figures 2 and 3.[7,8] The Kuantan River is the major source of water supply for domestic, industrial, and agricultural purposes that provides 350,000 cubic meters per day and covers 1630 km^2 of catchment area.[8,11] The Belat River is the second largest river that flows from southwest to east coast in Kuantan and flows through one administrative region that includes forests, agricultural areas, middle-level villages, and urban areas (B-1–B-7). The Belat River is also a source of domestic water supply and covers 43.27 km^2 of catchment area.[12] The Galing River flows through the Kuantan city on the east coast of Kuantan and has two tributary streams that merge into a single artery (G1–G5) immediately before joining the Kuantan River and the main drainage system of the Kuantan.[7,13] The Galing River flows through the most urbanized area of Kuantan, as shown in Figures 2 and 3. The western side of this river is indicated by notations G1-1–G1-5, whereas its eastern side is denoted by notations G2-1–G2-3 in Figure 1. The catchment area and length of the Galing River are 22.7 km^2 and 7.7 km, respectively. Owing to the different land usages as detailed above, different levels of pollution are expected. Therefore, our research group focuses on effectively understanding and evaluating the effect of the sewage/household wastewater discharged from urbanized areas in the Kuantan district on the river water quality by using ion-exclusion/cation-exchange chromatographic (IEC/CEC) data with water quality index (WQI) and land usage patterns.

In this study, several key water quality parameters, such as dissolved oxygen (DO), total phosphate (TP), chemical oxygen demand (COD), and pH, which are used in the WQI classification of the Department of Environment, Malaysia, were monitored, as shown in Table 1. These parameters are closely related to river water quality degradation caused by sewage/household wastewater.[1,14] Additionally, IEC/CEC data were

Table 1. Classification of ammoniacal nitrogen, COD, DO, and pH in the WQI of the Department of Energy in Malaysia.

CLASS	USES	PARAMETER			
		NH_4^+-N (mg/L)	COD (mg/L)	DO (mg/L)	pH
I	Conservation of natural environment Water Supply I—practically no treatment necessary Fishery I—very sensitive aquatic species	<0.1	<10	>7	6.5–8.5
II	Water Supply II—conventional treatment required Recreational use with body contact Fishery II—sensitive aquatic species	0.1–0.3	10–25	5–7	6.5–9.0
III	Water Supply III—extensive treatment required Fishery III—common, of economic value, and tolerant species; livestock drinking	0.3–0.9	25–50	3–5	5.0–9.0
IV	Irrigation	0.9–2.7	50–100	1–3	5.0–9.0
V	None of the above	>2.7	>100	<1	–

Note: Source: Ref. 14.

applied to determine the various anions (SO_4^{2-}, Cl^-, and NO_3^-) and cations (Na^+, K^+, NH_4^+, Mg^{2+}, and Ca^{2+}) present in the river water, which are important for understanding several biological reactions in aquatic environments.[2]

Generally, to monitor anions and cations, either two ion chromatographic systems or using anion-exchange and cation-exchange chromatographic separations twice is required. In this study, IEC/CEC data for the simultaneous determination of anions and cations were used to simplify and demonstrate effective monitoring.[15–17] The above IEC/CEC data and several parameters used in the WQI were effectively evaluated along with the land usage data to understand the severity of pollution, owing to urbanization.

Materials and Methods

Reagents. All the reagents were obtained from Sigma-Aldrich Co. (Greater St. Louis, MO, USA). Pure water (18 MΩ cm at 25°C) obtained from an ELGA-DV25 system was used for dissolving and diluting the reagents. The standard solutions used in the IEC/CEC system were diluted from the stock solutions to the appropriate concentrations with pure water.

River water sampling. In this study, to precisely assess the water quality degradation by the sewage/household wastewater from urbanized areas, we collected the water samples in June, which was the month with the lowest mean precipitation (132.8 mm) from 2008 to 2013 in Kuantan.[18] The Kuantan, Belat, and Galing river water samples were collected from nine (on June 1, 2014), seven (on June 8, 2014), and eight (on June 14, 2014) different sites in the daytime, respectively. All the river water samples were collected at the center of the river in the surface water layer (0–15 cm from the surface). The water samples for the IEC/CEC system were filtered through a membrane filter (φ 0.45 urn; Acrodisc®–25 mm syringe filters; Pall Corp.) immediately following collection and then refrigerated at 6°C. The water samples for monitoring COD and TP were refrigerated without filtration at 6°C.

IEC/CEC system for anions and cations. The IEC/CEC system consists of an eluent delivering pump (DP-8020; Tosoh), an oven for separation column (CTO-10Avp; Shimadzu), and a conductivity detector (CDD-6A; Shimadzu). To obtain good separation resolutions for the IEC/CEC peaks, two TSKgel Super IC-A/C separation columns packed with a polymethacrylate-supported weakly acidic cation-exchange resin (WCX) in the H^+-form (150 mm × 6.0 mm ID; 4 μm particle size, and 0.1 meq/mL capacity) were connected in tandem. The column temperature, eluent flow rate, and injection volume were 40°C, 0.5 mL/minute, and 30 μL, respectively.

The IEC/CEC system is able to separate anions based on ion-exclusion/penetration effects in the WCX phase and cations based on the cation-exchange effect with functional groups (carboxylate groups) in the column, as shown in Figure 4A and B. The eluent contained a mixture of 6.0 mM tartaric acid and 2.0 mM 18-crown-6. Under optimal conditions, the calibration curves of the analyte were linear in the 0.050–1.0 mM range, and the correlation coefficients were 0.9958–0.9999. The detection limits ($S/N = 3$) were 0.632–2.22 μM. The relative standard deviation of the peak areas of the analyte ions were 0.40–1.5%.

Analyses of WQI. DO was determined locally using a DO meter (DO-31P; DKK-TOA Corp.) immediately following sample collection. COD was determined by using a UV-visible detector (DR900; Hach Company) with a COD test reagent (COD-HR; C-MAC) based on the dichromate method using potassium dichromate.[19] TP was determined by a UV–visible detector with a TP test reagent (TP-HR; C-MAC) based on the decomposition of a phosphorus compound using alkali metal salts of peroxodisulfate and phosphovanadomolybdate.[20] The pH values were measured

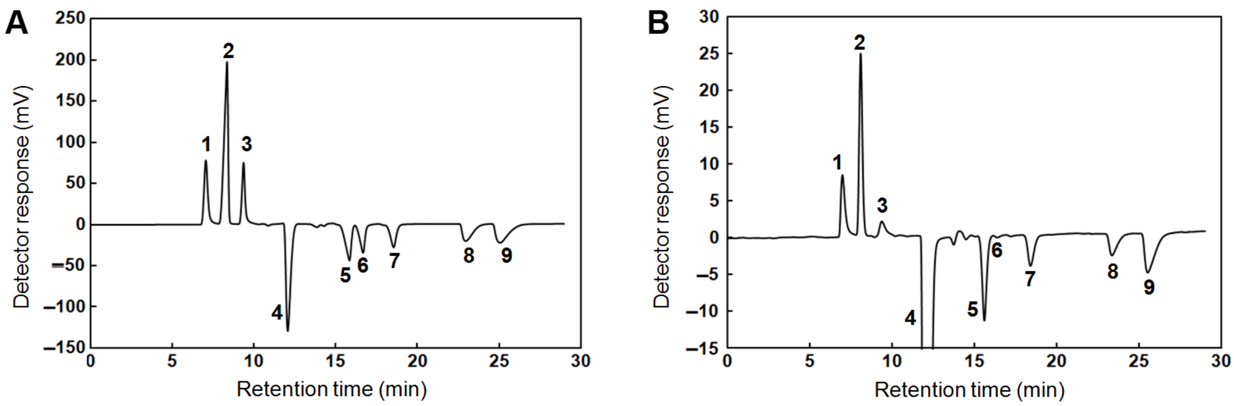

Figure 4. Ion-exclusion/cation-exchange chromatogram of inorganic anions and cations. Injected sample: (**A**) a mixture of $MgSO_4$, KCl, $NaNO_3$, NH_4Cl, and KNO_3 (1.0 mM each) and (**B**) river water sampled at point K-6 in the Kuantan River (Fig. 2).

Notes: Separation column: Two TSKgel Super IC-A/C columns (150 mm × 6.0 mm ID) packed with WCX in the H^+-form; eluent: 6 mM tartaric acid and 2 mM 18-crown-6 ether; column temperature: 40°C; flow rate: 0.5 mL/minute; injection volume: 30 μL; and detector: conductivity. Peak: 1 = SO_4^{2-}, 2 = Cl^-, 3 = NO_3^-, 4 = elution dip, 5 = Na^+, 6 = NH_4^+, 7 = K^+, 8 = Mg^{2+}, and 9 = Ca^{2+}.

using a pH meter (CyberScan pH 510; Thermo Scientific) in the laboratory immediately following collection.

Results and Discussion

Distribution of the WQI in Kuantan, Belat, and Galing rivers. The total average percentage of the forest area of the Kuantan River basin is 52.3%, which is the highest value among the three rivers (Kuantan, Belat, and Galing) as shown in Figure 3. In contrast, housing and business/servicing areas comprise 7.78% and 0.829% of the Kuantan River basin, respectively, and these values are the lowest among the three rivers. These land usage data show that the Kuantan River basin has the lowest human activity and the lowest average values of COD (11.5 mg/L), TP (1.01 mg/L), and total inorganic nitrogen (TIN; NO_3^--N plus NH_4^+-N) (0.177 mg/L), but the highest DO value (5.39 mg/L) among the three rivers as shown in Figure 5.

In contrast, the total average percentages of housing and business/servicing areas of the Galing River basin are 30.5% and 5.38%, respectively; these values are the highest among the three river basins, while its forest area comprises 16.3% of the total basin area. These data show that the Galing River basin area is the most urbanized river basin and has the highest human activity. Therefore, the average values of COD

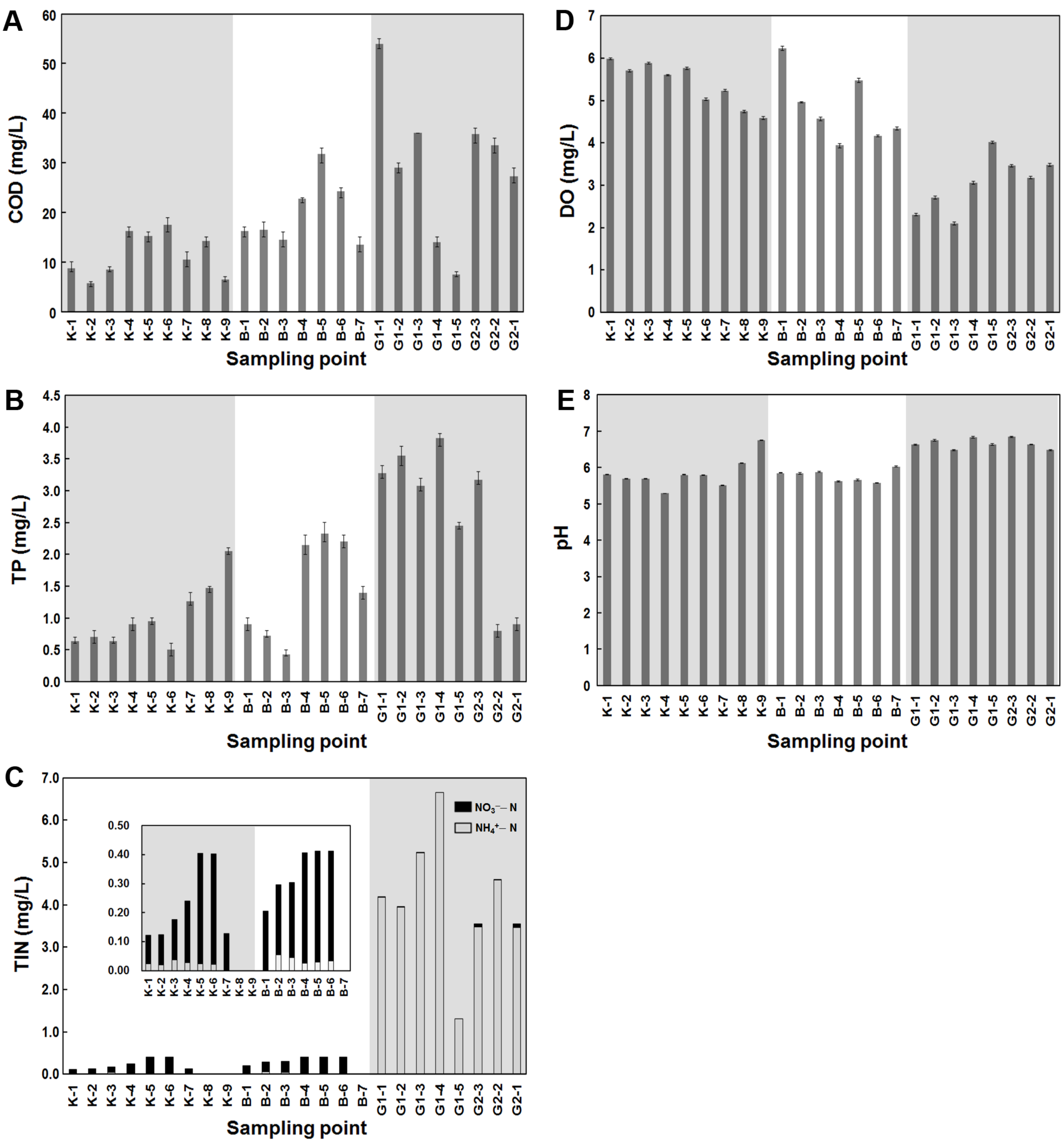

Figure 5. Comparison of (**A**) COD ($n = 4$); (**B**) TP ($n = 3$); (**C**) TIN (NO_3^--N plus NH_4^+-N) ($n = 3$); (**D**) DO ($n = 3$); and (**E**) pH ($n = 3$) for the Kuantan, Belat, and Galing rivers.

(29.6 mg/L), TP (2.63 mg/L), and TIN (4.12 mg/L) are the highest, while that of DO (3.04 mg/L) is the lowest as shown in Figure 5.

In the Belat River basin, the total average percentages of housing and business/servicing areas are 21.1% and 1.69%, respectively, while the forest area comprises 15.3% of the total basin area. These land usage data show that the urbanization level of the Belet River basin area is intermediate between that of the Galing and Kuantan river basins. Therefore, the average values of COD (19.9 mg/L), TP (1.45 mg/L), TIN (0.291 mg/L), and DO (4.82 mg/L) are also intermediate between those of the Galing and Kuantan river basins.

Additionally, significant differences were observed between the values of COD, TP, TIN, and DO of the Kuantan and Belat rivers ($P_{(COD)}$: 1.22×10^{-8}, $P_{(TP)}$: 9.47×10^{-4}, $P_{(TIN)}$: 1.95×10^{-5}, and $P_{(DO)}$: 1.01×10^{-4}) and between those of the Belat and Galing rivers ($P_{(COD)}$: 1.10×10^{-4}, $P_{(TP)}$: 3.28×10^{-2}, $P_{(TIN)}$: 5.84×10^{-15}, and $P_{(DO)}$: 1.56×10^{-6}), as shown by the statistical *t*-test ($P = 0.05$). Considering pH, the significant difference between Kuantan and Belat rivers ($P_{(pH)}$: 0.206) was not shown, whereas that between Belat and Galing rivers ($P_{(pH)}$: 1.56×10^{-6}) was shown by the statistical *t*-test.

From the above results, it may be concluded that increase in COD, TP, and TIN and decrease in the DO values in the following order: Kuantan River < Belat River < Galing River, and that these values are inseparably connected with changes in land usage (urbanization). These values also show that the Galing River is the most polluted river among the three rivers.

Distribution of the ionic concentrations in the Kuantan, Belat, and Galing rivers. In the water samples obtained from the Kuantan and Belat rivers, the concentrations of all the ions, except NH_4^+, gradually increased from upstream to middle-stream, as shown in Figure 6. The concentrations of NH_4^+ did not show any consistent pattern. In the case of the Galing River, no particular trends were seen in the concentrations of the ions from upstream to middle-stream.

Additionally, among the rivers monitored, the concentrations of almost ions, except NO_3^-, increased in the following order: Kuantan River < Belat River < Galing River, in the same order as the total average percentages of housing and business/servicing areas in each river basin area. In statistical *t*-test, significant difference between Kuantan, Belat and Galing rivers were obtained for all the ions ($P = 1.51 \times 10^{-15}$–2.66×10^{-3}), except NH_4^+ and Ca^{2+}, between Kuantan and Belat rivers. From the above results, it may be concluded that the increase in the ionic concentrations, except NO_3^-, was closely related with changes in the land usage (urbanization), which is same as WQI data.

The ionic concentrations, with the exception of NO_3^- and NH_4^+, increased drastically (SO_4^{2-}: 68.3–2730 mg/L, Cl^-: 311–13,290 mg/L, Na^+: 154–6429 mg/L, K^+: 12.6–291 mg/L, Mg^{2+}: 33.8–1363 mg/L, and Ca^{2+}: 11.0–317 mg/L), and the compositions of the samples dramatically changed from middle-stream to downstream (Kuantan River: K-7–K-9, Belat River: B-7, and Galing River: G1-4–G1-5). As shown in Figure 7, the average concentration ratios of the ions in the downstream regions resembled the ion concentration ratios in seawater,[21] suggesting that the main reason for the increasing ion concentrations in the downstream regions was mixing of river water with seawater. According to Faudzi et al, the average salinity values of K-7 and K-9 were 18.72 and 28.58 ppt (g/L), respectively, and high salinity was detected in every season.[22] From the above results, Kuantan, Belat, and Galing river water samples obtained within 12.6, 9.0, and 1.8 km from the estuary, respectively, were affected by seawater, and it is difficult to evaluate the effect of the discharged sewage/household wastewater from the urbanized areas at these sampling points by the IEC/CEC system.

Thus, it can be concluded that the ion concentrations were affected by two factors: the increasing percentages of housing and business/servicing areas (urbanization level) and mixing of river water with seawater.

Comparison of the biological reactions in Kuantan, Belat, and Galing rivers. As shown in Figure 8A and B, the concentrations of NO_3^--N were 3.71–18.1 times and 4.44–14.9 times higher than those of NH_4^+-N in the Kuantan and Belat rivers, respectively. Additionally, the DO values in the Kuantan (4.59–5.98 mg/L) and Belat rivers (3.95–6.24 mg/L) suggest that these rivers are in the aerobic state.[23,24] Therefore, aerobic oxidation of organic compounds by microorganisms and nitrification reactions by nitrifying bacteria could occur in these rivers.[25] Through aerobic oxidation, the organic compounds in the river water decompose into NH_3 and dissolve as NH_4^+. Subsequently, NH_4^+ derived from the decomposed organic compounds and present in the sewage/household wastewater is oxidized into NO_3^- through nitrification. Consequently, the concentration of NO_3^- was higher than that of NH_4^+ in the Kuantan and Belat rivers.

In contrast, the NH_4^+ concentration was 11.9–1182 times higher than the NO_3^- concentration in the Galing River (Fig. 8C). Additionally, the average DO value in the Galing River was 2.87 mg/L, indicating a poor aerobic state.[23,24] Owing to anaerobic decomposition of organic compounds in the river water, gases such as CO_2 and CH_4 and ions such as NH_4^+ and HPO_4^{2-} were generated. Additionally, NH_4^+ derived from the decomposed organic compounds and present in the discharged sewage/household wastewater was not oxidized under low-oxygen conditions. NO_3^- was reduced to N_2 gas through denitrification.[26] Consequently, the concentration of NH_4^+ was higher than that of NO_3^-.

Relationships between COD and TIN in Kuantan, Belat, and Galing rivers. From the data obtained, a good positive correlation ($r^2 = 0.792$) between TIN and COD was obtained for the Kuantan and Belat rivers. In contrast, a different trend was observed for the Galing River, as shown in Figure 9. The COD values increased in a phased manner in the following order: Kuantan River < Belat River < Galing River,

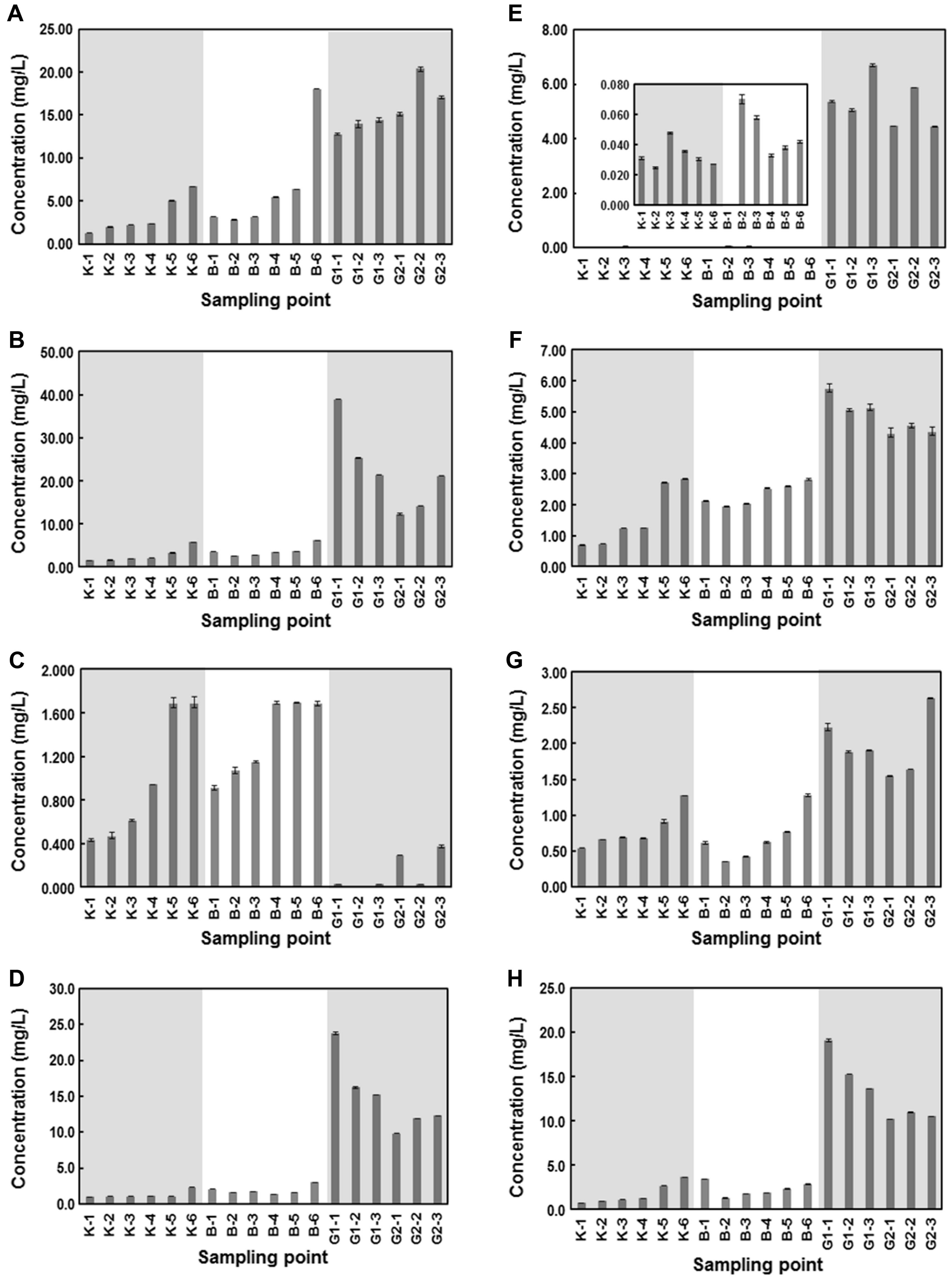

Figure 6. Comparison of the inorganic ion concentrations (**A**) SO_4^{2-}; (**B**) Cl^-; (**C**) NO_3^-; (**D**) Na^+; (**E**) NH_4^+; (**F**) K^+; (**G**) Mg^{2+}; and (**H**) Ca^{2+} for the Kuantan, Belat, and Galing rivers.

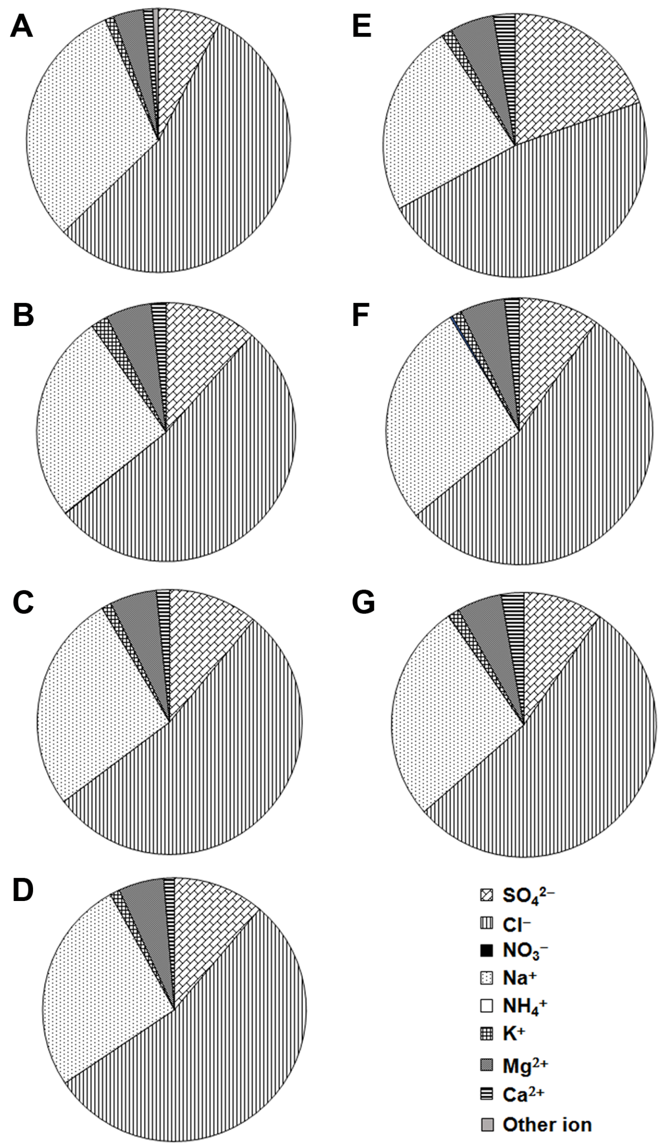

Figure 7. Comparison of the concentration ratio of sea water (**A:** sea water[21]) and collected water samples (**B:** K–7, **C:** K–8, **D:** K–9, **E:** B–7, **F:** G1–4, and **G:** G1–5).

and a significant difference between the Kuantan, Belat, and Galing rivers were observed using the statistical *t*-test. The TIN values increased in the same order as COD, and there was a dramatic increase in the TIN value in the Galing River compared with the Kuantan and Belat rivers. A significant difference in TIN values was observed between the Kuantan, Belat, and Galing rivers using the statistical *t*-test, and the smallest *P*-value was obtained for the Belat and Galing rivers ($P_{(TIN)}$: 5.84×10^{-15}). Based on the above results, the sewage/household wastewater discharged from the Galing River basin area is predicted to contain quite high concentrations of TIN (NH_4^+-N) compared with that discharged from the Kuantan and Belat river basin areas.

Additionally, a close relationship between the above trends and the types of sewage/household wastewater treatment systems used in Kuantan city is expected. In Kuantan, there are 228 sewerage treatment plants, many of which were built in the early 1970s, of which individual septic tanks (ISTs) serve 51%, the centralized sewer system serves 47%, and individual primitive systems serve the remaining 2% of sewage/household wastewater.[27] However, ISTs are not highly efficient in removing nutrients and organic compounds (COD) with removal capacities of 5–18%[28] and 50–78%,[29] respectively.

As a result, high concentrations of TIN and COD were presumed to be obtained in the Galing River samples, owing to deficiencies in the water treatment capacity for sewage/household wastewater from the Galing River basin area.

Comparison of the monitored rivers with other major urban rivers in Malaysia. Finally, we compared the Kuantan, Belat, and Galing rivers with eight major urban rivers that pass through principal cities that are in the top 20 in terms of population in Malaysia.[6]

As shown in Table 2, the Galing River has the second highest concentration of NH_4^+-N, whereas the Belat and Kuantan rivers have the second lowest and the lowest NH_4^+-N concentrations among all the rivers considered. Normally, the amount of ammonia in surface waters in urban areas is influenced by human activities, such as sewage treatment plant effluents, industrial point sources, and untreated water discharged from human sewage or household waste.[30]

Further, the Galing River has the fifth highest maximum COD value, whereas the Belat and Kuantan rivers have the third lowest and the lowest maximum COD values, respectively. In contrast, the Galing River has the third lowest minimum DO value, whereas the Belat and Kuantan rivers have the second highest and the highest minimum DO values, respectively. In developing countries, urban rivers are used as a drainage system, and hence, they are polluted because of the discharge of incompletely treated or untreated human sewage or household wastewater and because of the delays in the construction of adequate water treatment systems.[17]

As evident from the above data, the Galing River is one of the most polluted rivers in the Peninsular Malaysia, and the construction of adequate sewage treatment systems is required to preserve the water quality of the Galing River.

Conclusions

In the present study, by using the IEC/CEC data with WQI and land usage data, we have effectively demonstrated the following:

(1) The pollution levels in the three rivers (Kuantan River: Classes I–III, Belat River: Classes I–III, and Galing River: Classes I–V) are related to the urbanization of the river basin area (the average percentages of the housing and business/servicing areas are in the following order: Kuantan River (7.78% and 0.829%) < Belat River (21.1% and 1.69%) < Galing River (30.5% and 5.38%)).

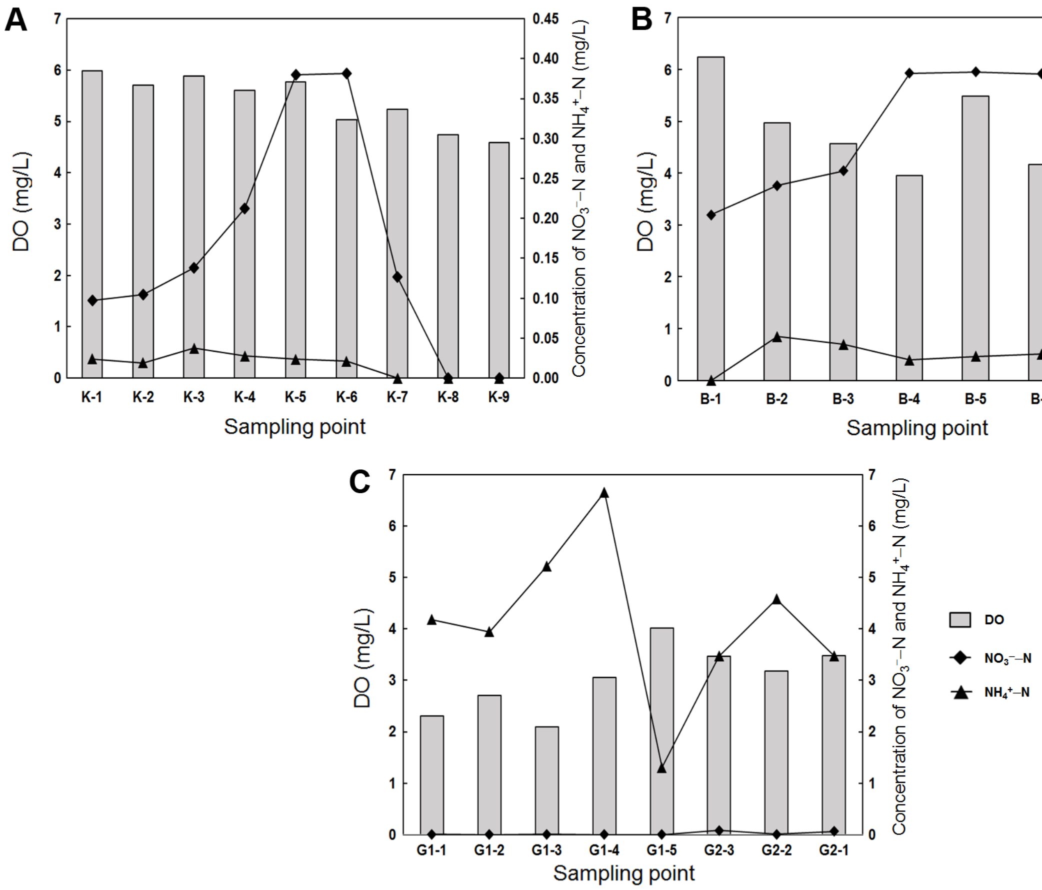

Figure 8. NO_3^--N, NH_4^+-N, and DO contents in the (**A**) Kuantan River; (**B**) Belat River; (**C**) Galing River.

(2) Simultaneous determination of anions and cations using IEC/CEC data was successfully achieved in order to study the differences in biological reactions in rivers with different pollution levels.

(3) Serious pollution in the Galing River is expected by observing the obtained COD, DO and TIN values owing to poor water treatment (ISTs: 51%, centralized sewer system: 47%, and individual primitive systems: 2%) of the household/sewage wastewater discharged from the river basin area.

(4) The Galing River is one of the most polluted rivers not only in Kuantan but also in Peninsular Malaysia because of the high human activity in the Galing River basin area.

The above results show that the water quality of the Galing River is a serious concern compared to that of the Kuanan and Belat rivers, and monitoring of the sewage/household wastewater discharged from the Galing River basin area is required in the future to understand its effects on the Galing River; to optimize the sewage treatment systems from the point of view of their ability to degrade organic compounds, remove nutrients, and provide aeration; and to improve the water quality from Class IV/V (e.g., irrigation or only drainage) to Class II/III (e.g., recreation usage).

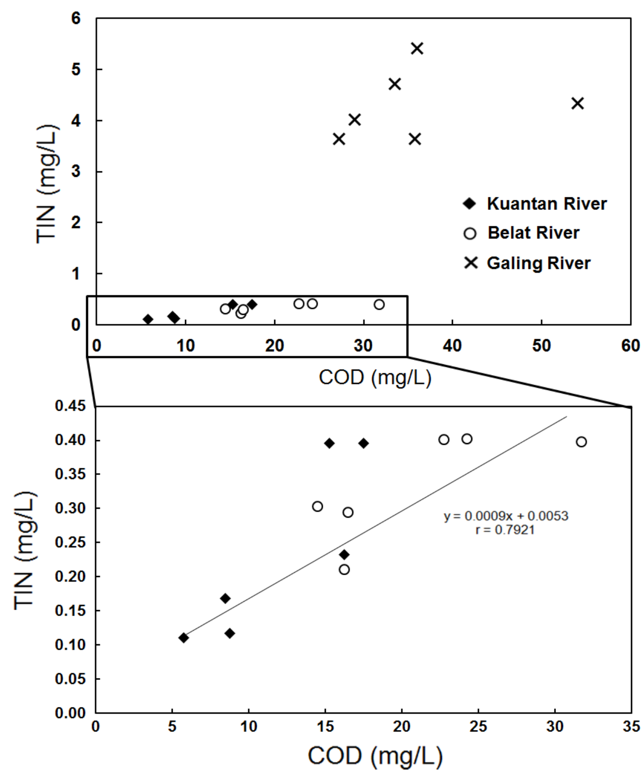

Figure 9. Relationship between TIN and COD in the Kuantan, Belat, and Galing rivers.

Table 2. Water quality of Kuantan, Belat, Galing, and several major urban rivers in Malaysia.

NAME OF THE RIVER	PARAMETER/CLASS				CITY (POPULATION)	REFERENCE
	NH_4^+-N (mg/L)	COD (mg/L)	DO (mg/L)	pH		
Kuantan River	0.00–0.0373/Class I	5.75–17.5/Class I–II	4.59–5.98/Class II–III	5.29–6.75/Class III	Kuantan (427,515)	This study
Belat River	0.00–0.0544/Class I	13.5–31.8/Class I–II	3.95–6.24/Class II–III	5.58–6.03/Class III		
Galing River	1.30–6.65/Class IV–V	7.50–54.0/Class I–IV	2.10–4.02/Class III–IV	6.48–6.84/Class III		
Klang River	4.59/Class V	44.0/Class III	3.19/Class III	7.24/Class I	Kuala Lumpur (1,588,750)	31
Gombak River	1.01–14.7/Class IV–V	4.00–105/Class I–V	0.400–10.9/Class I–V	5.71–7.89/Class III	Kuala Lumpur (1,588,750)	32
Langat River	0.12–2.13/Class II–IV	14.3–219/Class II–V	2.54–7.54/Class I–IV	6.39–7.09/Class III	Kajang (795,522)	33
Penchala River	0.00–6.94/Class I–V	1.37–165/Class I–V	0.160–7.58/Class I–V	6.57–7.44/Class I	Petaling Jaya (613,977)	34
Skudai River	0.19–5.48/Class II–V	19.5–71.9/Class II–IV	2.37–7.64/Class I–IV	6.17–6.74/Class III	Johor Bahru (497,067)	35
Melana River	1.47–3.72/Class IV–V	24.0–40.6/Class II–III	2.33–4.07/Class III–IV	–	Johor Bahru (497,067)	36
Merbok River	1.03–2.53/Class IV	27.1–35.0/Class III	4.23–8.06/Class I–III	7.53–8.42/Class I	Sungai Petani (443,488)	37
Petani River	1.03–1.79/Class IV	21.8–23.4/Class II	3.42–4.39/Class III	7.30–7.56/Class I	Sungai Petani (443,488)	37

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Author Contributions

Sample analysis, data evaluation, and drafting of the manuscript: DK with contribution from MMY, MM, NN, and KT. Water sample: DK supported with MHbAR and WMFbWI. Headed the water quality monitoring section of this project: DK. All authors have read and approved the final manuscript.

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