

Water Quality Assessment of the Inanam River in Kota Kinabalu, Sabah, Malaysia

Fera Cleophas^{1*}, Nur Zaida Zahari², Farrah Anis Fazliatul Adnan³, Kamsia Budin¹, Hardianshah Saleh² and Baba Musta²

¹Enviro-LL, Faculty of Science and Technology, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia.

²Rural Water Supply Living Lab, Faculty of Science and Technology, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia.

³Small Island Research Centre, Faculty of Science and Technology, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia.

*Corresponding author:

Fera Cleophas,
Enviro-LL,
Faculty of Science and Technology,
Universiti Malaysia Sabah,
88400 Kota Kinabalu,
Sabah,
Malaysia.

Email: fera.cleo@ums.edu.my

History

Received: 30th March 2025
Received in revised form: 21st June 2025
Accepted: 30th July 2025

Keywords

Urban river
Water Quality Index
National Water Quality Standard
Physicochemical parameters
Biological indicators

Abstract

This study provides a comprehensive assessment of the water quality of the Inanam River, Kota Kinabalu, Sabah, Malaysia, across four sampling stations from upstream to downstream. Both in-situ and ex-situ analyses were performed to evaluate physicochemical and biological parameters, including BOD, COD, ammoniacal nitrogen (AN), TSS, DO, pH, temperature, TDS, salinity, electrical conductivity (EC), fecal coliform, and total coliform. The Water Quality Index (WQI) was determined following Malaysia's National Water Quality Standards (NWQS). Findings reveal that the Inanam River falls into Class II and Class III categories, with DO, COD, and AN levels in several locations meeting or exceeding Class III thresholds, particularly in downstream segments. Urban stretches exhibited the most significant water quality deterioration, highlighting the urgent need for targeted pollution control and management interventions.

INTRODUCTION

Rivers play a crucial role in sustaining human societies and natural ecosystems, providing water for domestic consumption, agricultural irrigation, industrial processing, aquaculture, and a variety of recreational activities. They also serve as natural habitats for diverse aquatic and riparian species, thereby supporting biodiversity and maintaining ecological balance. However, in Malaysia, the rapid pace of urbanization, coupled with intensified industrial activities, has significantly exacerbated riverine pollution, leading to the deterioration of water quality and posing serious threats to both water security and ecosystem health [1]. Expansion of urban settlements often results in increased sewage discharge, stormwater runoff, and solid waste generation, while industrial growth contributes chemical effluents, heavy metals, and organic pollutants [2]. According to the Department of Environment [3], monitoring of 672 rivers nationwide revealed that 61% were classified as clean, 30% as slightly polluted, and 9% as polluted. The major sources of contamination are both point-source discharges, such as industrial effluent and municipal wastewater, and non-point sources, including land clearing, agricultural runoff, livestock farming, and soil erosion from construction activities [4]. These

pollutants not only degrade water quality but can also disrupt aquatic food webs, impair river ecosystem services, and increase treatment costs for potable water supply [5]. The Inanam River, a major watercourse in Kota Kinabalu, Sabah, is a prime example of a river under multiple anthropogenic pressures. Flowing through densely populated residential areas and industrial zones, it is highly susceptible to contamination from domestic sewage, commercial waste, and industrial discharges. Its catchment area also encompasses agricultural and semi-rural zones, which contribute nutrient-rich runoff, further elevating the risk of eutrophication[6].

Previous assessments have classified the Inanam River as slightly polluted, corresponding to Class II under Malaysia's Water Quality Index (WQI) [3,7]. Given the escalating demands on water resources and the high financial burden associated with river rehabilitation, an accurate, up-to-date assessment of its water quality is essential. Such evaluation provides a scientific basis for informed decision-making, enabling policymakers, environmental managers, and local stakeholders to design targeted mitigation strategies. This study therefore, aims to determine the current status of the Inanam River by quantifying a range of key physicochemical and biological parameters,

benchmarking them against the National Water Quality Standards (NWQS), and categorizing the river's condition within the WQI framework.

MATERIALS AND METHODS

Study Area

The Inanam River is a significant tributary located in the northern sector of Kota Kinabalu, Sabah, Malaysia, with an approximate length of 13.4 km. Originating from the foothills in the semi-rural hinterland, the river flows southwest through a progressively urbanizing corridor before discharging into the South China Sea. The catchment area encompasses a mosaic of land uses, ranging from low-density residential zones and agricultural lands to high-density urban settlements and industrial estates. This land-use gradient exerts considerable influence on the river's hydrology, water quality, and ecological characteristics.

Hydrologically, the Inanam River experiences a tropical rainforest climate with high annual rainfall exceeding 2,500 mm, influenced by both the Northeast and Southwest monsoons. Intense rainfall events contribute to significant surface runoff, which mobilizes sediments, nutrients, and contaminants from the surrounding catchment. The river's flow regime is also shaped by tidal influence near the coastal downstream section, creating brackish conditions that can alter physicochemical parameters and affect aquatic species distribution.

The spatial arrangement of these stations enables the assessment of land-use impacts on river water quality, from minimally disturbed upstream environments to heavily urbanized and industrialized downstream areas. **Fig. 1** illustrates the geographical distribution of the four sampling stations along the Inanam River, highlighting their relative positions.

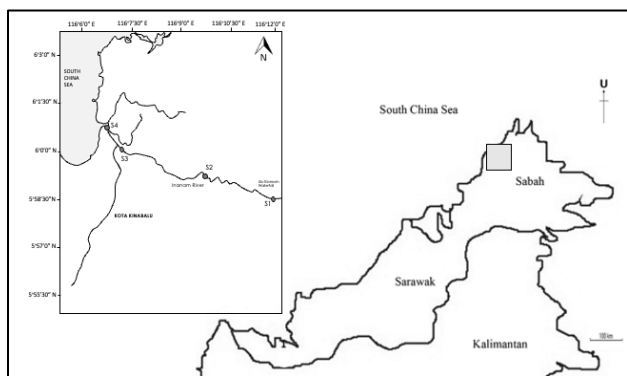


Fig. 1. Location map of the Inanam River study area in Kota Kinabalu, Sabah, Malaysia, showing the four sampling stations (S1–S4) from upstream to coastal downstream, and the river's position within the broader geographical context of northern Borneo.

For the purpose of this study, four representative sampling stations were selected to capture the spatial variability in water quality along the river's continuum:

- *S1 (Upstream)*: Located in the semi-rural headwater zone, characterized by low population density, minimal built infrastructure, and mixed secondary forest cover. Land use is dominated by small-scale agriculture and scattered housing, with limited direct anthropogenic pollution sources. This station serves as a reference point for baseline water quality conditions.
- *S2 (Midstream)*: Situated within a mixed residential and agricultural landscape, with active livestock farming and

smallholdings. Non-point source pollution from animal waste, fertilizers, and domestic effluent is expected to influence water quality in this section.

- *S3 (Downstream)*: Flowing through dense urban development interspersed with industrial facilities, workshops, and commercial premises. The area is also home to informal squatter settlements lacking proper sanitation infrastructure, contributing untreated domestic wastewater directly into the river. This section represents the highest anticipated anthropogenic pressure.
- *S4 (Coastal Downstream)*: Positioned near the river mouth where freshwater mixes with incoming seawater, creating brackish conditions. This zone is directly influenced by tidal dynamics and coastal processes. It is bordered by mixed-use development, including fishing settlements and small-scale aquaculture operations.

Sampling Procedure

Water sampling was conducted at multiple strategic locations along the Inanam River to capture spatial variability in water quality. Sampling sites were selected based on land use characteristics, proximity to potential pollution sources (e.g., residential areas, industrial zones, agricultural lands), and accessibility. At each site, in-situ measurements of physicochemical parameters, including pH, electrical conductivity (EC), dissolved oxygen (DO), temperature, salinity, and turbidity, were performed using a YSI ProDSS multiparameter probe, which was calibrated prior to field deployment to ensure accuracy.

Water samples for laboratory analysis were collected in pre-cleaned polyethylene bottles following standard procedures outlined by the American Public Health Association [8]. Samples intended for biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nutrient analysis (nitrate, phosphate, sulphate), and microbiological assessment (total and fecal coliforms) were immediately stored in iceboxes at 4 °C to minimize biological activity and chemical transformation. All samples were transported to the laboratory and processed within 48 hours of collection to maintain sample integrity.

Laboratory Analysis

Laboratory analyses were conducted in accordance with standardized protocols to ensure reliability and comparability of results:

Biochemical Oxygen Demand (BOD)

BOD was determined using the Winkler titration method, which measures the amount of oxygen consumed by microbial organisms during the decomposition of organic matter over a 5-day incubation period.

Chemical Oxygen Demand (COD)

COD was measured using the Hach Method 8000, a closed reflux colorimetric technique that quantifies the oxygen equivalent of organic matter susceptible to oxidation by dichromate in acidic conditions.

Total Suspended Solids (TSS)

TSS was assessed via the gravimetric method [8], involving filtration of a known volume of water through a pre-weighed glass fiber filter, followed by drying and reweighing to determine the mass of suspended particles.

Nutrient Analysis

Concentrations of nitrate (NO_3^-), phosphate (PO_4^{3-}), and sulphate (SO_4^{2-}) were quantified using a HACH DR/2800 spectrophotometer, following reagent-based colorimetric methods specific to each analyte.

Microbiological Analysis

Total coliforms and fecal coliforms were enumerated using the membrane filtration technique, with incubation at 37.5°C for total coliforms and 44°C for fecal coliforms. Results were expressed in colony-forming units per 100 mL (CFU/100 mL).

Water Quality Index (WQI) Calculation

The Water Quality Index (WQI) was computed to provide an integrative assessment of river health. The WQI was derived using the Malaysian DOE formula, which incorporates six core parameters: BOD, COD, ammoniacal nitrogen (AN), pH, DO, and TSS. Each parameter was normalized and weighted according to its significance in water quality assessment. The resulting WQI score was used to classify the river condition into one of five categories (Class I to V), as defined by the National Water Quality Standards (NWQS).

RESULTS AND DISCUSSION

General Water Quality Trends

The water quality assessment of the Inanam River revealed distinct spatial variations across the four sampling stations (S1 to S4), reflecting the influence of surrounding land use and anthropogenic activities. Water temperature exhibited a downstream increasing trend, ranging from 24.08°C at S1 to 29.15°C at S4. This gradient may be attributed to reduced canopy cover, increased urban heat island effects, and thermal discharges from industrial and domestic sources. Elevated temperatures can influence dissolved oxygen solubility and metabolic rates of aquatic organisms [9,10].

The pH values ranged from 6.16 to 8.94, indicating conditions from neutral to slightly alkaline. These values fall within acceptable limits for most aquatic life, although localized alkalinity may be influenced by industrial effluents or agricultural runoff containing lime-based substances [11,12]. DO levels showed a marked decline downstream. The highest concentration was recorded at S1 (9.95 mg/L), corresponding to Class I under the NWQS, indicative of pristine conditions. In contrast, S4 recorded the lowest DO (2.39 mg/L), falling into Class III, suggesting significant organic pollution and reduced aeration, likely due to sewage inputs and stagnant flow conditions.

EC values varied significantly, with the lowest at S1 (37.3 $\mu\text{S}/\text{cm}$) and the highest at S3 (1000 $\mu\text{S}/\text{cm}$). Elevated EC at downstream sites reflects increased ionic concentration from urban runoff, industrial discharges, and leaching of salts from surrounding soils. Both TSS and turbidity increased progressively downstream, peaking at S3 with TSS = 94.05 mg/L. This trend suggests intensified erosion, sediment transport, and particulate pollution from construction activities, stormwater runoff, and unregulated waste disposal [13].

Nutrient concentrations, particularly nitrate and phosphate, were elevated at S3, indicating agricultural runoff and domestic wastewater inputs. Notably, phosphate levels exceeded the NWQS Class V threshold at multiple sites, raising concerns about potential eutrophication and algal blooms. BOD and COD values were generally within NWQS limits, though COD peaked at S1 (37.2 mg/L), placing it in Class III. This anomaly may be

due to localized organic loading or episodic discharges. These parameters are critical indicators of organic pollution and oxygen demand in the aquatic system.

AN concentrations were highest at S4 (7.25 mg/L), exceeding the Class V threshold, signifying severe pollution likely from untreated sewage, industrial effluents, and leachate from urban waste. High AN levels are toxic to aquatic life and contribute to oxygen depletion [14]. Microbial contamination was most pronounced at S3, where total and fecal coliform counts were highest. This reflects direct sewage discharge, poor sanitation infrastructure, and runoff from densely populated areas. Such contamination poses serious public health risks, especially for communities relying on river water for domestic use. **Fig. 2** presents a correlation heatmap of the water quality parameters, illustrating the strength and direction of relationships among variables such as temperature, pH, dissolved oxygen, turbidity, and nutrient concentrations.

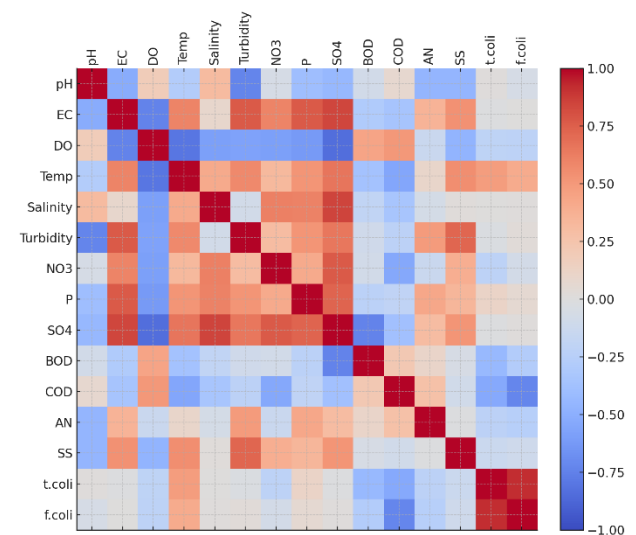


Fig. 2. Correlation heatmap of the water quality parameters.

The grouped correlation heatmap organizes water quality parameters into seven thematic categories (general, ions, sediment, nutrients, oxygen, organic load, and microbiological indicators). Parameters related to ionic content, such as EC, salinity, and SO_4 , form a tight positive cluster, reflecting common sources from dissolved salts in urban runoff, industrial effluents, and tidal influence, while showing strong negative correlations with DO, indicating that ionic enrichment is associated with oxygen depletion.

Sediment-related parameters (turbidity and SS) are highly correlated with each other and positively associated with nutrients and ions, suggesting that sediment transport plays a role in delivering dissolved pollutants to the river. Nutrients (NO_3 , P, AN) are positively correlated with EC and SO_4 , pointing to shared anthropogenic sources such as fertilizers, detergents, and sewage effluent, with AN showing moderate associations with turbidity and phosphate from organic-rich waste inputs. DO is negatively correlated with most ionic, sediment, and nutrient parameters, confirming that these factors collectively contribute to oxygen depletion, especially in downstream polluted areas. BOD and COD are moderately correlated, but COD shows negative associations with microbial indicators, implying different dominant pollution sources for organic load versus microbial contamination. Microbiological parameters (total

coliform and fecal coliform) exhibit a very strong positive correlation, confirming fecal contamination as a major contributor to the bacterial load, primarily from untreated domestic wastewater. Overall, the heatmap highlights three key pollution linkages in the Inanam River: a nutrient–ion–sediment cluster from agricultural runoff and urban stormwater, a DO depletion cluster linked to ionic and nutrient enrichment, and a microbial contamination cluster originating from inadequate sanitation in densely populated areas.

River Water Quality Index

The Water Quality Index (WQI) was calculated based on the subindices of six key parameters, with the results presented in Fig. 3. The WQI serves as an effective tool for detecting water quality trends, identifying areas of deterioration or improvement, and prioritizing resources for targeted interventions. It also plays a vital role in raising public awareness and supporting communication between stakeholders involved in river management and protection.

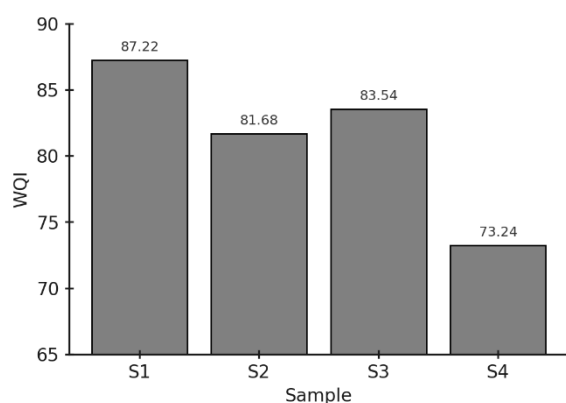


Fig. 3. Water Quality Index (WQI) values for four sampling stations along the Inanam River.

For the Inanam River, WQI values ranged from 73.24 to 87.22. The highest value was recorded at S1 (upstream), while the lowest was observed at S4 (coastal downstream). Based on the National Water Quality Standards (NWQS) classification, S1–S3 were categorized as Class II, indicating generally clean water suitable for recreational use, while S4 fell under Class III, reflecting slight pollution and the need for more advanced treatment before use as a potable water source. Overall, the river's average WQI falls within Class II, suggesting that conventional treatment systems would be adequate for water supply; however, downstream sections such as S4 would require enhanced treatment to meet drinking water standards.

For the Inanam River, WQI values ranged from 73.24 to 87.22. The highest value was recorded at S1 (upstream), while the lowest was observed at S4 (coastal downstream). Based on the National Water Quality Standards (NWQS) classification, S1–S3 were categorized as Class II, indicating generally clean water suitable for recreational use, while S4 fell under Class III, reflecting slight pollution and the need for more advanced treatment before use as a potable water source [3]. Overall, the river's average WQI falls within Class II, suggesting that conventional treatment systems would be adequate for water supply; however, downstream sections such as S4 would require enhanced treatment to meet drinking water standards [6,7]. The spatial variation in water quality along the Inanam River is strongly influenced by surrounding land use, pollution sources, and hydrological processes [1,2,5]. The Water Quality Index

(WQI) values ranged from 87.22 at the upstream station (S1) to 73.24 at the coastal downstream station (S4), indicating a progressive decline in water quality from the relatively undisturbed semi-rural headwaters to the urbanized and tidally influenced lower reaches [11]. According to the National Water Quality Standards (NWQS), stations S1–S3 fall under Class II, representing generally clean waters, while S4 is classified as Class III, reflecting slight pollution [8]. This pattern demonstrates the cumulative effects of anthropogenic activities as the river flows through increasingly developed areas [9,10,13].

Upstream conditions at S1 were characterized by higher dissolved oxygen (DO) levels, lower electrical conductivity (EC), and minimal nutrient enrichment. These results are consistent with the low population density, limited agricultural intensity, and absence of major industrial activities in the headwater catchment [6,7]. Conversely, midstream and downstream stations, particularly S3 and S4, exhibited elevated concentrations of ammoniacal nitrogen (AN), turbidity, suspended solids (SS), and microbial indicators, alongside reduced DO concentrations. These deteriorations coincide with the presence of high-density settlements, industrial facilities, and squatter communities, many of which lack proper wastewater management systems [5,12]. The tidal influence at S4 further compounds these impacts by altering salinity and promoting pollutant mixing from marine and riverine sources [11].

The correlation analysis reinforces these observations. DO displayed strong negative correlations with EC, temperature, salinity, turbidity, nitrate (NO₃), phosphate (P), and sulphate (SO₄) ($r = -0.571$ to -0.840 , $p < 0.01$), indicating that ionic enrichment, nutrient loading, and suspended particulates collectively contribute to oxygen depletion [9,10,13]. In contrast, EC, turbidity, phosphate, and sulphate were strongly and positively correlated, pointing to shared sources such as nutrient-rich agricultural runoff, detergent residues, and untreated domestic or industrial wastewater [12,14]. Nutrient parameters, particularly phosphate and nitrate, exceeded NWQS thresholds in several locations and showed strong correlations with turbidity and sulphate, suggesting that sediments play a significant role in transporting nutrients into the river system [3,4].

Microbiological analyses revealed that fecal coliform (*f.coli*) and total coliform (*t.coli*) counts were highest at S3, with both parameters showing a very strong positive correlation ($r = 0.915$, $p < 0.01$). This confirms that fecal contamination is a dominant component of microbial loads in the river, likely originating from untreated domestic sewage and inadequate sanitation facilities [6,7]. Unlike nutrients and ionic parameters, microbial contamination exhibited weaker correlations with other water quality parameters, suggesting distinct pollution pathways, primarily point-source discharges from households and community-level wastewater outlets rather than diffuse agricultural or industrial runoff [2,5].

Overall, the findings indicate three major pollution linkages in the Inanam River: (i) a nutrient–ion–sediment cluster originating from agricultural runoff, detergents, and stormwater flows [12–14]; (ii) a DO depletion cluster driven by nutrient and ionic enrichment, particularly in urban and industrial stretches; and (iii) a microbial contamination cluster primarily linked to untreated domestic wastewater discharges [6,7]. These interconnected processes contribute to the spatial pattern of water quality degradation observed along the river continuum [5,11].

CONCLUSION

This study has demonstrated significant spatial variability in water quality along the Inanam River, with a marked decline in WQI from Class II in upstream and midstream sections to Class III in the downstream coastal section. The deterioration in water quality is primarily associated with elevated nutrient concentrations, ionic enrichment, increased sediment loads, and microbial contamination, all of which are strongly influenced by urbanization, industrial activity, agricultural practices, and inadequate sanitation infrastructure in densely populated areas. While Class II waters, such as those in the upper and middle reaches, remain suitable for recreational activities and can be treated for potable water supply using conventional treatment systems, Class III waters, such as those found at S4 (coastal downstream), require more advanced treatment processes to meet drinking water standards. The elevated AN, turbidity, and coliform levels at downstream sites indicate the urgent need for targeted intervention in pollution management, particularly in urbanized and industrial zones. Effective mitigation strategies should include upgrading wastewater treatment infrastructure in densely populated settlements to reduce microbial contamination, implementing riparian buffer zones and erosion control measures to limit sediment-bound nutrient transport, and enforcing stricter monitoring of industrial effluent discharges to control ionic and chemical pollution. Additionally, community engagement and public education campaigns are essential to reduce domestic pollution inputs, particularly from detergent use, improper waste disposal, and excessive fertilizer application. Addressing these issues will not only improve the ecological health of the Inanam River but also safeguard public health, enhance the sustainability of water resources, and reduce the costs associated with potable water treatment. Through a combination of engineering solutions, regulatory enforcement, and community-driven initiatives, the river can be rehabilitated to meet both ecological and societal needs in the long term.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

FUNDING

This study was financially supported by the Skim Dana Khas Universiti Malaysia Sabah (SDK 0268/2020).

REFERENCES

1. Mokhtar Z, Idris SH, Kenway S, Pikaar I. Analysing the regulatory mechanisms of river pollution in Malaysia. *Int J Bus Econ Law*. 2024;31(1):23–37.
2. Camara M, Jamil NR, Abdullah AF. Impact of land uses on water quality in Malaysia: a review. *Ecol Process*. 2019;8-10.
3. Department of Environment Malaysia. Annual Environmental Quality Report. Putrajaya: DOE Malaysia; 2019.
4. Department of Environment Malaysia. Control Initiatives on Pollution of Water Resources. Putrajaya: DOE Malaysia; 2021.
5. Lanree @ Henry Asing. River pollution in Malaysia: conservation instead of endlessly cleaning works. *Int J Acad Res Bus Soc Sci*. 2024;14(1):885-898.
6. Ladoni AMH. The sources of pollution in the Likas and Inanam River Basin in Kota Kinabalu, Sabah. *Sosiohumanika*. 2009;2(1): 89-106.
7. Ku KH, Golingi T, Lim CS, Yangkat Y, Moduying V. Preliminary environmental profile study of Inanam River Catchment, Sabah. In: *Proc IAHR World Congress*; 2017.
8. Standard methods for the examination of water and wastewater. 23rd ed. Washington (DC): American Public Health Association; 2017.
9. Croghan D, Van Loon AF, Bradley C, et al. Identifying the impacts of urbanization and extreme flows on river water temperatures in headwater catchments. *Hydrol Sci J*. 2025;70(2):347–357.
10. Bello AD, Hashim NB, Haniffah MRM. Predicting impact of climate change on water temperature and dissolved oxygen in tropical rivers. *Climate*. 2017;5(3):58.
11. Abdul Aziz IL. Climate change and the future of river water quality in Inanam Likas River Basin, Kota Kinabalu, Sabah [dissertation]. Shah Alam: Universiti Teknologi MARA; 2016.
12. Mokhtar Z. Review of Malaysia's environmental waterway compliances with industrial effluent discharge. *Int J Bus Econ Law*. 2023;30:1.
13. Arman NZ, Aris A, Salmiati, et al. Water quality assessment of Johor River Basin, Malaysia using multivariate analysis. *Environ Sci Pollut Res Int*. 2025;32(4):1766-1782.
14. Wang L, Luo H, Wu J, et al. A review of the emerging risks of acute ammonia nitrogen toxicity to aquatic decapod crustaceans. *Water*. 2023;15(1):27.