

Seasonal Monitoring of Volatile Organic Compounds and Trihalomethanes in Sungai Sarawak Kiri: A Study of Batu Kitang Water Treatment Plant

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ABSTRACT

This study evaluates the occurrence of volatile organic compounds (VOCs) and trihalomethanes (THMs) in raw and treated water from the Batu Kitang Water Treatment Plant, Sarawak, Malaysia. Sampling occurred seasonally over one year at the inlet and outlet stages of the treatment process. All samples were analyzed for BTEX compounds and regulated THMs using gas chromatography–mass spectrometry (GC-MS). Results consistently showed concentrations below the method detection limits, indicating the effectiveness of the conventional treatment system and minimal contamination from the urban catchment area. This longitudinal study highlights the robustness of tropical water treatment systems and contributes to the regional dataset on disinfection by-products in Southeast Asia. Recommendations are provided for continued monitoring and potential inclusion of emerging contaminants.

Keywords: volatile organic compounds, trihalomethanes, drinking water, BTEX, disinfection by-products, tropical water treatment

INTRODUCTION

Safe and clean water is fundamental to public health. The increasing concern over chemical contaminants in water sources, especially volatile organic compounds (VOCs) and disinfection by-products (DBPs) like trihalomethanes (THMs) has prompted extensive research worldwide. VOCs, particularly BTEX compounds (benzene, toluene, ethylbenzene, and xylenes), originate from a variety of anthropogenic sources including petroleum refining, industrial discharge, and urban runoff (ATSDR 2007; USEPA 2017). These compounds have been associated with severe health outcomes, including haematological disorders, neurotoxicity, and carcinogenicity (WHO 2017, IARC 2012).

THMs are formed during the chlorination process when disinfectants react with natural organic matter (NOM) present in the water. Their presence in finished water has raised significant health concerns due to associations with bladder and colorectal cancers, reproductive disorders, and liver toxicity (Bull RJ et al., 2011, USEPA 2006). Recent regulatory frameworks and guidelines such as those issued by the WHO and the USEPA have emphasized the need to control these compounds within acceptable risk thresholds (WHO 2017; USEPA 2006).

Sarawak, a Malaysian state on Borneo Island, is highly dependent on surface water for domestic consumption. Sungai Sarawak Kiri, the largest river supplying water to Kuching, has witnessed rapid land use changes, urban

encroachment, and agricultural expansion. These transformations heighten the risk of pollutant infiltration into water bodies, which in turn demands effective treatment and robust surveillance. Despite this, there remains a paucity of longitudinal data specifically addressing BTEX and THMs in this tropical region.

Most research in Malaysia has focused on industrial zones in Peninsular Malaysia, where significant detections of THMs have been documented (Chowdhury S et al.,2010) However, little attention has been given to monitoring frameworks in East Malaysia, particularly within rural-urban transitional zones such as Kuching. This gap limits the capacity of water safety planners to respond to emergent threats in dynamic environments. Our study addresses this need through a year-long seasonal monitoring strategy, encompassing both dry and wet monsoon periods. This design not only ensures detection across variability cycles but also helps evaluate the resilience of conventional treatment systems against fluctuating pollutant loads.

The novelty of our work lies in integrating climatic seasonality with disinfection by-product monitoring, thus providing new insights into the temporal dynamics of water contamination in tropical urbanizing regions. Moreover, the findings may inform regional strategies under the Sustainable Development Goals (SDG 3.9 and SDG 6.1) by demonstrating how routine monitoring aligns with the goals of ensuring access to safe drinking water and reducing hazardous chemical exposure.

MATERIALS AND METHODS

Study Area and Sampling

Batu Kitang Water Treatment Plant is located approximately 15 km southeast of Kuching city centre. It processes surface water drawn from Sungai Sarawak Kiri, which flows through varied topographies and land-use areas including residential zones and agricultural fringes. Four sampling campaigns were conducted to coincide with seasonal climatic shifts: June 2024 (dry season), October 2024 (inter-monsoon), February 2025 (wet season), and June 2025 (dry season repeat).

In each campaign, 1-liter grab samples were collected from both the raw water inlet and the post-treatment outlet. Sampling bottles were made of amber glass to prevent photodegradation and were pre-washed and pre-labeled. All samples were preserved on-site in ice-cooled containers and immediately transported to the Laboratory for processing.

Sampling occurred at Batu Kitang WTP (15 km from Kuching) during June 2024, October 2024, February 2025, and June 2025. Both raw (inlet) and treated (outlet) samples were collected using amber glass bottles in accordance with USEPA guidelines.

Analytical Methods

Samples were analyzed for BTEX and THMs using USEPA Methods 8260C/5030C and 8260D via GC-MS. Detection limits were 0.005 mg/L for BTEX and 0.003 mg/L for THMs. QA/QC procedures included blanks, duplicates, and certified reference materials.

RESULTS

Across all four seasonal campaigns, the concentrations of benzene, toluene, ethylbenzene, and xylenes in both raw and treated samples were consistently below detection limits (<0.005 mg/L). Similarly, THMs including chloroform, bromoform, dibromochloromethane, and bromochloromethane were also undetectable (<0.003 mg/L) in all samples. These results are tabulated in Table 1 and confirm the absence of measurable contamination under current conditions. Due to the absence of quantifiable concentrations (all values below detection limits), advanced statistical modelling was not applicable. However, the consistent non-detect pattern across all seasonal sampling points suggests temporal stability of the treatment system.

There were no statistically significant differences observed across seasons, suggesting treatment system stability regardless of potential fluctuations in raw water quality. This consistency may be attributed to robust

coagulation-sedimentation-filtration protocols and optimized chlorination practices. No anomalies were reported during the sampling period in terms of rainfall or treatment adjustments.

Table 1. BTEX and THM concentrations (mg/L) from June 2024 to June 2025

Parameter	Inlet 1	Outlet 1	Inlet 2	Outlet 2	Inlet 3	Outlet 3	Inlet 4	Outlet 4
BTEX (mg/L)								
Benzene	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Toluene	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Ethylbenzene	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Xylenes	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
THMs (mg/L)								
Chloroform	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Bromoform	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Dibromochloromethane	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Bromochloromethane	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003

DISCUSSION

The present study provides a rare longitudinal assessment of volatile organic compounds (BTEX) and regulated trihalomethanes (THMs) in a tropical water treatment system, demonstrating consistent non-detection across all sampling points and seasons. While this finding may be interpreted as an indication of excellent water quality and treatment efficiency, a more nuanced interpretation is warranted, particularly in the context of analytical detection limits, environmental dynamics, and emerging public health concerns.

At face value, the absence of detectable BTEX compounds in both raw and treated water suggests minimal upstream anthropogenic contamination within the Sungai Sarawak Kiri catchment. This observation is consistent with the relatively lower intensity of industrial activities in this region compared to more heavily urbanised basins in Peninsular Malaysia. However, it is important to recognise that BTEX compounds are highly volatile and susceptible to rapid environmental dissipation, especially under tropical conditions characterised by high temperatures and intense solar radiation. As such, their non-detection may reflect both genuinely low environmental loading and physicochemical behaviour that limits persistence in surface water systems.

Similarly, the absence of detectable THMs in treated water indicates effective control of disinfection by-product formation within the Batu Kitang Water Treatment Plant. This is likely attributable to optimised treatment processes, including coagulation, sedimentation, filtration, and controlled chlorination practices. In contrast to studies conducted in other tropical and subtropical regions such as Vietnam and Indonesia where elevated THM levels have been associated with increased natural organic matter (NOM) during monsoon periods, the present findings suggest a stable treatment performance that is resilient to seasonal variability. This stability is particularly noteworthy given the known influence of hydrological fluctuations on precursor availability and DBP formation potential.

Nevertheless, interpreting non-detectable concentrations as complete absence of risk would be overly simplistic. Analytical results reported as below detection limits (<MDL) do not preclude the presence of contaminants at trace levels below the sensitivity threshold of the analytical method. The method detection limits employed in

this study (0.005 mg/L for BTEX and 0.003 mg/L for THMs), while compliant with USEPA protocols, may not capture ultra-trace concentrations that could be toxicologically relevant under chronic exposure scenarios. Increasingly, evidence suggests that long-term exposure to low concentrations of disinfection by-products and organic micropollutants may still pose cumulative health risks, particularly for vulnerable populations.

From a methodological standpoint, the absence of quantifiable concentrations limits the application of inferential statistical analyses or trend modelling. However, the consistent pattern of non-detects across all four seasonal sampling campaigns provides indirect evidence of temporal stability in both source water quality and treatment performance. Rather than representing a limitation alone, this uniformity can be interpreted as an indicator of system robustness. Nonetheless, future studies employing more sensitive analytical techniques, such as liquid chromatography–high-resolution mass spectrometry (LC-HRMS), may enable detection of trace-level contaminants and facilitate more sophisticated statistical and predictive modelling approaches.

Importantly, the scope of this study is confined to regulated BTEX compounds and THMs, which represent only a fraction of the broader spectrum of chemical contaminants of emerging concern. There is a growing recognition that unregulated disinfection by-products such as halo acetic acids, nitrosamines, and halo nitromethanes as well as emerging pollutants including pharmaceuticals, endocrine-disrupting compounds, and microplastics, may pose equal or greater risks to human health. These contaminants are often more persistent, bioactive, and difficult to remove using conventional treatment processes. As such, reliance solely on traditional indicator compounds may underestimate the true burden of chemical exposure in drinking water systems.

From a public health and policy perspective, the findings of this study reinforce the importance of proactive and continuous water quality surveillance, particularly in rapidly urbanising regions. The demonstrated effectiveness of the Batu Kitang Water Treatment Plant highlights the value of maintaining well-optimised conventional treatment systems, even in the absence of advanced treatment technologies. At the same time, the results underscore the need for adaptive monitoring frameworks that can respond to evolving environmental pressures, including land use change, agricultural intensification, and climate variability.

Climate change represents a critical emerging determinant of water quality. Increasing frequency and intensity of extreme weather events including heavy rainfall, flooding, and prolonged drought can significantly alter the transport and concentration of pollutants, as well as the composition of natural organic matter in source waters. These changes may, in turn, influence the formation dynamics of disinfection by-products in ways that are not captured under current baseline conditions. The absence of seasonal variation observed in this study should therefore not be interpreted as a permanent characteristic, but rather as a snapshot under relatively stable climatic conditions.

Finally, this study contributes to addressing a notable gap in regional data on chemical water quality in East Malaysia, particularly within tropical river systems undergoing gradual urbanisation. By integrating seasonal monitoring with standardised analytical methods, the study provides a valuable baseline for future comparative research and supports evidence-based decision-making in water resource management. Moving forward, expanding the analytical scope, improving detection sensitivity, and incorporating risk-based modelling approaches will be essential for advancing water safety in line with global health and sustainability agendas.

CONCLUSION

The Batu Kitang Water Treatment Plant has demonstrated robust performance in consistently producing potable water free of detectable BTEX and THMs, even under variable seasonal conditions. These results not only highlight effective treatment design and operation but also suggest that current source water conditions remain relatively unpolluted.

This longitudinal study fills a critical data gap in tropical water quality research and offers a template for seasonally integrated monitoring protocols. Continued investment in water quality surveillance and expansion into emerging contaminants will be essential for safeguarding public health and aligning with global sustainable development objectives. Future monitoring frameworks should incorporate emerging contaminants such as

pharmaceuticals, pesticides, endocrine-disrupting compounds, and microplastics, which are increasingly recognized as significant threats to water safety.

Limitation

Future studies incorporating trace-level detection methods or larger datasets may enable statistical modelling such as time-series analysis or probabilistic risk assessment.

Credit Author Statement

Lim Siong Hee: Conceptualization, Methodology, Investigation, Writing – Original Draft. Sam Froze Jiee: Data collection, Supervision, Writing – Review & Editing. Romano Ngui: Formal analysis, Resources, Writing – Review & Editing.

Declaration of Competing Interest

The authors declare no competing interests.

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Ethical Clearance

Ethical clearance obtained from the Ethical Committee of Universiti Malaysia Sarawak.

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