Journal of Tropical Resources and Sustainable Science
Website : http://journal.umk.edu.my/index.php/jtrss/
eISSN : 2462-2689
Vol: 13, Issue 1, 2025, 365-372
DOI: https://doi.org/10.47253/jtrss.v13i2.1675

RESEARCH ARTICLE

Assessment of physicochemical and microbial water quality in rivers of Jeli, Kelantan, Malaysia

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ARTICLE HISTORY
Received : 15 July 2025
Accepted : 27 July 2025
Online : 15 December 2025

KEYWORDS
river,
water quality index,
water quality,
pollution,
water parameters

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ABSTRACT

Rivers in Jeli, Kelantan serve vital ecological, recreational, and socio-economic functions, but their water quality is increasingly threatened by tourism activities and associated land-use changes. This study evaluated the physicochemical and microbial quality of water at four major rivers Lata Janggut, Lata Keding, Lata Kashmir, and Lata Renyuk using the Malaysian Water Quality Index (WQI) and enumeration of *Escherichia coli*. Water samples were analysed for key parameters, including dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3-N), total suspended solids (TSS), and pH. Statistical analysis showed that WQI values ranged from 84.87 to 91.50 (mean ± SD: 87.70 ± 3.06), classifying the rivers as Class I–II (excellent to good quality). DO ranged from 7.01 to 8.62 mg/L (mean: 7.97 ± 0.67), BOD from 2.73 to 8.20 mg/L (mean: 6.22 ± 2.42), and TSS from 3.00 to 16.00 mg/L (mean: 6.75 ± 5.67). *E. coli* counts varied from 9 to 79 CFU/100 mL (mean: 43.25 ± 22.58), with all sites below the US EPA recreational guideline of 126 CFU/100 mL. However, episodic spikes indicate intermittent faecal contamination. The findings highlight the importance of integrated monitoring of chemical and microbial parameters for sustainable river management and public health protection in tourism areas.

1. INTRODUCTION

Freshwater resources, especially rivers, are critical components of ecological integrity, public health, and local economies, particularly in regions experiencing rapid tourism growth. In Malaysia, rivers are extensively utilised for recreational purposes, agriculture, domestic consumption, and tourism-related activities. The increasing reliance on these rivers, especially in rural areas such as Jeli, Kelantan, has led to escalating concerns regarding water quality deterioration (Hanif et al., 2020; Zain et al., 2018).

The environmental pressures facing Malaysian rivers are multifaceted and escalating. Tourism, while offering socio-economic benefits and opportunities for local development, is widely recognised as a key driver of environmental change and water quality degradation. Visitor numbers at popular freshwater recreation sites in Malaysia are reported to range from several hundred to over a thousand per weekend during peak seasons (Norazlimi et al., 2017; Zain et al., 2018). High visitor densities can lead to increased solid and organic waste, higher nutrient and contaminant loads, and physical disturbance of riverbanks and riparian zones (Cham et al., 2020; Thani et al., 2019). Littering, improper waste disposal, and inadequate toilet facilities at tourism sites further contribute to direct contamination, with negative implications for both ecological health and public safety (Vinueza et al., 2021). Such contamination not only threatens aquatic ecosystems but also poses acute public health risks, including outbreaks of waterborne diseases such as gastroenteritis and skin infections among recreational users (WHO, 2021; Bharathithasan et al., 2021). These challenges are compounded by insufficient enforcement of environmental regulations, especially in rural areas where regulatory oversight and infrastructure investment tend to be limited (Saeed et al., 2014). Seasonal variability, such as monsoon-driven runoff, can exacerbate the transport of pollutants into river systems, leading to episodic declines in water quality that are often undetected by routine monitoring (Hanif et al., 2020).

Previous research on Malaysian rivers has predominantly focused on physicochemical indicators, including studies on urbanised or industrial systems (DOE, 2014; Mohd Amin et al., 2014; Zain et al., 2018). These studies have provided important insights into pollution trends, sources, and management approaches. However, rural and tourism-impacted rivers remain understudied, particularly with regard to the complex interactions between anthropogenic activities and riverine ecosystem health (Cham et al., 2020). Most monitoring programmes neglect to include microbial assessments—such as faecal indicator bacteria—which are essential for evaluating public health risks associated with recreational water use (Ishii & Sadowsky, 2008; Bharathithasan et al., 2021; WHO, 2021). As a result, there is a critical knowledge gap concerning the full spectrum of contaminants, the temporal dynamics of pollution events, and the actual risks faced by local communities and tourists. Addressing this gap is crucial, given that current monitoring may not capture short-term spikes in contamination that coincide with peak tourism period.

Globally, the integration of physicochemical and microbial indicators is increasingly recognised as best practice for water quality assessment, given the direct implications for waterborne diseases and environmental sustainability (WHO, 2021; Vinueza et al., 2021). In Malaysia, river water quality is benchmarked against the Department of Environment (DOE) Water Quality Index (2014), which classifies rivers into five classes based on key parameters such as DO, BOD, COD, TSS, pH, and faecal coliforms. For microbial safety, the DOE guideline for recreational waters is ≤400 CFU/100 mL for faecal coliforms, while the US EPA (2012) guideline is ≤126 CFU/100 mL for *E. coli*, and the World Health Organization (WHO, 2021) provides additional global benchmarks. However, routine surveillance often remains fragmented and insufficiently responsive to the pressures exerted by tourism expansion, particularly in rural destinations such as Jeli. There is a pressing need for comprehensive, site-specific studies that bridge the gap between environmental science, public health, and tourism management.

Given this context, the present study is designed to provide an integrated assessment of physicochemical and microbial water quality parameters at four prominent rivers in Jeli, Kelantan: Lata Janggut, Lata Keding, Lata Kashmir, and Lata Renyuk. By benchmarking observed water quality against national and international guidelines, and by analysing both chemical and biological risks, this research aims to generate evidence-based recommendations to inform effective management strategies and policy interventions for sustainable river tourism. Therefore, the objectives of this research are: (i) to investigate key physicochemical and microbial water quality parameters at selected river tourism sites; (ii) to benchmark the observed water quality against national and international guidelines; and (iii) to provide evidence-based recommendations for improved management strategies to mitigate contamination risks associated with tourism activities.

2. MATERIALS AND METHODS

2.1. Study area

This study was conducted at four popular river tourism sites located in Jeli, Kelantan, Malaysia: Lata Janggut, Lata Keding, Lata Kashmir, and Lata Renyuk. These sites are situated within a humid tropical region, characterised by high annual rainfall (typically >2,500 mm) and marked seasonal variation in river flow associated with monsoon and inter-monsoon periods. The rivers assessed are small to medium in size and serve as prominent recreational destinations for both local residents and tourists. The surrounding land use at each site comprises a mosaic of mixed forest, agricultural areas, and small settlements, representing typical catchment conditions in the region. Site selection was based on several criteria, including accessibility, frequency of tourist visitation, and the need to represent upstream-to-downstream water quality gradients, consistent with approaches recommended in previous studies (Hanif et al., 2020). This approach allows for the assessment of spatial variability in water quality relative to tourism intensity and landscape setting.

The geographical coordinates of each sampling site were determined using a handheld global positioning system (GPS), and are provided in Table 1. Water samples were collected at representative points within the primary recreational zones of each river, using a random sampling method to minimise site selection bias. These locations were used as the basis for subsequent calculation of the Water Quality Index (WQI) and assessment of physicochemical and microbial parameters.

Table 1: Georeferenced of the selected sampling locations

Station	Latitude (N)	Longitude (E)
Lata Kashmir (Figure 1.1.)	05°40'11.04	101°41'51.07
Lata Renyuk (Figure 1.2)	05°34'49	101°53'5
Lata Keding (Figure 1.3)	05°44'48.68	101°50'54.92
Lata Janggut (Figure 1.4)	05°40'16.61	101°46'13.97

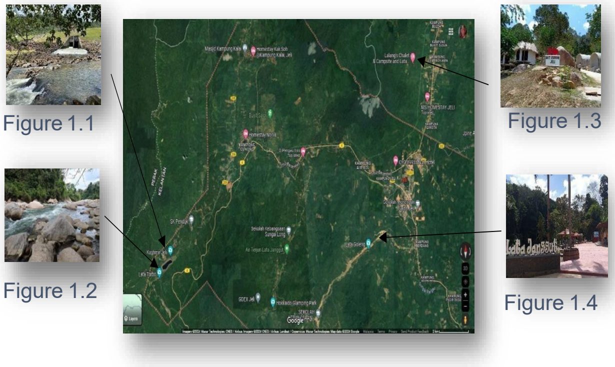

Figure 1: Map of sampling location at Jeli, Kelantan, Malaysia

2.2. Sampling strategy

Sampling was conducted in September 2024 to characterise water quality during the post-monsoon period, which coincides with peak tourism activity in Jeli, Kelantan. At each river site, samples were collected at both upstream and downstream points to capture spatial variability related to potential tourism impacts. For each location, triplicate samples were collected on three separate days, resulting in a total of 24 samples per parameter across all sites. Physicochemical water samples were collected using acid-washed polyethylene bottles, while samples for microbiological analysis were collected in sterile glass bottles to prevent contamination. Immediately after collection, all samples were stored in insulated cooler boxes with ice packs to maintain a temperature of approximately 4°C, and were transported to the laboratory for analysis within 6 hours of sampling, in accordance with APHA Standard Methods (APHA, 2017; Zain et al., 2018).This sampling approach ensures adequate replication for statistical analysis and captures temporal and spatial heterogeneity in river water quality during periods of high recreational use.

2.3. In-situ measurements

In-situ parameters measured included temperature, pH, dissolved oxygen (DO), turbidity, and conductivity, using a calibrated YSI 556 MPS multi-parameter sonde. Turbidity was measured in NTU using a portable turbidity meter (Hach 2100Q). All instruments were calibrated daily with certified standard solutions prior to fieldwork (APHA, 2017). Detection limits were as specified by the manufacturer: pH (0.01 units), DO (0.01 mg L^{-1}), conductivity (1 µS cm^{-1}).

2.4. Laboratory analyses

Biochemical Oxygen Demand (BOD) was determined by incubating water samples in airtight BOD bottles at 20°C for five days and measuring the initial and final DO concentrations with a DO meter (APHA, 2017). Chemical oxygen demand (COD) was measured by closed reflux, colorimetric titration (APHA 5220C), with absorbance read at 600 nm using a Hach DR6000 spectrophotometer. Total suspended solids (TSS) were analysed gravimetrically after filtration through pre-weighed glass fibre filters and drying at 105°C for 24 hours (APHA 2540D). Ammoniacal nitrogen (NH_3-N) was analysed using the salicylate method, quantified by spectrophotometric measurement at 655 nm wavelength (APHA, 2017).

Escherichia coli (*E. coli*) enumeration was performed using the membrane filtration technique. Water samples were filtered through sterile 0.45 µm cellulose acetate membranes, placed onto Chromocult® Coliform Agar (Merck), and incubated at 37°C for 24 hours. Colonies displaying characteristic blue-violet coloration were counted and reported as colony-forming units per 100 mL (CFU/100 mL), as per standard microbiological procedures (APHA, 2017).

2.5. Water quality index (WQI) calculation

The WQI was calculated per Malaysian DOE (2014) guidelines, incorporating six parameters: DO, BOD, COD, NH_3-N, TSS, and pH. WQI classification boundaries were: Class I (>92.7), Class II (76.5–92.7), Class III (51.9–76.5), Class IV (31–51.9), and Class V (<31) (Zain et al., 2018). Sub-indices for each parameter were derived using DOE-prescribed curves and equations.

The WQI formula and sub-index weightings applied were:

$$WQI = (0.22 * SIDO) + (0.19 * SIBOD) + (0.16 * SICOD) + 0.15 * SIAN) + (0.16 * SISS) + (0.12 * SIpH)$$

Where SIDO, SIBOD, SICOD, SIAN, SISS, and SIpH represent the sub-indices for dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, ammoniacal nitrogen, suspended solids, and pH, respectively. Sub-indices were calculated based on established DOE equations and standard curves.

2.6. Statistical analysis

All data were analysed using Microsoft Excel 365 and SPSS v27. Descriptive statistics (mean, SD, minimum, maximum) were computed. Data normality was checked via Shapiro-Wilk test. For comparisons between sites, one-way ANOVA was applied where assumptions were met; otherwise, nonparametric Kruskal-Wallis tests were used (Zain et al., 2018; Hee et al., 2019). Statistical significance was accepted at $p<0.05$. Statistical analyses were used to evaluate variations between sites and parameters, with results compared against Malaysian and international water quality guidelines (DOE, 2014; EPA, 2012).

3. RESULT AND DISCUSSION

3.1 Physicochemical water quality

The physicochemical characteristics of water quality for the four river tourism sites in Jeli, Kelantan are summarised in Table 2 (mean ± SD, n = 9 per site). Parameters analysed include dissolved oxygen (DO), pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and ammoniacal nitrogen (NH_3-N), with results benchmarked against the Malaysian Department of Environment (DOE, 2014) standards and recent studies (Hanif et al., 2020; Zain et al., 2018).

Dissolved oxygen (DO) concentrations across all sites ranged from 7.01 to 8.62 mg L^{-1}, with the highest mean value recorded at Lata Keding. These elevated DO levels indicate well-oxygenated river conditions, which support healthy aquatic ecosystems and are indicative of low organic pollution. All sites exceeded the DOE threshold for Class II rivers (>5 mg L^{-1}), and differences in DO between Lata Keding and Lata Renyuk were statistically significant (ANOVA, $p < 0.05$). The higher DO at Lata Keding likely reflects increased reaeration or lower immediate organic load, while the relatively lower value at Lata Renyuk may be influenced by site-specific hydrology and organic inputs.

All sites exhibited pH values between 6.56 and 7.38, falling within the optimal range (6.5–8.5) for riverine environments set by DOE (2014), and thus considered safe for both ecological health and recreational use. This stability suggests effective natural buffering capacity and limited influence from acidifying or alkalinising inputs.

Biochemical oxygen demand (BOD) showed notable variation between sites. The lowest BOD was observed at Lata Janggut (2.73 mg L^{-1}), whereas Lata Keding recorded the highest BOD (8.20 mg L^{-1}), exceeding the Class II guideline (6 mg L^{-1}). Elevated BOD at Lata Keding is most likely attributable to increased organic matter from visitor activities and improper disposal of solid and liquid waste, as has been reported in other recreational river studies (Thani et al., 2019; Mohd Amin et al., 2014a). Statistically significant differences in BOD were found among sites ($p < 0.05$). This pattern signals the need for improved visitor management and waste handling, particularly during peak seasons.

Chemical oxygen demand (COD) values ranged from 22.00 to 35.00 mg L^{-1}, with Lata Kashmir showing the highest mean COD. Both Lata Kashmir and Lata Janggut exceeded the DOE Class II threshold for COD (25 mg L^{-1}), indicating moderate levels of organic and inorganic pollutants, likely introduced by both tourism-related waste and surface runoff from nearby Pergau dam and settlement, consistent with findings by Cham et al. (2020). Significant differences in COD among sites ($p < 0.05$) highlight the effect of local land use and visitor pressure. Regular monitoring of COD is recommended to track cumulative pollution trends.

Table 2: Physicochemical water quality parameters and Water Quality Index (WQI) at four river tourism stations in Jeli, Kelantan (n = 3 per site, September 2024). All units as shown. DOE (2014) class boundaries: Class I (>92.7), Class II (76.5–92.7), Class III (51.9–76.5), Class IV (31–51.9), Class V (<31).

Water Quality Parameter	Unit	Water Sampling Station (n=3)			
		Lata Janggut	Lata Keding	Lata Renyuk	Lata Kashmir
DO	mg/L	8.28	8.62	7.01	7.97
BOD	mg/L	2.73	8.2	7.8	8.15
COD	mg/L	27	22	25	35
AN	mg/L	0.4	0.2	0.3	0.1
TSS	mg/L	3	3	5	16
pH	-	7.33	7.38	6.56	7.02
Conductivity	µS/ cm	38.2	73.8	61.3	54.1
TDS	mg/L	24.05	47.45	30.51	35.75
Temperature	C	26	25.9	24.04	24.6
Turbidity	NTU	1.72	2.41	1.24	32.1
Total phosphorus	mg/L	0.1	0.1	0.01	0.1
Nitrogen	mg/L	0.2	0.2	0.01	0.2
Overall WQI		91.5	84.87	85.67	89.75
Class		II	II	II	II
Water Quality Status		Clean	Clean	Clean	Clean

Total suspended solids (TSS) varied between 3.00 and 16.00 mg L^{-1}. Lata Kashmir exhibited the highest TSS, though all values remained well below the DOE Class II limit (50 mg L^{-1}). The higher TSS at Lata Kashmir is likely the result of riverbank disturbance and sediment resuspension due to recreational use and possible upstream erosion following rainfall events. High TSS can reduce water clarity, affecting both ecological health and visitor experience (Zain et al., 2018). The spatial variation in TSS corresponds to differences in site management and intensity of use. Ammoniacal nitrogen (NH_3-N) remained consistently low across all sites (0.10 to 0.40 mg L^{-1}), suggesting minimal nutrient pollution and little agricultural or domestic effluent impact. All values were below the DOE Class II guideline (0.3 mg L^{-1}), indicating limited influence from non-point source pollution.

The overall Water Quality Index (WQI) values ranged from 84.87 to 91.50, classifying all rivers within Class II according to DOE (2014) criteria (76.5–92.7). Notably, Lata Janggut recorded the highest WQI (91.50), bordering Class I (>92.7), which reflects excellent water quality and limited human impact. In contrast, Lata Keding had the lowest WQI (84.87), highlighting more substantial anthropogenic influence, likely from higher tourist density and related activities. Figure 2 provides a visual representation of WQI values at each river site, including DOE class boundaries, illustrating these differences and allowing for straightforward comparison among the sites. As depicted in Figure 2, all rivers achieved WQI values within Class II, with Lata Janggut approaching the Class I threshold, confirming its relatively pristine condition compared to the others. It should be noted that these results are collected during a single post-monsoon during the peak tourism season, which may limit the ability to capture temporal variability or extreme events. Nevertheless, the observed trends provide important insight into the influence of tourism and land use on river water quality in Jeli.

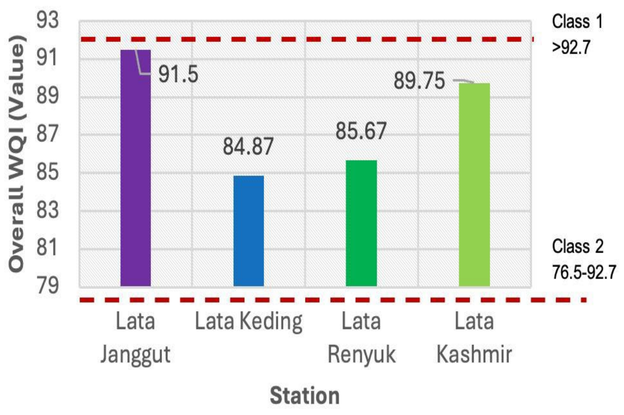

Figure 2: Overall Water Quality Index (WQI) for four river tourism sites in Jeli, Kelantan (mean ± SD, n = 3, September 2024). DOE class boundaries are indicated for reference.

3.2 Microbial water quality

The microbial water quality, as measured by *E. coli* counts, is detailed in Table 3. Mean *E. coli* counts ranged from 31.0 ± 13.3 CFU/100 mL at Lata Keding to 50.3 ± 22.5 CFU/100 mL at Lata Janggut, with the highest single value of 79 CFU/100 mL recorded at Lata Kashmir. All observed values remain below both the Malaysian DOE (2014) recreational guideline for faecal coliforms (400 CFU/100 mL) and the US EPA (2012) guideline for *E. coli* (126 CFU/100 mL), indicating an overall low direct risk to recreational users during the monitoring period.

However, the data reveal considerable site-specific and temporal variability. For instance, the relatively higher mean *E. coli* counts at Lata Janggut and Lata Kashmir notably during weekends and post-rainfall sampling suggest the influence of transient contamination sources. These may include improper waste disposal by visitors, the lack of adequate sanitation infrastructure, and surface runoff mobilising animal or human waste from adjacent areas. Similar episodic increases in *E. coli* have been documented in tropical recreational rivers, where rainfall events rapidly transport faecal contaminants into waterways (Vinueza et al., 2021; Ng et al., 2021).

The highest single *E. coli* measurement at Lata Kashmir (79 CFU/100 mL), while still within permissible limits, is a cause for concern if such spikes coincide with peak visitor presence, as even short-term exceedances can increase the risk of waterborne illness (Ng et al., 2021). This finding underscores the inadequacy of relying solely on routine, average-based monitoring to capture microbial risk in dynamic river tourism settings.

Furthermore, the observed range and variability of *E. coli* counts align with studies indicating that tropical river systems are especially prone to rapid microbial fluctuations, particularly in the context of intense rainfall and high recreational use (Bharathithasan et al., 2021; Shamima Shultana & Khan, 2022). The results thus highlight the importance of not only maintaining regular microbial monitoring especially during periods of increased site usage and following precipitation but also implementing rapid response measures to protect public health.

Table 3. *E. coli* counts (CFU/100 mL; mean ± SD) at four river tourism stations in Jeli, Kelantan (n = 4 per site, September 2024). Malaysian DOE guideline for faecal coliforms in recreational water: 400 CFU/100 mL; US EPA guideline for *E. coli*: 126CFU/100 mL.

Site	Sample 1	Sample 2	Sample 3	Sample 4	Mean ± SD
Lata Kashmir	50	9	23	79	40.25 ± 31.24
Lata Keding	50	27	25	22	31.00 ± 13.34
Lata Renyuk	61	43	41	55	50.00 ± 9.42
Lata Janggut	56	51	73	21	50.25 ± 22.54

3.3 Comparative analysis of physicochemical parameters

Figure 3 provides a comparative visual summary of the key physicochemical parameters—dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and pH—measured at each site. Notably, BOD values were highest at Lata Kashmir (8.20 mg L^{-1}) and Lata Keding (7.45 mg L^{-1}), both exceeding the Class I threshold (<3 mg L^{-1}) set by the DOE (2014) and suggesting a moderate degree of organic pollution. These values point to significant organic matter input, likely arising from increased recreational activities, improper disposal of organic waste, and high visitor density, especially during weekends and holidays. Similar patterns of BOD elevation due to tourism pressure have been documented in Malaysian rivers (Zain et al., 2018; Thani et al., 2019). In comparison, Lata Janggut (2.73 mg L^{-1}) and Lata Renyuk (3.56 mg L^{-1}) maintained lower BOD levels, consistent with less intensive use and more substantial forested buffer zones.

COD values further differentiate the sites: Lata Kashmir recorded the highest COD (35.00 mg L^{-1}), followed by Lata Janggut (32.50 mg L^{-1}). Both of these values surpass the 30 mg L^{-1} threshold often cited as a marker of moderate to high oxidisable pollutant load (DOE, 2014), and are higher than the 22–28 mg L⁻¹ range commonly reported for rural Malaysian rivers in previous studies (Zain et al., 2018). The high COD at Lata Kashmir is likely a consequence of greater influxes of both organic and inorganic pollutants due to heavy visitor load and possible upstream sources, while the relatively elevated COD at Lata Janggut may be linked to episodic pollution events, natural debris, or specific land use factors in the catchment area.

TSS values exhibit marked spatial variability. Lata Kashmir demonstrated the highest TSS (16.00 mg L^{-1}), significantly above the other sites—Lata Renyuk (5.00 mg L^{-1}), Lata Janggut (3.00 mg L^{-1}), and Lata Keding (3.00 mg L^{-1}). Elevated TSS at Lata Kashmir is indicative of greater erosion, riverbed disturbance, or direct particulate input, likely due to intense recreational activities or inadequate riparian management. Such increases in suspended solids not only reduce water clarity and aesthetic value but also impact aquatic habitats by promoting sedimentation and reducing light penetration. Lower TSS at the other sites reflects less disturbance and better retention of sediment by riparian vegetation.

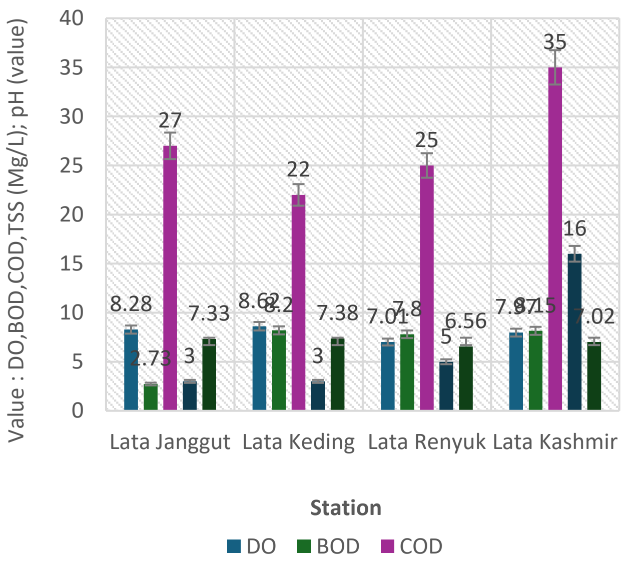

Figure 3: Physicochemical water quality parameters for each river tourism site in Jeli, Kelantan (n = 3 per site). DOE (2014) class boundaries shown as reference lines.

DO concentrations remained above the minimum ecological threshold (≥5 mg L^{-1}) at all sites, with Lata Keding registering the highest mean DO (8.62 mg L^{-1}) and Lata Kashmir the lowest (7.01 mg L^{-1}). The lower DO at Lata Kashmir could be attributed to greater oxygen consumption resulting from the higher BOD and COD measured at this site, whereas higher DO at Lata Keding suggests efficient reaeration or lower immediate oxygen demand, possibly due to river morphology or hydrological conditions.

pH levels across all rivers were relatively stable, ranging from 6.56 to 7.38, comfortably within the DOE (2014) recommended range of 6.5–8.5 for healthy river systems. This indicates that neither acidification nor alkalinisation poses a concern at any site, supporting the continued suitability of these rivers for recreational use.

The combined spatial patterns of these key parameters underscore the link between intensive tourism activities, local land use, and river water quality deterioration, particularly at Lata Kashmir and Lata Keding. These trends warrant the implementation of targeted river management interventions and regular monitoring to prevent further degradation.

3.4 Integrated discussion and management implication

The water quality assessment across the four rivers in Jeli, Kelantan, reveals a nuanced landscape: most sites sustain generally good conditions, yet certain locations are vulnerable to episodic pollution, especially after rainfall or intensive use. These site-specific and temporal variations, reflected in elevated BOD, COD, and occasional *E. coli* spikes, highlight the limitations of current management and monitoring regimes that rely on periodic sampling and do not always account for short-term contamination events.

Our results suggest that management efforts should be closely aligned with these patterns of risk. For example, site-specific interventions such as improved sanitation, targeted waste management, and high-frequency event-based monitoring have been shown to effectively reduce episodic pollution and public health risks in Southeast Asian and Malaysian river recreation sites (Shamima Shultana & Khan, 2022; Abdullah et al., 2023). Furthermore, recent work has demonstrated that integrating microbial and physicochemical monitoring is essential for accurate risk assessment in Malaysian recreational waters (Ng et al., 2021).

Rather than blanket strategies, adaptive management such as flexible water quality monitoring during weekends or after storms, and more robust maintenance of existing facilities would address the episodic nature of the pollution documented in this study (Shamima Shultana & Khan, 2022). Clear communication of water quality risks to stakeholders, supported by targeted education campaigns at high-use sites, will further promote responsible behaviour and risk mitigation (Ng et al., 2021). Involving local communities and stakeholders in both monitoring and management processes is also critical for long-term success.

Overall, this study demonstrates that evidence-based, site-specific, and adaptive management is essential to sustain the ecological, recreational, and public health value of Jeli's river systems. Continued research and monitoring responsive to the temporal and spatial dynamics revealed here will be crucial in ensuring that river tourism remains both safe and sustainable (Abdullah et al., 2023; Shamima Shultana & Khan, 2022).

4. CONCLUSION

This study presents a comprehensive evaluation of both physicochemical and microbial water quality at four major rivers supporting tourism in Jeli, Kelantan. Overall, the rivers maintained excellent to good status according to the Malaysian Water Quality Index (WQI) classification (Class I–II), with dissolved oxygen, ammoniacal nitrogen, and chemical oxygen demand consistently meeting the Department of Environment (DOE, 2014), US EPA (2012), and WHO (2021) guidelines for recreational waters.

However, the detection of elevated biochemical oxygen demand and total suspended solids at certain locations underscores the impacts of intensive human activity and highlights the need for site-specific management. Episodic spikes in *E. coli,* particularly during weekends and following rainfall, indicate transient microbial contamination events that can pose health risks to recreational users risks not always captured by average or routine monitoring.

These findings demonstrate the necessity for integrated monitoring programs that include both chemical and microbial water quality indicators, in combination with improved sanitation infrastructure, targeted public awareness initiatives, and robust waste management at high-use sites. Adaptive management strategies, such as event-based monitoring and rapid response protocols, are recommended to more effectively mitigate episodic pollution risks.

Continued research and responsive monitoring, especially during peak tourism and rainfall events, will be essential for maintaining the ecological health, public safety, and economic sustainability of river-based tourism in Jeli and comparable rural destinations. Future work should address intra-annual variability and further investigate the effectiveness of management interventions in reducing pollution loads and protecting water quality.

ACKNOWLEGMENT

The authors extend their gratitude to Universiti Malaysia Kelantan and Universiti Teknologi Malaysia for their generous support of this research under the CRG project (R/SGJP/A0800/00425A/003/2018/00569) and Jabatan Perhutanan Negeri Pahang (JPNP) for the Lubuk Yu Project (R/JPNP/A0800/00425A/007/2025/01399).

REFERENCES

Abdullah, S., Harun, S., Mohamad, R., & Wong, Y. K. (2023). The effectiveness of sanitation interventions in reducing faecal contamination at river recreation sites: A Malaysian case study. Science of the Total Environment, 893, 164682.

APHA. (2017). Standard methods for the examination of water and wastewater (23rd ed.). American Public Health Association, American Water Works Association, Water Environment Federation.

Bharathithasan, M., Ravindran, D. R., Rajendran, D., Ishak, I. H., & Ravi, R. (2021). Analysis of chemical compositions and larvicidal activity of nut extracts from Areca catechu Linn against Aedes (Diptera: Culicidae). PLoS ONE, 16(11), e0260281.

Cham, H., Malek, S., Milow, P., & Mohd Raznan, R. (2020). Web-based system for visualisation of water quality index. All Life, 13(1), 426–432.

Department of Environment (DOE). (2014). National water quality standards for Malaysia. Ministry of Natural Resources and Environment, Putrajaya, Malaysia.

EPA. (2012). Recreational water quality criteria. United States Environmental Protection Agency. https://www.epa.gov/wqc/2012-recreational-water-quality-criteria

Hanif, M. H., Isa, M. M., & Ishak, M. H. (2020). The effect of monsoon on the water quality of rivers in Kelantan. Malaysian Applied Biology, 49(1), 143–149.

Hee, L. W., Ismail, W. I. W., & Hashim, N. W. (2019). Water quality analysis of Malaysian rivers: A review. Journal of Sustainability Science and Management, 14(2), 1–14.

Ishii, S., & Sadowsky, M. J. (2008). Escherichia coli in the environment: Implications for water quality and human health. Microbes and Environments, 23(2), 101–108. https://doi.org/10.1264/jsme2.23.101

Mohd Amin, M. F., Heijman, S. G. J., & Rietveld, L. C. (2014). The potential use of polymer flocculants for pharmaceuticals removal in wastewater treatment. Environmental Technology Reviews, 3(1), 61–70.

Ng, L. Y., Lee, Y. Y., Md Zain, N. M., & Ahmad, A. (2021). Microbial contamination and health risks in Malaysian recreational waters: Current status and future needs. Water Research, 198, 117208.

Saeed, S. M. G., Ahmad, M. K., & Rahman, M. Z. A. (2014). Assessment of river water quality using the water quality index (WQI): A case study of Langat River, Malaysia. EnvironmentAsia, 7(2), 1–5.

Shamima Shultana, S., & Khan, M. (2022). The impact of river water pollution on human health in Malaysia. Malaysian Journal of Medicine and Health Sciences, 18(2), 34–40.

Thani, N. S. M., Ghazi, R. M., Amin, M. F. M., & Hamzah, Z. (2019). Phytoremediation of heavy metals from wastewater by constructed wetland microcosm planted with Alocasia puber. Jurnal Teknologi, 81(5), 17–23.

Vinueza, D., Ochoa-Herrera, V., Maurice, L., Cevallos, J., Espinoza, N., Ponce, F., & Lopez, D. (2021). Determining the microbial and chemical contamination in Ecuador's main rivers. Scientific Reports, 11, 17640.

WHO. (2011). Guidelines for drinking-water quality (4th ed.). World Health Organization.

WHO. (2021). Guidelines on recreational water quality: Volume 1. Coastal and fresh waters. World Health Organization.

Zain, R. A. M. M., Shaari, N. F. I., Amin, M. F. M., & Jani, M. (2018). Effects of different dose of zeolite (Clinoptilolite) in improving water quality and growth performance of red hybrid tilapia (Oreochromis sp.). ARPN Journal of Engineering and Applied Sciences, 13(24), 9421–9426.

