INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
ISSN: 2180-3242 e-ISSN: 2600-7959

IJSCET

Vol. 16 No. 2 (2025) 220-234
https://publisher.uthm.edu.my/ojs/index.php/ijscet

Innovative Approaches to Water Quality Assessment: Integrating Physicochemical and Biological Indicators in Forest Eco-Park Upstream Rivers

Nurul Amni Ali[1], Aqilah Zakiah Jahani[2], Nor Amani Filzah Mohd Kamil[3]*, Nurhidayah Hamzah[4]

[1] *Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA*
[2] *Green Plus Consultancy (M) Sdn Bhd, 41, Medan Perhentian, Medan Kidd, 30200 Ipoh, Perak Darul Ridzuan, MALAYSIA*
[3] *Micropollutant Research Centre, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA*
[4] *Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA*

*Corresponding Author: noramani@uthm.edu.my
DOI: https://doi.org/10.30880/ijscet.2025.16.02.014

Article Info

Received: 11 January 2025
Accepted: 20 August 2025
Available online: 6 September 2025

Keywords

Biological indicators, macroinvertebrates, Water Quality Index, canonical correspondence analysis

Abstract

Measuring the Water Quality Index (WQI) is essential for evaluating water conditions, especially in ecologically sensitive areas. However, assessing physicochemical indicators alone may not provide sufficient information about the overall health of river ecosystems. This study integrates macroinvertebrates as biological indicators to complement traditional WQI assessments, offering a more holistic and ecologically meaningful understanding of water quality. The research was conducted at upstream rivers in four forest eco-parks: Forest Eco-Park Soga Perdana Hill (FESP), Forest Eco-Park Mount Lambak (FEML), Forest Eco-Park Mount Pulai II (FEMP), and Forest Eco-Park Bantang River (FEBR), Johor, Malaysia. Conventional WQI parameters—including Ammonia Nitrogen (AN), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Total Suspended Solids (TSS), and pH—were compared with macroinvertebrate-based bioassessment using the Biological Monitoring Working Party–Average Score Per Taxon (BMWP-ASPT) index. Data analysis using Microsoft Excel showed a strong inverse correlation between BMWP-ASPT and WQI (R^2 = 0.9385; Pearson r = -0.93974). While WQI classified FEBR as slightly polluted (WQI = 73.77, Class III), BMWP-ASPT indicated cleaner conditions (8.04), suggesting that macroinvertebrate-based methods may reveal different ecological insights, particularly in areas with subtle anthropogenic pressures. These findings have practical implications for sustainable water management, especially in recreational eco-parks and data-limited settings, where the integration of biological and physicochemical indicators can support more comprehensive and adaptive monitoring practices.

1. Introduction

A river is a natural stream of freshwater that flows across land, typically emptying into an ocean, sea, lake, or another river [1]. The river plays a vital role in the hydrological cycle and is an essential resource for human societies, wildlife and the environment. Water quality is a critical factor influencing the health and sustainability of river ecosystems, particularly in protected natural areas such as forest eco-parks. Rivers within eco-parks support diverse flora and fauna and serve as a resource for waterfront recreational activities. River preservation is important as rivers offer habitats to a wide range of aquatic life, including fish, phytoplankton, zooplankton, and benthic species. In addition, aquatic plants and microorganisms are crucial in sustaining the ecological equilibrium and overall health of these riverine environments [2], [3].

However, these areas are on the growing list of vulnerable ecosystems in danger of environmental pressures such as air, water, and noise pollution from adjacent human activities, climate change, and excessive logging. According to Wei et. al [4], human activities influence hydrological processes primarily through the use of artificial water systems, land management, and water regulation. Tourism, agriculture, and improper waste management contribute to water quality degradation through pollution. For instance, the influx of tourists in eco-parks often leads to littering and improper waste disposal, introducing contaminants into the river ecosystem. Additionally, agricultural runoff from nearby farmlands can result in the accumulation of harmful chemicals, such as pesticides and fertilizers, further deteriorate water quality. Climate change has an impact on water flow and sediment dynamics. Global climate shifts disrupt the natural water cycle by altering rainfall patterns and affecting river hydrology. Changes in precipitation, such as heavier rainfall or extended droughts, can lead to both excess sedimentation and erosion of riverbanks [5]. These processes are further intensified by human activities like deforestation and land use changes, which amplify runoff and sediment transport, undermining the stability of river systems.

Logging, both legal and illegal, poses a significant threat to the river systems in these areas. The removal of trees reduces the forest's ability to retain soil, causing extensive erosion during periods of rainfall [6]. As a result, sediment is washed into rivers, making the water turbid and reducing the light available to aquatic plants and organisms. Such changes disrupt aquatic ecosystems, affecting species that depend on clean water. Additionally, the lists of vegetation alter hydrological patterns, with clear-cutting techniques increasing flood risks, while more sustainable logging methods can mitigate these effects.

The risk poses by contaminants in river water can affect human health and the entire ecosystem [7], [8], [9]. Water pollution sources range from various chemicals and pathogens to physical parameters, often involving both organic and inorganic pollutants [10]. Human activities impacting biodiversity have significant implications for human well-being and that of others [11]. Human exposure to environmental contaminants can occur through dermal contact, ingestion of contaminated water, or consumption of recreationally sourced fish and shellfish. Such exposures pose health risks ranging from minor illnesses to severe and potentially fatal conditions. Vulnerable populations, including children, the elderly, and individuals with compromised immune systems, are at greater risk due to their heightened susceptibility [12]. Furthermore, polluted rivers can diminish economic opportunities related to fishing, tourism, and agriculture, impacting local communities' livelihoods.

River pollution has far-reaching threats to natural ecosystems, often disrupting the balance essential for healthy biodiversity and ecological services. In ecosystems, pollution weakens biodiversity by reducing species populations, which is critical as many aquatic species serve as primary indicators of water quality and contribute to food chains that support larger animals. Gangwar [13] found that elevated effluent concentrations reduce fish survival times. A decline in biodiversity disrupts ecosystem functioning, leading to water purification, nutrient cycling, and habitat structure losses, which are vital for ecosystem resilience.

Managing and maintaining water resources presents a significant challenge. One effective method to address water pollution is through regular assessment of water quality, which helps determine the level of contamination. Conducting water sampling allows for the identification of pollution sources, whether from natural events or human activities. Analysing the composition of water and observing changes over time provides insight into the influence of various inputs on water quality. This information supports the development of strategies aimed at reducing pollution and safeguarding aquatic ecosystems. To accurately evaluate the condition of river streams, both physicochemical and biological indicators are utilized. Ensuring the precision of these indicators is essential for effective water quality monitoring and improvement.

The river surroundings provide a habitat for freshwater flora and fauna, including macroinvertebrates, one of the biological indicators that decompose and transform natural matter and pollutants and can withstand various human-induced stressors in the water. The health of rivers can be determined by examining the diversity of macroinvertebrates in well-oxygenated water [1]. Macroinvertebrates inhabit stream ecosystems and exhibit varying levels of tolerance to pollution and environmental stress. Due to their limited mobility, they are unable to escape unfavorable conditions quickly, making them reliable indicators of water quality [14]. These organisms are commonly observed in upstream areas, where pollution-sensitive families like Caenidae and Hydropsychidae are more prevalent, while more tolerant groups such as Chironomidae tend to dominate downstream locations

[15]. Species such as mayflies, stoneflies, and caddisflies are particularly sensitive to pollutants and are typically found in clean, well-oxygenated waters, indicating good ecological conditions.

Macroinvertebrates are crucial in regulating freshwater ecosystems by controlling algal blooms, decomposing organic material, and cycling nutrients. They are widely recognized as effective biological indicators of freshwater health. To interpret macroinvertebrate sampling results, score-based biotic indices are frequently applied in water resource management [16]. These indices simplify extensive environmental monitoring data by assigning scores to taxa, typically at the family or genus level, based on their tolerance to organic pollution. Higher or lower reflect the sensitivity of specific groups, depending on the index used[17]. As integral components of aquatic ecosystems, macroinvertebrates contribute to ecological balance, and their preservation is important for maintaining water quality and assessing the overall health of freshwater environments [18]. Their presence or absence can reflect the river's ecological condition and pollution tolerance. Employing biological indicators such as macroinvertebrates is also a cost-effective and practical approach for evaluating water quality.

The Department of Environment uses the Water Quality Index (WQI) and National Water Quality Standards for Malaysia (NWQS), which are water parameters that are physical-chemical indicators used to assess river water quality in Malaysia. WQI has been used for 25 years, while NWQS determine suitable water uses according to the WQI [19]. However, WQI requires laboratory work and analysis and provides limited information on pollutants' impact on fauna and flora. Physical indicators include taste, color, odor, temperature, turbidity, solids, and electrical conductivity. Chemical indicators include acidity, alkalinity, biological oxygen demand, chlorine, hardness, dissolved oxygen, hardness and pH, commonly used to evaluate river water quality [20]. Evaluating physicochemical parameters alone may not fully capture the ecological condition of river ecosystems. In certain situations, chemical testing may also overlook specific pollutants due to natural processes or limitations in detection methods [21].

This limitation has led to increased interest in biological indicators, especially macroinvertebrates, which are sensitive to habitat changes and pollution levels. Macroinvertebrates respond over time to environmental stressors and offer a more stable indication of ecosystem health. Several biotic indices—such as the Hilsenhoff Biotic Index (HBI), Family Biotic Index (FBI), Ephemeroptera-Plecoptera-Trichoptera (EPT) richness, and the Biological Monitoring Working Party–Average Score Per Taxon (BMWP-ASPT)—have been developed and applied in various regions. Among these, BMWP-ASPT stands out for its ease of application, especially in tropical settings with limited taxonomic expertise, as it requires only family-level identification [17].

The use of biological indicators, particularly those based on macroinvertebrates, is a globally recognized and commonly applied approach for evaluating water quality. Macroinvertebrates, such as those found in the Johor River, have proven to be reliable indicators when used alongside chemical assessments. According to Yusop et. al [22], the Biological Water Quality Index (BMWQI) values ranging from 3.8 to 4.25 indicated a moderate pollution level in the Johor River, emphasizing the strong connection between physicochemical and biological indicators. Zakiah et al. [23] highlighted the Average Score Per Taxon (ASPT) index as practical and efficient tool for water quality evaluation, showing clear differences between upstream and downstream sections. This method helps standardize the use of macroinvertebrate diversity as bio-indicators, which is vital for maintaining the health of connected freshwater systems. Weng & Chee [14] recommend using macroinvertebrates in future restoration programs as biological monitoring agents. Their findings indicated that station 2 (located from upstream to midstream) had Class II water quality, while station 6 (downstream) showed signs of possible contamination. A related study along Asah River in Tioman Island, Johor, using the BMWP index, recorded Class II water quality at upstream and midstream points. The Ephemeroptera, Plecoptera, and Trichoptera (EPT) index score of macroinvertebrates in ecological monitoring [24]. Similarly, the BMWP-ASPT method was employed in research on Kanye and Magaga Dams in Kano, Nigeria, where higher index values were observed in the upper parts of the dams compared to the lower sections. This suggests a richer diversity of macroinvertebrates in less polluted areas. The study confirmed the BMWP-ASPT index as useful tool for detecting organic pollution in Nigerian water bodies, although further refinement is necessary to tailor the index to the sensitivity of local species [25].

However, most of these indices, including BMWP-ASPT, were originally developed in temperate regions, and their direct application in tropical ecosystems may overlook species-specific sensitivities and ecological context. This presents a research gap: while macroinvertebrate indices are increasingly used in Malaysian rivers, there is limited study on how well they correlate with WQI in tropical forest eco-parks where human interaction is seasonal and concentrated. Moreover, inconsistencies in results—such as cases where WQI indicates slight pollution, but macroinvertebrate indices suggest clean conditions—require further investigation.

This study aims to bridge that gap by assessing the correlation between WQI and BMWP-ASPT in upstream rivers of four forest eco-parks in Johor, Malaysia. By comparing biological and physicochemical indicators side by side, the study seeks to evaluate the reliability of BMWP-ASPT in tropical recreational rivers and explore its practical applications in field monitoring. Findings from this research can guide future environmental policies, strengthen eco-tourism sustainability, and contribute to the development of more region-specific bioassessment tools.

Combining biological indicators with physicochemical evaluations is vital for comprehensive environmental monitoring. Therefore, assessing stream water quality through both chemical and biological parameters is necessary to ensure the protection and sustainability of healthy freshwater systems. This study focuses on establishing a relationship between the BMWP-ASPT index, derived from macroinvertebrate indicators, and the WQI, which is based on physicochemical parameters such as ammonia nitrogen (AN), biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), pH level and total suspended solid (TSS). Monitoring the quality of stream water holds particular importance, especially in Malaysia, where such streams serve as vital water sources. The findings of this study are expected to contribute to public health protection, ecosystem preservation, and offer meaningful understanding for future water quality research.

1.1 Biological Monitoring Working Party – Average Score Per Taxon (BMWP-ASPT) as Biological Indicators

The performance and reliability of macroinvertebrate-based assessments, such as the BMWP-ASPT index, can be influenced by several environmental and methodological factors, particularly in tropical ecosystems. Seasonal changes—such as variations in rainfall, temperature, and flow regimes—can significantly affect both physicochemical parameters (captured by WQI) and biological communities. During the wet season, increased runoff and dilution may temporarily improve WQI scores while simultaneously disturbing macroinvertebrate habitats, leading to potential misalignments in index interpretation. Conversely, dry seasons may stabilize habitat conditions but concentrate pollutants, thus complicating correlations between indices [26].

Furthermore, the BMWP-ASPT index, originally designed for temperate systems, may not fully account for site-specific species diversity and sensitivity within tropical riverine ecosystems, risking ecological misclassification. The comparison of BMWP usage in temperate and tropical ecosystems highlights several critical challenges in applying this index beyond its original context. The BMWP (E) index, developed in temperate regions such as England, was compared with a modified tropical version, BMWP-CR, in a study conducted along the River Aturukuku in Eastern Uganda. Although BMWP-CR incorporated a broader range of macroinvertebrate taxa representative of tropical environments, both indices showed limited effectiveness in accurately distinguishing between pollution gradients. In several cases, they produced results that contradicted those of diversity-based indices, such as the Shannon-Wiener index, and physicochemical analyses. For example, urban sites with greater anthropogenic pressure were occasionally rated as having better water quality than rural, less disturbed sites, indicating potential misclassification. These discrepancies are largely attributed to biogeographical differences in species sensitivity and ecological response, which the original temperate scoring system does not adequately capture [27]. Differences in sampling techniques, timing, and site selection can further introduce bias, affecting the consistency and validity of observed relationships between WQI and BMWP-ASPT [28]. To ensure accurate ecological assessments, future studies should consider local species tolerance levels, conduct multi-seasonal sampling, and apply standardized protocols that reduce spatial and temporal variability.

The application of the BMWP-ASPT index in tropical ecosystems presents several limitations when compared to its original use in temperate regions. Developed in the UK, the index relies on the sensitivity scores derived from macroinvertebrate families commonly found in temperate rivers (Ochieng et al., 2020). However, tropical ecosystems typically host a much higher biodiversity[29],[30], including many endemic or undocumented species that are either absent from the BMWP scoring system or inaccurately represented. This mismatch may lead to incorrect assessments, where tolerant tropical species are misclassified as sensitive, or sensitive species are overlooked. Environmental variables have been shown to exert a stronger influence on macroinvertebrate beta diversity than spatial factors, primarily due to environmental filtering driven by gradients such as elevation, dissolved oxygen, and substrate type[31],[32],[33]. This effect is amplified by the sensitivity and dispersal abilities of certain macroinvertebrate taxa, including mayflies, stoneflies, and caddisflies, which actively seek suitable habitats after emergence[34],[35].

Over the years, the BMWP-ASPT index has been widely applied in numerous studies across both temperate and tropical regions to assess river water quality based on macroinvertebrate communities (e.g.[27], [36]. The application of biotic indices is different based on regions due to the climate and types of pollution. BMWP – ASPT scores system have been developed to many countries to adjust with the suitability of the country and yet, the results remain reliable [37]. Thus, the BMWP-ASPT index was chosen for this study due to its balance between scientific robustness and practical applicability. Unlike HBI and FBI, which require detailed taxonomic identification and are calibrated for temperate regions, BMWP-ASPT operates effectively at the family level [17], making it more feasible for field studies in tropical environments where taxonomic resources may be limited. Additionally, While the EPT Index is based on the number of distinct taxa from the orders Ephemeroptera, Plecoptera, and Trichoptera—groups that are highly sensitive and less tolerant to organic pollution and habitat disturbance—it may underrepresent water quality in tropical rivers where these taxa are naturally less dominant [38]. In contrast, the BMWP-ASPT index, which uses a broader range of macroinvertebrate families with assigned pollution tolerance scores, offers a more inclusive and adaptable assessment approach, particularly in diverse tropical ecosystems. BMWP-ASPT's adaptability and proven correlation with physicochemical indicators like the Water Quality Index (WQI) make it a suitable choice for comprehensive water quality assessment in diverse ecological contexts.

2. Methodology

This section describes the location of site sampling, macroinvertebrate sampling and analysis, river water sampling and analysis, and statistical analysis.

2.1 Site Location

This paper conducted an in-situ analysis at four different Forest Eco Parks: Mount Lambak, Soga Perdana Hill, Mount Pulai II, and Bantang River, Johor, Malaysia, which are popular destinations for hiking and jungle trekking enthusiasts. The parks, known for their scenic beauty, open from 7:00 am to 6:00 pm and offer free entrance to attract more tourists. The same stream flow feeds all the chosen stream locations (from upstream to downstream). This study was conducted exclusively during the dry season to minimize hydrological variability and ensure consistent sampling conditions across sites. While it is acknowledged that seasonal fluctuations—particularly between dry and wet periods—can influence both water quality parameters and macroinvertebrate assemblages, the focus on the dry season was intended to reduce confounding effects such as stormwater runoff and high-flow disturbances.

Soga Perdana Amenity Forest along the park's stream, each spaced approximately 6 meters apart. Spanning 49.3 hectares, with 10 hectares thoughtfully developed to include essential facilities, it is located 3.2 km east of Batu Pahat town. The forest is easily accessible, making it an ideal spot for a serene retreat. These sampling points are free from developmental disturbances, making them ideal for assessing stream water quality using bio-index and WQI. The Global Positioning System (GPS) coordinates for the sampling stations were recorded at 1.84836° N, 102.96453° E. **Figure 2** presents the site conditions at Soga Perdana. Meanwhile, Mount Lambak's waterfall is situated 14.8 kilometers from Parit Raja via Jalan Batu Pahat and 36.1 kilometers from Universiti Tun Hussein Onn Malaysia. Mount Lambak, located in Kluang, Johor, stands 510 meters above sea level and is approximately 5 kilometers from the Kluang town center. This eco-park, part of the forest eco-park initiative, is a popular destination for nature lovers and hikers, offering well-marked trails of varying difficulty. Despite its relatively moderate height, the climb can be steep in sections, providing a fulfilling challenge for both casual and seasoned hikers. The area surrounding Mount Lambak is lush with greenery, and the summit rewards visitors with panoramic views of the rolling hills and nearby villages, making it a must-visit for outdoor enthusiasts.

Mount Pulai II Forest Eco-Park, located within the Mount Pulai Forest Reserve in Johor, Malaysia, is a significant site known for its ecological value and recreational opportunities. The area is characterized by the Dipterocarp Hill Forest, which supports a diverse range of flora and fauna, contributing to the region's rich biodiversity. Strategically positioned 10 kilometers from the town of Nenas and approximately 40 kilometers from Johor Bahru, Mount Pulai II is easily accessible, making it a popular destination for both residents and tourists. Bantang River Forest Eco-Park, located in Bekok, Johor, Malaysia, is a captivating eco-park that forms part of the expansive Mount Ledang National Park. Renowned for its verdant tropical rainforest, crystal-clear rivers, and stunning waterfalls, this park is a hub for eco-tourism. Visitors are drawn to its natural allure and enjoy hiking, swimming, and camping activities. The park's combination of breathtaking scenery and ease of access makes it a preferred destination for locals and tourists alike. The park is located at approximately 2.3298° N latitude and 103.1625° E longitude.

Station 1 (a) **Station 2 (b)** **Station 3 (c)**

Fig. 1 *Mount Lambak Forest Eco-Park's sampling stations*

Fig. 2 *Soga Perdana Forest Eco-Park's sampling stations*

Fig. 3 *Mount Pulai II Forest Eco-Park's sampling stations*

Fig. 4 *Bantang River Forest Eco-Park's sampling stations*

2.2 Macroinvertebrates Sampling and Analysis

Macroinvertebrate sampling was conducted over the course of one month at each eco-park, with samples collected on a weekly basis. The method used for collection was timed kick sampling, a widely adopted technique in many countries due to its cost-effectiveness and ability to yield consistent and dependable results [22]. Sampling was repeated multiple times at each station to ensure that specimens were gathered from various parts of the same site [39]. These macroinvertebrates are generally easier to locate in river environments, commonly found beneath rocks [40]. In fast-moving sections of the stream, large rocks were manually lifted, and any visible macroinvertebrates were carefully transferred into petri dishes using forceps [23]. Once collected, the samples were sorted and examined for classification. The tools used in this process included a fishnet, pipette, petri dishes, magnifying glass, gloves, and boots.

The Biological Monitoring Working Party-Average Score per Taxon (BMWP - ASPT), was selected in this study to describe the distribution of the communities of species. BMWP is a river water quality scoring system that assigns a score from 1 to 10 to each macroinvertebrate taxon based on their sensitivity to organic pollution [41]. ASPT is a BMWP modification that corrects values obtained from specific fluvial conditions. **Equation 1** is the equation to obtain the value of ASPT, where the BMWP value is divided by the total amount of diversity [42].

$$ASPT = \frac{BMWP}{n}. \qquad (1)$$

The BMWP-ASPT index was selected for this study due to its simplicity, widespread use, and minimal taxonomic resolution requirements. It allows for rapid assessment of water quality based on macroinvertebrate families, which is practical for fieldwork in eco-parks and areas with limited taxonomic expertise. Although originally developed for temperate rivers, BMWP-ASPT has been applied in several tropical studies, offering a useful reference point for comparison. Its numeric scoring system and ease of interpretation make it suitable for integration with physicochemical data to explore correlations and inconsistencies. Nevertheless, its limitations in tropical contexts are acknowledged and further discussed.

2.3 Water Sampling and Analysis

Water sampling was conducted from the proposed river location, considering environmental characteristics like weather, time, and date. Samples were collected weekly and stored in plastic water bottles at 4°C before being transported to the laboratory. Water samples were collected by rinsing bottles with the sampled water to avoid contamination. After sealing and labelling, they were carefully transported to the lab for physical and chemical analysis [43]. The list of equipment used to collect the water samples included plastic bottles, an ice pack, an ice box, gloves, and masking tape.

Laboratory testing was performed on six physicochemical parameters: AN, BOD, COD, DO, pH, and TSS. The result of each parameter was analysed using the WQI formula, as shown in Equation 2. In contrast, Table 1 shows the list of WQI equations for each parameter to evaluate before substituting into Equation 2 [19].

Table 1 *List of WQI equations for each parameter*

SIDO	0	for $x \leq 8$
	100	for $x \geq 92$
	$-0.395 + 0.03\,x^2 - 0.00020\,x^3$	for $8 < x < 92$
SIBOD	$100.4 - 4.23\,x$	for $x \leq 5$
	$108\,e^{-0.055x} - 0.1\,x$	for $x > 5$
SICOD	$-1.33\,x + 99.1$	for $x \leq 20$
	$103\,e^{-0.0157x} - 0.04\,x$	for $x > 20$
SIAN	$100.5 - 105\,x$	for $x \leq 0.3$
	$94\,e^{-0.573x} - 5\,\lvert x - 2 \rvert$	for $0.3 < x < 4$
	0	for $x \geq 4$
SISS	$97.5\,e^{-0.00676x} + 0.05\,x$	for $x \leq 100$
	$71\,e^{-0.0016x} - 0.015\,x$	for $100 < x < 1000$
	0	for $x \geq 1000$
SIpH	$17.2 - 17.2\,x + 5.02\,x^2$	for $x < 5.5$
	$-242 + 95.5\,x - 6.67\,x^2$	for $5.5 \leq x < 7$
	$-181 + 82.4\,x - 6.05\,x^2$	for $7 \leq x < 8.75$
	$536 - 77.0\,x + 2.76\,x^2$	for $x \geq 8.75$

$$WQI = (0.22 \times SIDO) + (0.19 \times SIBOD) + (0.16 \times SICOD) + (0.15 \times SIAN) + (0.16 \times SISS) + 0.12 \times (SIpH). \quad (2)$$

2.4 Statistical Analysis

The Pearson Correlation Coefficient (PCC) is a statistical method used to minimize dataset dimensionality and will be applied in this study. By standardizing the data to have a mean of zero and a variance of one, PCC supports the analysis of specific traits within the selected variables. Its primary purpose in this study is to identify and narrow down the most relevant parameters and metrics for examining the connection between environmental factors and biological indicators. The correlation values are determined using Equation 3[44], with the resulting coefficients presented in Table 2.

$$r = \frac{N\Sigma xy - (\Sigma x)(\Sigma y)}{\sqrt{[(N\Sigma x^2 - \Sigma x)^2][(N\Sigma y^2 - \Sigma y)^2]}}, \quad (3)$$

where

$r =$ $coefficient\ of\ correlation$

$x =$ $x - variable\ in\ sample$

$y =$ $y - variable\ in\ sample$

$n = \text{ } size\ of\ the\ sample.$

Table 2 *The correlation coefficient value [45]*

Size / Value of coefficient of correlation(r)	Correlation strength
0.91 until l.00 or -0.91 until -1.00	Very strong correlation
0.71 until 0.90 or -0.71 until -0.90	Strong correlation
0.51 until 0.70 or -0.51 until -0.70	Moderate correlation
0.31 until 0.50 or -0.31 until -0.50	Low correlation
0.01 until 0.30 or -0.01 until -0.30	Very low correlation

3. Results and Discussions

This section presents an assessment of water quality across all study locations using the BMWP-ASPT and WQI. Evaluation of River Health using BMWP-ASPT and WQI across study locations.

The connection between two key indicators, the BMWP-ASPT index and WQI was analysed. These indicators offer different but complementary perspectives on water quality. BMWP-ASPT assesses the presence of pollution-sensitive macroinvertebrates, while WQI considers a range of physicochemical factors to give an overall picture of water quality. Correlation analysis was performed using PCC, with an *r*-value of -0.93974, indicating a very strong correlation between these two indices. This suggests that biological diversity, as reflected by macroinvertebrate populations, aligns closely with the physicochemical water quality measures.

Table 3 summarizes the BMWP-ASPT scores across four forest eco-parks: Soga Perdana, Mount Pulai II, Mount Lambak, and Bantang River, measured weekly over three weeks. Soga Perdana shows a gradual decrease in BMWP-ASPT scores over the weeks, with an overall average of 7.27. Notably, Station 1 consistently scores higher, suggesting slightly better water quality than the other stations within Soga Perdana. Mount Pulai II, with an average BMWP-ASPT score of 7.07, also reflects moderate water quality, with Station 1 displaying the highest values across all weeks, indicating relatively better ecological conditions in that station. Mount Lambak demonstrates a slightly better water quality with an average BMWP-ASPT score of 7.39, peaking in Week 2, suggesting a temporary improvement in water conditions. Bantang River, however, stands out with the highest BMWP-ASPT score on average of 8.04, suggesting it has the healthiest water quality among the four locations, with consistently high scores across all stations and weeks.

Table 4 presents the WQI results for the same locations. Soga Perdana's WQI fluctuates between 84.67 and 87.02, with an average of 86.49, reflecting moderate water quality with minimal variation over the three weeks. Mount Pulai II records an impressive average WQI of 92.55, indicating excellent water quality, with all stations consistently scoring above 91, which implies stable and high-water quality. Similarly, Mount Lambak has a high average WQI of 92.32, with values ranging from 89.63 to 93.73, signifying a well-maintained aquatic environment. In contrast, Bantang River shows the lowest average WQI at 73.77, indicating poorer water quality compared to the other locations. The WQI values at Bantang River remain low and consistent, suggesting persistent environmental stressors or pollution impacting water quality.

Table 3 *BMWP-ASPT scores for all locations*

Location	Station	Week 1	Week 2	Week 3	Average (all weeks)	BMWP-ASPT
Soga Perdana	1	8.40	7.50	7.00	7.63	
	2	7.33	7.25	7.40	7.33	Moderate Clean Water
	3	6.60	6.75	7.17	6.84	
	Average	7.44	7.17	7.19	7.27	
Mount Pulai II	1	8.00	7.20	7.70	7.60	
	2	7.00	7.20	7.00	7.10	Moderate Clean Water
	3	6.80	6.40	6.20	6.50	
	Average	7.27	6.93	6.97	7.07	
Mount Lambak	1	7.33	8.50	8.20	8.01	
	2	6.33	7.40	7.50	7.10	Moderate Clean Water
	3	6.60	7.14	7.40	7.05	
	Average	7.27	6.93	6.97	7.39	
Bantang River	1	6.75	7.25	7.43	7.14	
	2	8.70	8.20	10.00	8.97	Clean Water
	3	8.30	7.75	8.00	8.02	
	Average	7.92	7.73	8.48	8.04	

Table 4 *WQI results for all four forest eco-parks*

Forest Eco-Park	Station	Week 1	Week 2	Week 3	Average (all weeks)	WQI
Soga Perdana	1	86.77	87.58	86.71	87.02	
	2	85.92	86.48	87.01	86.47	Class II
	3	86.80	84.89	86.29	85.99	
	Average	86.50	86.32	86.67	86.49	
Mount Pulai II	1	93.04	93.92	93.24	93.40	
	2	93.57	91.70	92.38	92.55	Class II
	3	94.59	90.62	87.82	91.01	
	Average	93.73	92.08	91.15	92.32	
Mount Lambak	1	93.30	93.20	91.30	93.00	
	2	91.90	92.20	89.60	91.00	Class II
	3	90.50	89.00	88.00	89.00	
	Average	91.90	91.47	89.63	91.00	
Bantang River	1	72.44	72.77	73.75	72.99	
	2	74.26	73.58	74.50	74.11	Class III
	3	73.21	73.51	75.86	74.20	
	Average	73.30	73.29	74.70	73.77	

Water quality in the four eco-parks studied ranged from Class II (Clean) and Class III (Slightly Polluted) based on WQI results. Soga Perdana, Mount Pulai II, and Mount Lambak all exhibited clean water characteristics with WQI values between 86.49 and 93.32, meaning they meet the criteria for relatively clean water, which is suitable for recreational purposes and the conservation of aquatic life. According to WQI scores, Class II of WQI ranges from 76.5 to 92.7 [19]. Meanwhile, the Bantang River showed slightly polluted water with a WQI of 73.77. However, as reflected in BMWP-ASPT scores, biological indicators suggest a relatively clean condition in all four locations. Bantang River recorded the highest score of 8.04. This slight discrepancy may be influenced by the high number of visitors that visit the area for recreational purposes, impacting physicochemical indicators. Bantang River is a popular eco-park, attracting many tourists who engage in various water-related activities, potentially contributing to water quality degradation. Visitor data were recorded for three eco-parks: Bantang River, Mount Pulai II, and Soga Perdana, while no visitor records were available for Mount Lambak. Among the three eco-parks, Bantang River recorded the highest number of visitors in 2024, with a total of 90,013, followed by Soga Perdana, with 23,502 visitors. Mount Pulai II had the lowest number of visitors, with only 276 recorded throughout the year. Tourist activity within forest eco-parks can significantly influence short-term water quality dynamics, particularly during peak visitation periods such as weekends and holidays. Increased foot traffic along riverbanks often leads to soil compaction and bank erosion, contributing to elevated turbidity and suspended solids in the water column, which can negatively affect WQI values [46]. Additionally, improper waste disposal and littering, including the introduction of organic matter, food remnants, and personal care products, can elevate biochemical oxygen demand (BOD) and nutrient levels [47], [48], further reducing water quality scores.

Previous research on the Bantang River in 2019 recorded a WQI of 94.16, indicating excellent water quality at the time. The BMWP also showed moderately good water quality. The significant decline in WQI from 94.16 in 2019 to 73.77 suggests growing environmental pressures, possibly linked to increased tourism and human activity in the area over the years [41]. In contrast, the other three locations – Soga Perdana, Mount Pulai II, and Mount Lambak – are less visited. Soga Perdana is a small river located on a hill, accessible mainly through hiking, limiting visitor numbers. Mount Pulai II, although accessible, tends to be overlooked by visitors in favour of the more popular which is Mount Pulai I. This lack of human interference may contribute to the cleaner water quality as reflected in their WQI values, particularly from a physicochemical perspective.

3.1 Correlation Between BMWP – ASPT and WQI

Table 5 presents a comparative analysis of the BMWP-ASPT and WQI scores for the four forest eco-parks evaluated in this study. Both scores were used to classify the water quality status of each eco-park, ranging from clean to polluted. This dual assessment enables a comprehensive water quality evaluation by integrating biological and chemical parameters. The results highlight variations in water quality across the eco-parks, reflecting differences in ecological conditions and potential impacts of environmental factors or human activities.

Table 5 *Summary of BMWP-ASPT and WQI scores in all four forest eco-parks*

Location	BMWP-ASPT Score	Water Quality Status (BMWP – ASPT)	Water Quality Index	Water Quality Status (WQI)
Soga Perdana	7.27	Rather clean – clean water	86.49	Class II - Clean
Mount Pulai II	7.07	Rather clean – clean water	92.32	Class II - Clean
Mount Lambak	7.39	Rather clean – clean water	91.00	Class II – Clean
Bantang River	8.04	Very clean water	73.77	Class III – Slightly polluted

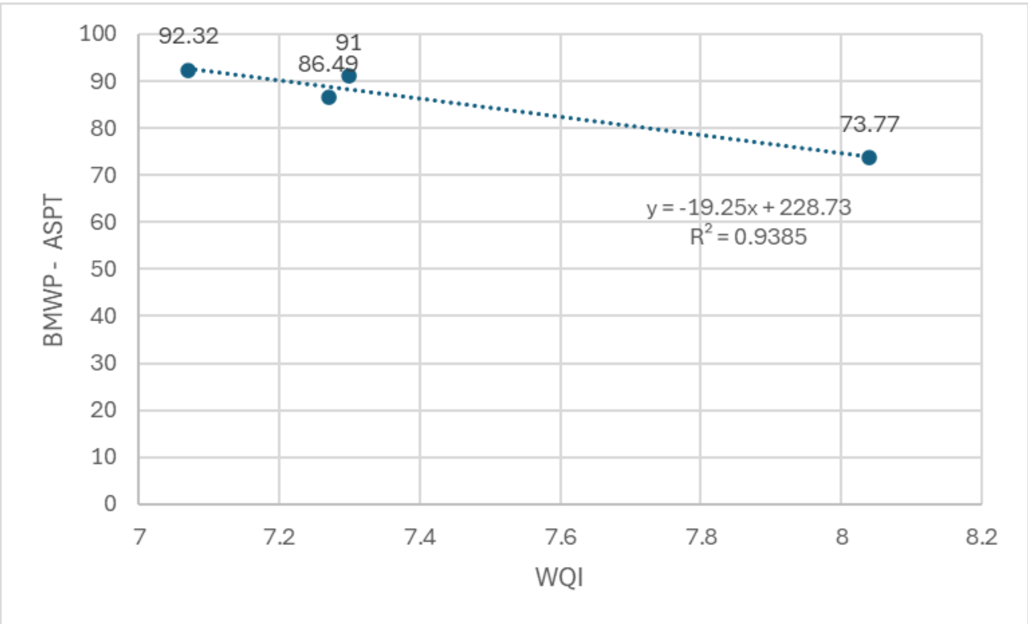

Fig. 5 *Scatter plot of correlation between bio-index and WQI*

Figure 5 shows a strong negative correlation (R^2 = 0.9385) between WQI and BMWP-ASPT scores. Although both indices usually increase with better water quality, this inverse trend suggests a mismatch in how biological and chemical indicators respond at the study sites. Higher WQI values, which reflect good chemical conditions, were linked to lower BMWP-ASPT scores. This could be due to delayed biological recovery, habitat disruption, or dominance of pollution-tolerant species. These findings highlight the need to use both types of indicators to get a clearer picture of river health.

Figure 5 demonstrates a negative linear correlation between the bio-index (BMWP-ASPT) and the WQI, with an R^2 value of 0.9385. This high R^2 indicates a strong correlation, suggesting that as the WQI increases, the ASPT score tends to decrease slightly. While this may seem counterintuitive at first – since both indices are typically used to indicate water quality - it reflects a known limitation of comparing biological and chemical indicators directly. WQI focuses on immediate physicochemical conditions, while BMWP-ASPT reflects longer-term ecological responses through macroinvertebrate presence [49], [50]. The inverse trend in this dataset may be influenced by site-specific ecological factors, such as the presence of tolerant macroinvertebrate taxa at slightly polluted sites or lagging biological recovery at chemically "clean" sites. The scatter plot highlights the complexity of using a single index to represent water quality and supports the argument for integrating both biological and chemical indicators to obtain more comprehensive assessment.

Notably, Bantang River has the highest ASPT score (8.04) despite its comparatively lower WQI (73.77), indicating a slightly polluted status. This correlation reinforces the idea that biological indicators such as BMWP-ASPT can sometimes show more resilience in biological communities, even when physicochemical parameters such as WQI suggest slight pollution.

Over time, the taxonomic and trait metrics of macroinvertebrate communities can either follow similar patterns or diverge. This difference often arises because the species within a community may change, yet the overall trait composition tends to stay consistent [51], [52], [53], [54], [55]. This consistency is due to multiple species sharing overlapping traits or occupying similar niches [21], [51], [52]. On the other hand, physicochemical parameters provide a snapshot of water quality at the time of measurement, but these values can shift significantly over time [56]. On the other hand, Wan Abdul Ghani et al. [57] (as cited in Moridi et al. [58]) stated how biological indicators perform in comparison to Water Quality Index (WQI) in Malaysia's Penchala River. Sampling was conducted at four stations over four different periods, and the findings revealed that biological indicators were more responsive to organic pollution than the WQI. Among these, the BMWP index proved to be the most dependable and could effectively complement the WQI for evaluating water quality in urban rivers.

4. Conclusion

The BMWP-ASPT index proved to be a reliable and practical tool for assessing water quality in forest eco-parks. Its strong negative correlation with the Water Quality Index (r = -0.93974) highlights its potential to complement physicochemical measurements in routine monitoring. Notably, while the WQI classified Bantang River as slightly polluted (Class III), the biological assessment indicated a cleaner condition. This contrast suggests that macroinvertebrate communities may reflect longer-term ecological resilience, capturing subtler environmental changes that chemical indicators alone might miss.

These findings underscore the importance of integrating biological and chemical approaches to gain a more complete understanding of river health—particularly in sensitive areas like recreational eco-parks where human activity can introduce short-term fluctuations. For practical application, this study supports the use of biological indicators in fieldwork, especially in regions with limited laboratory access where rapid screening is needed. Future research should consider seasonal sampling and explore local adaptations of biotic indices to better reflect tropical species' sensitivity. Expanding this approach to other high-risk river basins could also support more adaptive and ecosystem-based water resource management across Southeast Asia and other tropical regions.

Acknowledgement

We would like to express our appreciation for the support provided by all parties directly or indirectly involved in this research. We also thank our colleagues and collaborators for their support and assistance throughout the research process.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Nor Amani Filzah Mohd Kamil;* ***analysis and interpretation of results:*** *Aqilah Zakiah, Nurhidayah Hamzah;* ***draft manuscript preparation:*** *Nurul Amni Ali. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] C. Orozco-González and M. Ocasio-Torres, "Aquatic Macroinvertebrates as Bioindicators of Water Quality: A Study of an Ecosystem Regulation Service in a Tropical River," *Ecologies*, vol. 4, pp. 209–228, Mar. 2023, doi: 10.3390/ecologies4020015.

[2] S. Damseth *et al.*, "Assessing the impacts of river bed mining on aquatic ecosystems: A critical review of effects on water quality and biodiversity," *HydroResearch*, vol. 7, pp. 122–130, 2024, doi: https://doi.org/10.1016/j.hydres.2024.01.004.

[3] D. Padmalal and K. Maya, "Sand Mining: Environmental Impacts and Selected Case Studies," *Sand Min.*, 2014, [Online]. Available: https://api.semanticscholar.org/CorpusID:133977424

[4] D. Wei *et al.*, "Impacts of human activities and climate change on water and sediment evolution in four large subtropical river basins in China," *Ecol. Indic.*, vol. 155, p. 110958, 2023, doi: https://doi.org/10.1016/j.ecolind.2023.110958.

[5] U.S. Environmental Protection Agency, "Climate Adaptation and Source Water Impact," U.S. Environmental Protection Agency. [Online]. Available: https://www.epa.gov/arc-x/climate-adaptation-and-source-water-impacts#:~:text=Climate change threatens the quality,increase due to climate change.

[6] N. Sakadzo, "Effects of deforestation on soil functions and how reforestation can reverse them," vol. 9, Feb. 2021.

[7] A. Fitri, K. N. A. Maulud, D. Pratiwi, A. Phelia, F. Rossi, and N. Z. Zuhairi, "Trend Of Water Quality Status In Kelantan River Downstream, Peninsular Malaysia," *J. Rekayasa Sipil*, 2020, [Online]. Available: https://api.semanticscholar.org/CorpusID:234462799

[8] M. A. Hazritauding, "The Assessment of Water Quality Parameters Due to High and Low Flow for Batu Pahat River, Johor," *Recent Trends Civ. Eng. Built Environ.*, vol. 3, no. 1, pp. 596–605, 2021, [Online]. Available: https://penerbit.uthm.edu.my/periodicals/index.php/rtcebe/article/view/3228

[9] S. F. Azha *et al.*, "Enhancing river health monitoring: Developing a reliable predictive model and mitigation plan," *Ecol. Indic.*, vol. 156, p. 111190, 2023, doi: https://doi.org/10.1016/j.ecolind.2023.111190.

[10] M. H. Mauludi, "River Pollution in Malaysia." Enviro Knowledge Management Center (EKMC), p. 1, 2020. [Online]. Available: https://enviro2.doe.gov.my/ekmc/digital-content/mini-projek-river-pollution-oleh-muhammad-hakimi-bin-maludi/

[11] O. Elisha and F. Jebbin, "The Loss of Biodiversity and Ecosystems: A Threat to the Functioning of our Planet, Economy and Human Society," Nov. 2020.

[12] United States Environmental Protection Agency, "What are the trends in the condition of recreational waters and their effects on human health and the environment?," U.S. Environmental Protection Agency. [Online]. Available: https://www.epa.gov/report-environment/recreational-waters

[13] S. P. Gangwar, "EFFECT OF PHYSICO-CHEMICAL POLLUTION OF RIVER DEORANIA ON THE METABOLIC ACTIVITIES OF PREDATORY FISH, CHANNA PUNCTATUS AT DISTRICT BAREILLY (U.P.) INDIA," *Knowledgeable Res. A Multidiscip. J.*, 2023, [Online]. Available: https://api.semanticscholar.org/CorpusID:263301670

[14] T. Weng and B. Chee, "Water Quality Monitoring Using Biological Indicators in Cameron Highlands Malaysia," *J. Sustain. Dev.*, vol. 8, 2015, doi: 10.5539/jsd.v8n3p28.

[15] P. S. L. Musonge *et al.*, "Baseline assessment of benthic macroinvertebrate community structure and ecological water quality in Rwenzori rivers (Albertine rift valley, Uganda) using biotic-index tools," *Limnologica*, vol. 75, pp. 1–10, 2019, doi: https://doi.org/10.1016/j.limno.2018.12.001.

[16] S. Jalili, "Water Quality Assessment Based on HFBI& BMWP Index in Karoon River, Khuzestan Province, (Northwest of Persian Gulf)," vol. 4(1), 2020.

[17] B. Kohlmann, D. Vásquez, A. Arroyo, and M. Springer, "Taxonomic and Functional Diversity of Aquatic Macroinvertebrate Assemblages and Water Quality in Rivers of the Dry Tropics of Costa Rica," *Front. Environ. Sci.*, vol. 9, 2021, doi: 10.3389/fenvs.2021.660260.

[18] Q. Hussain, "Macroinvertebrates in streams: A review of some ecological factors," *Int. J. Fish. Aquac.*, vol. 4, 2012, doi: 10.5897/IJFA11.045.

[19] Department of Environment, "Environmental Quality Report 2020," Department of Environment, 2020. [Online]. Available: https://www.doe.gov.my/en/environmental-quality-report/

[20] P. Patil, D. V Sawant, and R. N. Deshmukh, "Physico-chemical parameters for testing of water - a review," *Int. J. Environ. Sci.*, vol. 3, pp. 1194–1207, 2012.

[21] S. W. Holt, E. A. & Miller, "Bioindicators: Using Organisms to Measure Environmental Impacts," Nature Education.

[22] Z. Yusop, A. A. Kadir, and Z. Z. Noor, "Benthic Macroinvertebrate Composition and Water Quality Status in Sungai Johor, Johor, Malaysia," *Chem. Eng. Trans.*, vol. 56, pp. 187-192 SE-Research Articles, Mar. 2017, doi: 10.3303/CET1756032.

[23] J. Zakiah, M. A. Ahmad Nazri, and A. Aliza, "Study of Water Quality Based on Diversity of Macroinvertebrates Using Average Score Per Taxon Method in Corporate Social Responsibility Program Approach at Gunung Belumut and Gunung Lambak Waterfall," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1022, p. 12059, May 2022, doi: 10.1088/1755-1315/1022/1/012059.

[24] S. Appalasamy, N. Arumugam, S. Sukri, and A. Rak, "Physico-chemical water quality and macroinvertebrate distribution along Sungai Asah in Pulau Tioman, Johor, Malaysia," *Songklanakarin J. Sci. Technol.*, vol. 40, pp. 1265–1270, Nov. 2018, doi: 10.14456/sjst-psu.2018.155.

[25] U. Bawa, I. Muhammad, and H. Ibrahim, "Assessment of water quality using biological monitoring working party (BMWP) and average score per taxon (ASPT) score at Kanye and Magaga dams, Kano," *Bayero J. Pure Appl. Sci.*, vol. 11, p. 210, May 2019, doi: 10.4314/bajopas.v11i2.28.

[26] C. Sun *et al.*, "The impacts of different seasons on macroinvertebrate community structure and functional diversity in the Jingui River, China," *Glob. Ecol. Conserv.*, vol. 51, p. e02876, 2024, doi: https://doi.org/10.1016/j.gecco.2024.e02876.

[27] H. Ochieng, R. Odong, and J. Okot-Okumu, "Comparison of temperate and tropical versions of Biological Monitoring Working Party (BMWP) index for assessing water quality of River Aturukuku in Eastern Uganda," *Glob. Ecol. Conserv.*, vol. 23, p. e01183, 2020.

[28] Y. Wang, J. M. Wilson, and J. M. VanBriesen, "The effect of sampling strategies on assessment of water quality criteria attainment," *J. Environ. Manage.*, vol. 154, pp. 33–39, 2015, doi: https://doi.org/10.1016/j.jenvman.2015.02.019.

[29] S. A. Al-Shami *et al.*, "Biodiversity patterns of aquatic macroinvertebrates in tropical forests streams as a response to logging activities and deforestation," *Acta Ecol. Sin.*, vol. 37, no. 5, pp. 332–339, 2017, doi: https://doi.org/10.1016/j.chnaes.2017.03.004.

[30] T. A. Gardner *et al.*, "Prospects for tropical forest biodiversity in a human-modified world," *Ecol. Lett.*, vol. 12, no. 6, pp. 561–582, Jun. 2009, doi: https://doi.org/10.1111/j.1461-0248.2009.01294.x.

[31] J. Heino, J. Soininen, J. Alahuhta, J. Lappalainen, and R. Virtanen, "Metacommunity ecology meets biogeography: effects of geographical region, spatial dynamics and environmental filtering on community structure in aquatic organisms," *Oecologia*, vol. 183, no. 1, pp. 121–137, 2017, doi: 10.1007/s00442-016-3750-y.

[32] Z. Li, J. Heino, J. Zhang, Y. Ge, Z. Liu, and Z. Xie, "Unravelling the factors affecting multiple facets of macroinvertebrate beta diversity in the World's Third Pole," *J. Biogeogr.*, vol. 50, no. 4, pp. 792–804, Apr. 2023, doi: https://doi.org/10.1111/jbi.14574.

[33] L. Wei *et al.*, "Effects of hypoxia on survival, apoptosis, and the transcriptome of the Chinese yellow pond turtle (Mauremys mutica)," *Gene*, vol. 936, p. 149120, 2025, doi: https://doi.org/10.1016/j.gene.2024.149120.

[34] X. Jiang, X. Xu, M. Tao, Z. Li, S. Zhang, and H. Li, "The effects of dispersal ability on metacommunity structure of macroinvertebrates in subtropical Chinese high-mountain streams: seasonal shifts in relative contribution of local environment and spatial processes," *Environ. Sci. Pollut. Res.*, vol. 28, no. 29, pp. 38573–38583, 2021, doi: 10.1007/s11356-021-13281-2.

[35] C. Wei, H. Li, J. Heino, and X. Jiang, "Seasonal variation and driving factors of beta diversity of macroinvertebrate assemblages in subtropical Chinese high-mountain streams," *Water Biol. Secur.*, p. 100379, 2025, doi: https://doi.org/10.1016/j.watbs.2025.100379.

[36] arman hadi Fikri and A. Wong, "COMPARATIVE ANALYSES OF BIOTIC INDICES BASED ON BENTHIC MACROINVERTEBRATES FOR STREAM WATER QUALITY ASSESSMENT AT TROPICAL STREAMS," vol. 26, pp. 47–67, Aug. 2021.

[37] F. Magbanua, J. Hilario, J. Salluta, B. Alpecho, S. Mendoza, and I. Lit, "Freshwater Biomonitoring with Macroinvertebrates in the Philippines: Towards the Development of the Philippine Biotic Index," *Limnologica*, vol. 102, p. 126098, Jul. 2023, doi: 10.1016/j.limno.2023.126098.

[38] F. Masese and P. Raburu, “Improving the performance of the EPT Index to accommodate multiple stressors in Afrotropical streams,” *African J. Aquat. Sci.*, vol. 42, pp. 219–233, Oct. 2017, doi: 10.2989/16085914.2017.1392282.

[39] K. Ariella and A. Moesriati, “The implementation of biological monitoring working party average score per taxon (BMWP-ASPT) in a water quality analysis at Kalibokor drainage in Surabaya region,” *AIP Conf. Proc.*, vol. 1908, no. 1, p. 30007, Nov. 2017, doi: 10.1063/1.5012707.

[40] U.S. Environmental Protection Agency, “Indicators: Benthic Macroinvertebrates,” U.S. Environmental Protection Agency. [Online]. Available: https://19january2017snapshot.epa.gov/national-aquatic-resource-surveys/indicators-benthic-macroinvertebrates_.html#:~:text=What are benthic macroinvertebrates?,the bottom sand and sediments.

[41] M. Zulhusni Zakaria and M. Mohamed, “Comparative analysis of Biotic Indices in water quality assessment: Case study at Sg. Bantang, Johor,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 269, no. 1, p. 12047, 2019, doi: 10.1088/1755-1315/269/1/012047.

[42] S. D. K. Dewi and W. Wardhana, “Water quality assessment of Saluran Tarum Barat, West Java, based on biological monitoring working party-average score per taxon (BMWP-ASPT),” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 481, no. 1, p. 12073, 2020, doi: 10.1088/1755-1315/481/1/012073.

[43] M. N. Uddin, M. S. Alam, M. N. Mobin, and M. Alim Miah, “An Assessment of the River Water Quality Parameters: A case of Jamuna River,” *J. Environ. Sci. Nat. Resour.*, vol. 7, Feb. 2015, doi: 10.3329/jesnr.v7i1.22179.

[44] T. Eslami and F. Saeed, “Fast-GPU-PCC: A GPU-Based Technique to Compute Pairwise Pearson’s Correlation Coefficients for Time Series Data—fMRI Study,” *High-Throughput*, vol. 7, no. 2. 2018. doi: 10.3390/ht7020011.

[45] N. S. Zainordin, N. Azlan, N. Arsaad, A. Mauliadi, A. F. M. Sharif, and N. C. E. Rosli, “Comparative Analysis of Airborne Particulates and Indoor Physical Parameters between Dry and Wet Laboratories at the Faculty of Forestry and Environment, Universiti Putra Malaysia,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1102, no. 1, p. 12061, 2022, doi: 10.1088/1755-1315/1102/1/012061.

[46] O. R. Alliance, “Silt, turbidity and suspended sediments in the aquatic environment: An annotated bibliography and literature review,” Ontario Rivers Alliance, 2014. [Online]. Available: https://www.ontarioriversalliance.ca/silt-turbidity-and-suspended-sediments-in-the-aquatic-environment-an-annotated-bibliography-and-literature-review/

[47] E. C. Ebere, V. A. Wirnkor, V. E. Ngozi, and I. S. Chukwuemeka, “Macrodebris and microplastics pollution in Nigeria: first report on abundance, distribution and composition,” *Env. Anal Heal. Toxicol*, vol. 34, no. 4, pp. e2019012-0, Dec. 2019, doi: 10.5620/eaht.e2019012.

[48] G. Fayomi, E. Onyari, and O. Nkwonta, “Qualitative assessment of the impact of waste littering and dumping on surface water quality in Nigeria,” *Reg. Sustain.*, vol. 6, no. 1, p. 100194, 2025, doi: https://doi.org/10.1016/j.regsus.2025.100194.

[49] V. H. R. D. M. Rosenberg, Ed., *Freshwater biomonitoring and benthic macroinvertebrates.* Chapman & Hall, 1993.

[50] W. A. Azmi, N. H. Hussin, and N. M. Amin, “Monitoring of water quality using aquatic insects as biological indicators in three streams of Terengganu,” *J. Sustain. Sci. Manag.*, vol. 13, pp. 67–76, Jun. 2018.

[51] T. W. H. Aspin *et al.*, “Drought intensification drives turnover of structure and function in stream invertebrate communities,” *Ecography (Cop.).*, vol. 41, no. 12, pp. 1992–2004, Dec. 2018, doi: https://doi.org/10.1111/ecog.03711.

[52] D. J. Baird *et al.*, “Toward a knowledge infrastructure for traits-based ecological risk assessment,” *Integr. Environ. Assess. Manag.*, vol. 7, no. 2, pp. 209–215, Apr. 2011, doi: https://doi.org/10.1002/ieam.129.

[53] K. S. Boersma, L. E. Dee, S. J. Miller, M. T. Bogan, D. A. Lytle, and A. I. Gitelman, “Linking multidimensional functional diversity to quantitative methods: a graphical hypothesis-evaluation framework,” *Ecology*, vol. 97, no. 3, pp. 583–593, Mar. 2016, doi: https://doi.org/10.1890/15-0688.

[54] N. K. Rideout *et al.*, “Environmental filtering of macroinvertebrate traits influences ecosystem functioning in a large river floodplain,” *Funct. Ecol.*, vol. 36, no. 11, pp. 2791–2805, Nov. 2022, doi: https://doi.org/10.1111/1365-2435.14168.

[55] H. H. Nguyen, E. A. R. Welti, P. J. Haubrock, and P. Haase, “Long-term trends in stream benthic macroinvertebrate communities are driven by chemicals,” *Environ. Sci. Eur.*, vol. 35, no. 1, p. 108, 2023, doi: 10.1186/s12302-023-00820-6.

[56] J. Aazami, A. Esmaili-Sari, A. Abdoli, H. Sohrabi, and P. Van den Brink, "Monitoring and assessment of water health quality in the Tajan River, Iran using physicochemical, fish and macroinvertebrates indices," *J. Environ. Heal. Sci. Eng.*, vol. 13, Dec. 2015, doi: 10.1186/s40201-015-0186-y.

[57] W. M. H. Wan Abdul Ghani, A. Abas Kutty, M. A. Mahazar, S. A. Al-Shami, and S. Ab Hamid, "Performance of biotic indices in comparison to chemical-based Water Quality Index (WQI) in evaluating the water quality of urban river," *Environ. Monit. Assess.*, vol. 190, no. 5, p. 297, 2018, doi: 10.1007/s10661-018-6675-6.

[58] A. Moridi, H. Khademi, R. Khalili, and E. Khataee, "Validation of physicochemical water quality results through cross-checking with biological indices," *Int. J. River Basin Manag.*, pp. 1–12, 2024, doi: 10.1080/15715124.2024.2414909.