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Water Quality Assessment using Selected Macroinvertebrate Based Indices and Water Quality Index of Sungai Air Hitam Selangor

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ABSTRACT: A study was conducted from July to December 2022 at Sungai Air Hitam, a small tributary of the Selangor River located within the Tanjung Karang Sub-basin in Malaysia (coordinates: 3° 24' 27" N, 101° 25' 54" E to 3° 28' 14" N, 101° 26' 59" E). This confluence is situated near three major downstream water treatment plants. The study assessed six water quality parameters—pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), ammonia (NH_3), and suspended solids (SS)—to calculate the Water Quality Index (WQI). Macroinvertebrates were sampled simultaneously using the dipping net method to obtain biotic indices for further evaluation of water quality. The results indicated that the WQI classified Sungai Air Hitam as Class III, with scores ranging from 56.9 to 64.6, suggesting the river is suitable for water supply and fisheries. However, the Biological Monitoring Working Party (BMWP) index categorized the water quality as poor, with scores between 30 and 42. Similarly, the Average Score Per Taxon (ASPT) ranged from 3.25 to 5.25, indicating pollution or environmental impact, while the Family Biotic Index (FBI) further classified the river as having poor to very poor water quality, with scores between 6.57 and 8.11. Overall, the study suggests that Sungai Air Hitam has experienced some degree of ecological degradation. These findings emphasize the need for continuous monitoring and remediation efforts to preserve and restore water quality.

KEYWORDS: Water quality parameters; river water; water quality index (WQI); macroinvertebrates; biotic indices

1. Introduction

Rivers and small streams are critical sources of freshwater, supporting natural reserves, aquatic habitats, irrigation, and public water supplies. Water, with its unique properties, is indispensable for life and various ecological processes. The quality of river water, defined by its physical, chemical, and biological attributes, determines its suitability for human use and its impact on the surrounding environment. However, river ecosystems worldwide are increasingly facing degradation due to stressors such as water pollution, urbanization, land-use changes, and climate change [1–4]. Water quality in rivers is governed by various physical, chemical, and biological parameters, which determine the river's capacity to support aquatic life, maintain ecosystem functions, and fulfill human needs. Physical attributes like water clarity, temperature, color, odor, and taste influence the aesthetic aspects of water quality. In contrast, chemical properties—such as conductivity, salinity, DO, BOD, COD, NH_3, anions, and SS, serve as primary indicators of water quality [5]. Water quality assessment is fundamental to environmental monitoring, and one of the most widely adopted tools for this purpose is the WQI [6]. WQIs simplify complex scientific data into formats easily understood by both technical and non-technical audiences, making them essential tools for water quality monitoring [7]. Various WQIs have been developed globally to assess river water quality, incorporating different sets of water quality parameters based on specific applications and regional requirements [8]. The WQI condenses information into a single value that reflects the overall condition of a water body [9]. This simplification enables efficient interpretation and comparison of water quality across diverse environments.

In 2007, the Malaysia Water Quality Index (MWQI) was updated to address Malaysia's specific environmental and regulatory needs. The MWQI incorporates six critical parameters: DO, BOD, COD, NH_3, SS, and pH [9, 10]. These variables provide a comprehensive representation of water quality, addressing both physical and chemical attributes. Since its inception in 1985, the MWQI has been used to assess a range of water bodies across Malaysia [8], including urban rivers, groundwater, agricultural and aquaculture catchments [4,10–12], ex-mining ponds [13–15], peat swamps [16], and recreational streams [17]. The Malaysian Department of Environment (DOE) endorses the MWQI as a reliable tool for assessing river water quality and has integrated it into the National Water Quality Standard (NWQS) [18]. The WQI offers a practical approach for categorizing water quality into meaningful classifications—such as good, medium, or poor—which aids in timely decision-making and the prioritization of water quality management efforts [19, 20]. Through this simplified ranking, the WQI supports proactive water resource management, helping stakeholders respond effectively to environmental concerns and protect public health [19].

The decline in water quality has led to significant disruptions in aquatic communities, which are often used as bioindicators of ecosystem health. Aquatic organisms, particularly macroinvertebrates and fish, play a crucial role in water quality assessments due to their measurable abundance and diversity [21, 22]. These organisms are sensitive to environmental changes, and their presence or absence reflects shifts in water quality. Benthic macroinvertebrates—such as aquatic insects, crustaceans, mollusks, and worms—are particularly useful as bioindicators [23, 24]. Their sensitivity to various physicochemical changes makes them essential components of biotic indices used for water quality assessments [25]. Biotic indices, such as the BMWP, ASPT, FBI, and Ephemeroptera, Plecoptera, Trichoptera (EPT) Richness Index, calculate scores by averaging the tolerance values assigned to species based on their response to organic pollution gradients [26]. These indices, initially developed in temperate regions, have been widely adapted to local fauna and climate conditions globally. Researchers have increasingly applied biotic indices to evaluate rivers, lakes, and ponds affected by diverse stressors [27–34]. However, there is a noticeable gap in the integrated use of biotic indices tailored specifically for peat swamp environments. While several studies have assessed water quality in peat swamps using physicochemical parameters [35, 36], they have not incorporated WQI or biotic indices, limiting a comprehensive understanding of ecological health.

Water bodies originating from peat swamps, such as Sungai Air Hitam, pose unique challenges due to their susceptibility to environmental changes from surrounding peat forests and adjacent oil palm plantations. The water quality of Sungai Air Hitam is particularly vulnerable to these factors, and any degradation could significantly affect Sungai Selangor, which relies on it for clean drinking water and supports local fisheries vital for income and employment [37]. Despite the growing use of biotic indices in other water bodies, limited research exists on adapting these indices to river water sourced from peat swamp ecosystems, which exhibit distinct physicochemical characteristics. This represents a critical gap, as standard indices may not fully capture the nuances of water quality changes in such environments. This study aims to address this gap by assessing the water quality of Sungai Air Hitam using both the WQIs and macroinvertebrate-based biotic indices, focusing on adapting or integrating biotic indices suitable for peat swamp ecosystems. Such a detailed evaluation is crucial, as Sungai Air Hitam serves as a key tributary of Sungai Selangor and plays a vital role in supporting regional water resources and ecosystems.

2. Materials and Methods

2.1.Study site.

Sungai Air Hitam (in Malay) or Air Hitam River is a small tributary of the Selangor River located within the Tanjung Karang Sub-basin, between 3° 24' 27" N, 101° 25' 54" E and 3° 28' 14" N, 101° 26' 59" E, as shown in Figure 1. Its upper stream area is surrounded by oil palm plantations, with water sources originating from several ponds and lakes in an ex-mining area adjacent to the Raja Musa Forest Reserve. The middle stream flows through Kampung Bestari Jaya and the Universiti Industri Selangor (UNISEL) main campus. With a total length of approximately 15 km, Sungai Air Hitam has an average water depth of 1.7 meters and a channel width of 5 meters. It is characterized by a low gradient and tranquil flow, with a discharge rate of 21.5 m^3/sec [38], before ultimately emptying into Sungai Selangor. Sungai Selangor is one of the most important rivers in Selangor in terms of water resources, supporting three major water treatment plant intakes (SSP1, SSP2, SSP3) located 3 km downstream [39]. The sampling site for this study was chosen 100 meters from the confluence with the Selangor River (3° 24' 28" N, 101° 25' 54" E). Evaluating the water quality at this site is crucial to understand its impact before it merges with the larger river.

2.2. Water sampling.

Water sampling was conducted at the selected site six times between June 2022 and November 2022. In situ analysis was performed for DO, temperature, and turbidity as part of the water quality evaluation. The YSI ProODO® was used to measure DO, while the Hach 2100Q turbidity meter was employed to measure turbidity, and the Hach sensION+ pH meter was used for pH measurement. River water samples were collected using a bucket attached to a rope. Composite samples were taken from different parts of the river and combined to provide a representative characterization of the river water. Samples for BOD_5 and SS analysis were collected in 1-liter polyethylene plastic bottles without preservatives and labeled accordingly.

For ammoniacal nitrogen (NH_3-N) and COD analysis, samples were collected and acidified to a pH lower than 2 using sulfuric acid (H_2SO_4) for preservation [40]. All samples, along with field replicates, were collected from the site and kept in a cold box at a temperature below 6°C until they reached the laboratory [22]. Six parameters were chosen for the WQI evaluation: DO, BOD, COD, NH_3-N, SS, and pH.

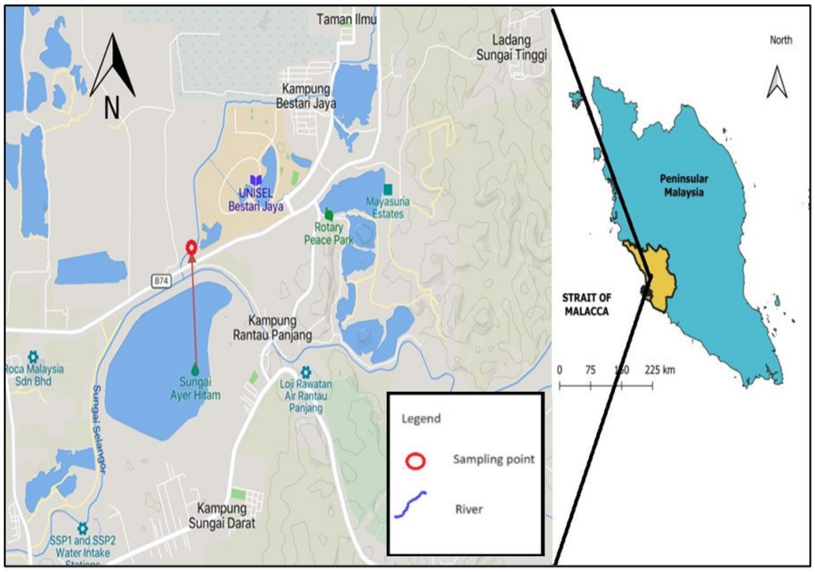

Figure 1. Sampling site at Sungai Air Hitam.

2.3. WQI

The WQI calculation in this study is based on six parameters: DO, BOD, COD, NH-3-H, SS, and pH. Each parameter is converted to a sub-index (SI) using specific formulas that reflect its environmental effect [54], which are then weighted and combined according to Equation 1:

$$WQI = (0.22 \times SIDO) + (0.19 \times SIBOD) + (0.16 \times SICOD) + (0.15 \times SIAN) + (0.16 \times SISS) + (0.12 \times SIpH) \quad (1)$$

Where SIDO is Subindex DO (% saturation), SIBOD is Subindex BOD, SICOD = Subindex COD, SIAN is Subindex NH3-N, SISS is Subindex SS, SIpH is Subindex pH.

2.4.Macroinvertebrate sampling and identification.

In this study, macroinvertebrates were sampled at designated sites using a multi-habitat monitoring approach [41]. This method was designed to capture local habitat variations, including submerged vegetation. Sampling areas were established along a 100-meter stretch of the river, beginning at the downstream section and progressing upstream [42]. A dip net attached to a wooden pole was used for sampling, enabling access to areas beneath submerged and riverine vegetation as well as shallow sections of the river. The dip net had a bag-shaped design with dimensions of 0.3 meters in both width and height and an opening mesh size of 500 µm [43]. During each sampling effort, the net was used to collect water and substrates, which were visually examined for organisms. A sieve with a 500 µm mesh size was also employed to separate unwanted materials and facilitate specimen collection. Collected organisms were preserved in containers filled with 70% ethanol until laboratory processing. In the laboratory, macroinvertebrates were cleaned, sorted, counted, and identified to the closest taxonomic level, referencing Freshwater Invertebrates of the Malaysian Region by Yule and Yong [44].

2.5.Biotic indices application

The BMWP index used in this research assessed water quality based on the presence of macroinvertebrate families at each sampling site [45]. Each taxon was assigned a sensitivity score, and the total score was used to classify water quality. The BMWP index was calculated by summing the tolerance scores of aquatic macroinvertebrates, with each score corresponding to a specific family of organisms. The calculation is represented in Equation 2:

$$\text{BMWP Score} = \sum (\text{no. of family x Sensitivity Score}) \qquad (2)$$

The BMWP scores obtained were subsequently used to calculate the average score, which is employed in another index for classifying aquatic ecosystems, known as the ASPT. The ASPT is determined by dividing the BMWP score by the total number of taxa that have been scored [46], as shown in Equation 3:

$$\text{ASPT} = (\text{BMWP score})/(\text{Number of Taxa (or Families)}) \qquad (3)$$

The Hilsenhoff FBI used in this study was calculated by multiplying the abundance of each indicator family by its respective tolerance value, summing these products, and then dividing the result by the total number of macroinvertebrates present in the sample [47]. The equation for the Hilsenhoff Biotic Index is presented in Equation 4.

$$\text{HBI Score} = \sum \frac{xi \times ti}{n} \qquad (4)$$

Where xi is the number of individuals of each family, ti is tolerance value of the family, and n is total individual in the sample.

The BMWP and ASPT classify water quality into five distinct categories: very good, good, moderate, poor, and bad [45, 46]. In contrast, the FBI employs a more detailed classification system with seven categories, as outlined by Hilsenhoff [47]. These categories are excellent, very good, good, fair, fairly poor, poor, and very poor water quality. A summary of these classifications is provided in Table 1.

Table 1. Classifications and scores of biotic indices. BMWP [45], ASPT [46], and FBI [47].

BMWP	Very good	Good	Moderate	Poor	Bad		
	>130	81 - 130	51 - 80	11 - 50	0 -10		
ASPT	Very good	Good	Moderate	Poor	Bad		
	> 7	6.0 -6.9	5.0 -5.9	4.0 - 4.9	< 3.9		
FBI	Excellent	Very good	Good	Fair	Fairly poor	Poor	Very poor
	0.0- 3.75	3.76- 4.25	4.26- 5.00	5.01 -5.75	5.76-6.50	6.51-7.25	7.25 -10.0

3. Results

3.1.Water quality parameters.

The mean values of various water parameters at the sampling point throughout the entire sampling period are detailed in Table 2. The mean pH value was 5.09 ± 0.12, with a minimum of 4.89 and a maximum of 5.24. This indicates that the river water tends toward acidic conditions due to the presence of humic and tannic acids from the decomposition of lignin [48, 51], attributable to the surrounding peatland in Sungai Air Hitam [49]. The river was classified under Category III of the NWQS for Malaysia [50]. The pH value at this site was lower than that reported in a 2011 study by Asraff et al. [38] but higher than that of peat swamp water in Batang Igan, Sarawak [48]. The mean DO level was 2.84 ± 0.87 mg/l, with a maximum of 4.74 mg/l and a minimum of 1.98 mg/l. The slow flow and water source from swamp forests contribute to low oxygen levels, consistent with findings for other peat wetlands [51]. The SS ranged from 9.0 mg/l to 105 mg/l, with a mean of 53.3 ± 39.1 mg/l, indicating that organic decomposition material is accessible to river flow. However, these values were significantly lower than the 2654 mg/l reported by Asraff et al. in 2011 [38]. The NH_3 concentration ranged from 0.24 mg/l to 0.65 mg/l, with a mean of 0.36 ± 0.12 mg/l, comparable to levels found in Batang Igan [48]. However, ammonia levels were not included in the 2011 study for comparison. The mean BOD was 3.91 ± 1.04 mg/l, with a maximum of 5.25 mg/l, while the COD was 41 ± 11.3 mg/l, ranging from 21.2 mg/l to 52.4 mg/l. The high COD levels indicate the presence of oxidizable organic material [51], likely from the surrounding peat swamp. These levels were much higher than the 10 mg/l reported in Sarawak by Rosli et al. in 2010 [48]

Table 2. Water quality parameter results throughout sampling period.

Parameter	Mean	StDev	Minimum	Maximum
pH	5.09	0.12	4.89	5.24
O_2 (mg/l)	2.84	0.98	1.98	4.74
TSS (mg/l)	53.3	39.1	9.0	105.0
NH_3 (mg/l)	0.36	0.16	0.24	0.65
BOD (mg/l)	3.91	1.04	2.10	5.25
COD (mg/l)	41.1	11.3	21.2	52.4

The correlations between water quality parameters are shown in Table 3. These correlations provide insights into how various parameters influence each other, aiding in the assessment of aquatic ecosystem health. The strongest positive correlation was observed between pH and TSS, with a correlation coefficient of 0.8567, indicating that higher pH levels are associated with increased SS concentration. A strong positive correlation (0.8411) was also found between COD and NH_3, suggesting that higher ammonia concentrations correspond to increased COD levels, reflecting elevated organic and inorganic substances, as suggested by Wang et al. [51]. Additionally, COD showed a significant positive correlation with BOD (0.7954), implying that waters with higher organic pollution (as indicated by BOD) also exhibit higher COD levels, representing greater oxygen demand for breaking down both organic and inorganic materials. The strongest negative correlation was observed between BOD and pH (-0.7956), indicating that as BOD levels rise, pH tends to decrease, reflecting increased acidity due to organic load.

Table 3. Pearson correlation of water quality parameters.

	O_2 mg/l	NH_3	BOD	TSS	COD	pH
O_2 mg/l	1.00					
NH_3	0.0204	1.00				
BOD	0.0010	0.7118	1.00			
TSS	0.5246	0.5126	0.512	1.00		
COD	0.0254	0.8411	0.7954	0.2754	1.00	
pH	0.5517	0.7916	-0.7956	0.8567	0.6340	1.00

3.2. WQI classification.

Throughout the study period, Sungai Air Hitam consistently maintained a Class III classification under the WQI, as shown in Table 4. This classification indicates suitability for water supply and fisheries. These findings align with the 2018 study by Chowdhury et al. [53], which categorized Sungai Air Hitam as slightly polluted and within Class III, as well as the 2020 classification by the DOE in their Environmental Quality Report [54]. However, the BOD Sub-Index classified Sungai Air Hitam as "clean" during the July sampling, while for most other months, it was "slightly polluted." An exception occurred on November 22, when the river was classified as "polluted." Regarding the ammonia sub-index, the river was categorized as "slightly polluted" in August, October, and December, while in other months, it was classified as "polluted." The variability in water quality appears to be influenced by the river's geographical location and surrounding economic activities, such as oil palm plantations, sand mining, and residential developments. Additionally, seasonal weather conditions, including precipitation and dry spells, significantly impact water quality, causing changes in river flow rates and water levels [55].

Table 4. Water quality performances of Sungai Air Hitam according to WQI and sub-index across the sampling period.

Sampling	SIDO	SIBOD	SICOD	SIAN	SISS	SIPH	WQI	Class
July 22	15.68	91.52	73.0	58.02	92.19	52.95	62.33	Class III
Aug 22	21.46	84.79	49.9	73.12	80.13	60.21	59.82	Class III
Sept 22	24.96	82.30	44.2	67.51	82.09	59.53	58.60	Class III
Oct 22	29.99	82.08	20.53	73.12	61.60	64.73	59.47	Class III
Nov 22	25.09	73.21	26.07	68.28	72.46	58.18	56.90	Class III
Dec 22	65.84	84.16	25.10	71.88	55.46	62.97	64.59	Class III

3.3. Macroinvertebrates.

The macroinvertebrate community sampled during the study period is detailed in Table 5. A total of 316 individuals belonging to 22 families, 13 orders, and 9 classes were identified. This represents a lower number of families compared to the 27 families recorded in a microbenthic assemblage study by Hettige et al. (2020) from rivers in an adjacent basin [34]. The composition and abundance of macroinvertebrate families are illustrated in Figure 2. The Coenagrionidae (damselflies, order Odonata) exhibited the highest abundance, with 67 individuals recorded, followed by Chironomidae (midges, order Diptera), with 62 individuals. The family Libellulidae (Odonata) contributed 30 individuals. In contrast, the families Glossiphoniidae, Erpobdellidae, and Syrphidae were represented by the fewest individuals. Chironomid midges inhabit a wide range of aquatic environments, from fast-moving streams to stagnant ponds rich in decomposing organic matter. Although studies of Malaysian Chironomidae are limited [55], this family is commonly found in highland rivers, such as those in the Cameron Highlands [57], and in polluted environments, including recreational rivers [29, 56]. The presence of pollution-tolerant families such as Chironomidae impacts the sensitivity of indices like the BMWP score, as reported by Jumaat [28]. Pollution-sensitive macroinvertebrates, such as those from the orders Trichoptera and Ephemeroptera, were observed during sampling, whereas Plecopterans were absent. This absence contributed to low scores across all biotic indices, contrasting with cleaner water bodies where these families dominate [27, 29, 56]. Notably, no previous records of macroinvertebrate communities in Sungai Air Hitam are available for direct comparison with this study's findings.

Table 5. Taxonomic list of all macroinvertebrates collected at the sampling points.

Phylum	Class	Order	Family
Annelida	Polychatae	Not assign	Aeolosomatidae
Annelida	Clitellata	Arhynchobdelilida	Erpobdellidae
Annelida	Clitellata	Haplotaxida	Haplotoxidae
Annelida	Clitellata	Lumbriculida	Lumbriculidae
Annelida	Clitellata	Rhynchobdellida	Glossiphoniidae
Annelida	Clitellata	Haplotoxida	Tubificidae
Arthropoda	Malacostraca	Decapoda	Atyidae
Arthropoda	Malacostraca	Decapoda	Palaemonidae
Arthropoda	Insecta	Diptera	Chironomidae
Arthropoda	Insecta	Diptera	Syrphidae
Arthropoda	Insecta	Ephemeroptera	Baetidae
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae
Arthropoda	Insecta	Odonata	Coenagrionidae
Arthropoda	Insecta	Odonata	Cordullidae
Arthropoda	Insecta	Odonata	Gomphidae
Arthropoda	Insecta	Odonata	Libellulidae
Arthropoda	Insecta	Odonata	Protoneuridae
Arthropoda	Insecta	Tricoptera	Hydropsychidae
Arthropoda	Insecta	Ephemeroptera	Cainidae
Mollusca	Gastropoda	Hygrophila	Lymnaiedae
Mollusca	Gastropoda	Neotaenioglossa	Thiaridae
Mollusca	Gastropoda	Archhitaenioglossa	Viviparidae

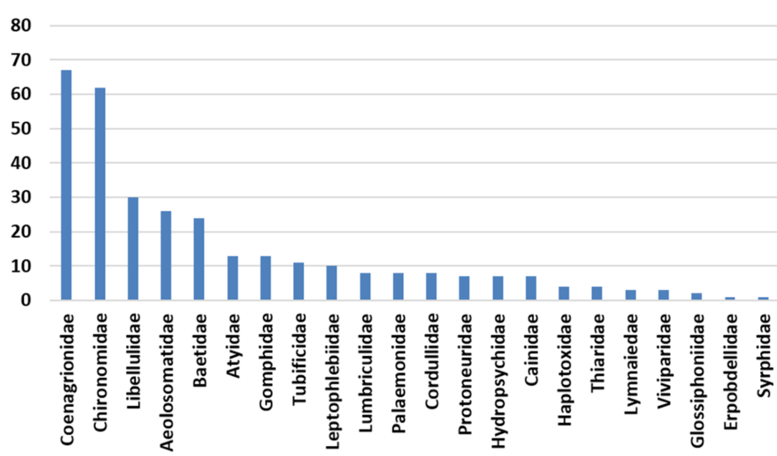

Figure 2. Abundance of individuals from the sampling period.

3.4.Biotic indices.

This study employed three macroinvertebrate-based biological indicators, BMWP, ASPT, and FBI calculated based on the tolerance levels of individual macroinvertebrate taxa sampled during the study period. These indices, detailed in Table 6, evaluate water quality by assessing the sensitivity of key macroinvertebrate groups to pollution and considering the number of taxa present in each sample [56]. The results from July to December 2022 indicate that Sungai Air Hitam was generally in poor condition based on biotic indices. The BMWP scores ranged from 30 to 42, ASPT scores from 3.45 to 5.25, and FBI values from 6.57 (poor) to 8.11 (very poor).

Notably, the July sample showed that water quality, as indicated by biotic indices, was poorer than the WQI, which classified the river as slightly polluted. Conversely, in December, biotic indices showed improved scores, aligning with the WQI's positive classification. This improvement was influenced by satisfactory sub-index performance in WQI parameters, such as BOD and SS, which elevated the overall WQI rating.

Table 6. Water quality during sampling using WQI and Biotic Indices.

Sampling	WQI	Class	BMWP	Class	ASPT	Class	FBI	Class
Jul-22	62.3	Class III	30	Poor quality	4.29	Poor quality	7.44	Poor
Aug-22	59.8	Class III	36	Poor quality	4.00	Poor quality	8.11	Very poor
Sep-22	58.6	Class III	30	Poor quality	4.29	Poor quality	8.10	Very poor
Oct-22	59.5	Class III	34	Poor quality	3.78	Poor quality	7.61	Poor
Nov-22	56.9	Class III	38	Poor quality	3.45	Poor quality	7.72	Poor
Dec-22	64.6	Class III	42	Poor quality	5.25	good	6.57	Fairly poor

Table 7. Pearson correlation of WQI with selected biotic indices.

Biotic Index	Pearson Correlation	Correlation Coefficient
BMWP	-0.189	0.719
ASPT	-0.745	0.089
FBI	-0.801	0.03

Pearson Correlation Analysis was employed in this study to assess the relationship between the abundance of macroinvertebrate biotic indices and the WQI [28]. Table 7 presents the Pearson correlation coefficients between the WQI and selected biotic indices. BMWP, Pearson Correlation: -0.189 and Correlation Coefficient: 0.719. This indicates a weak negative correlation between WQI and BMWP. While the correlation coefficient is quite low, the negative sign suggests that as WQI increases [41], BMWP tends to decrease, and vice versa. However, the strength of this correlation is not particularly strong. The Pearson correlation of WQI and ASPT, -0.745 with coefficient of 0.089, this signals a strong negative correlation between WQI and ASPT. The high negative correlation coefficient indicates a strong relationship. In this case, as WQI increases, ASPT tends to decrease significantly, and vice versa. The WQI had Pearson Correlation of -0.801 with FBI and Correlation Coefficient: 0.030, this signifies a strong negative correlation between WQI and FBI. Like ASPT, the high negative correlation coefficient suggests a strong relationship. As WQI increases, FBI tends to decrease significantly, and vice versa. ASPT and FBI show stronger negative correlations with WQI compared to BMWP. FBI shows the strongest negative correlation among the three indices with WQI. Negative correlations imply that as WQI improves (i.e., water quality gets better), the values of ASPT, FBI, and BMWP tend to decrease, indicating healthier biological conditions.

4. Discussion

The findings from this study, based on physico-chemical parameters and biotic indices, suggest that the water quality of Sungai Air Hitam is influenced by both natural and anthropogenic factors. The WQI consistently classified the river as Class III, indicating suitability for water supply and fisheries, though often at the threshold of slight pollution. Seasonal fluctuations, such as improved BOD and SS levels in December, appear to reflect periodic influences from precipitation patterns and surrounding land use. These include the impact of oil palm plantations and residential areas, both of which are known contributors to organic loading. Additionally, the sampling station selected was located before the confluence with Sungai

Selangor. Biotic indices, including the BMWP and FBI, generally indicated poor to very poor ecological conditions throughout the sampling period. This result aligns with previous studies on tropical rivers in Malaysia, where rivers in agricultural and urbanized regions tend to show low biodiversity and a high representation of pollution-tolerant species compared to rivers in pristine areas [57]. The strong negative correlations between WQI and indices such as FBI and ASPT support the idea that organic pollution adversely impacts the macroinvertebrate community structure [58]. Notably, pollutant-sensitive taxa like Trichoptera and Ephemeroptera were observed, although their presence was limited. This suggests that Sungai Air Hitam may still harbor marginal habitats capable of supporting these sensitive species. However, the current study has several limitations. The absence of historical WQI and biotic data for Sungai Air Hitam prevented direct comparisons over time. Additionally, the study's duration may not have fully captured seasonal variations or long-term trends.

5. Conclusions

The findings from both the physico-chemical and biological assessments of Sungai Air Hitam indicate notable water quality degradation. This degradation is primarily attributed to low pH, low DO levels, and high COD, which are linked to the presence of organic matter from the surrounding peat swamp forest. The combined use of biotic indices and the WQI in this study provided a more comprehensive understanding of the river's health. The biotic index proved to be a valuable complement to physico-chemical parameters, enhancing the overall assessment of water quality. Given these findings, periodic monitoring of Sungai Air Hitam is recommended to track long-term trends in water quality. Notably, previous studies did not incorporate WQI or key parameters such as BOD and COD, which limited the scope of past assessments.

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Competing Interest

No conflict of interest was reported by author.

Author Contribution

Harisham Abu Sama: Served as the main author and corresponding author. Conducted sampling, data collection, laboratory analysis, and contributed to the manuscript preparation. Muhammad Ali Yuzir: Acted as a water quality advisor, providing guidance on research design and overall study framework. Shamila Azman: Served as a water quality and methodology advisor, offering expertise in analytical methods and procedural approaches.

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