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Evaluating the Influence of Water Quality on Macroinvertebrate Diversity Using Bioindicator Analysis

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Abstract

Freshwater ecosystems in agricultural regions are threatened by runoff and land use, but biological responses to equivocal water quality changes remain underrepresented in traditional monitoring. The specific research that this study attempt to address is how water quality affects the diversity of macroinvertebrates which serve as bioindicators for freshwater ecosystem health. The study was carried out at Sawah Ring, Tangkak in the state of Johor and it is a fresh river system situated in an area with active paddy cultivation. The concentration of dissolved oxygen (DO), pH, temperature, salinity and conductivity were measured in situ using a multiparameter water quality meter and the overall quality was assessed using Water Quality Index (WQI). Macroinvertebrates were collected by kick sampling, identified at family level and community diversity was determined through the Shannon-Weiner Index (H'). Correlation analysis among biological parameters and water quality characteristics was studied. The WQI values fell between 80.80 and 81.84 thus placing all the sampling sites in Class II which are generally good water. Most physicochemical parameters were agreeable for aquatic life but strongly acidic pH and moderate conductivity suggested that there were localized environmental stres. In all, twelve families' macroinvertebrates were present at each site revealing medium diversity with a Shannon-Weiner Index value from 2.33 to 2.44. Both pollution-sensitive which is Ephemeroptera families and resistant taxa which Chironomidae were observed. Macroinvertebrate diversity exhibits definitive responses to changes in dissolved oxygen (DO) and pH. In summary, the data suggests that water quality has a strong impact on macroinvertebrate diversity and supports that fact macroinvertebrates are good bioindicators for accessing freshwater ecosystem health in agriculturally influenced landscapes.

1. Introduction

Freshwater ecosystems, such as rivers, streams, wetlands and lakes are some of the most valuable yet vulnerable ecosystems on our planet. These ecosystems also provide several ecological services such as sediment transport, flood regulation, nutrient cycling, filtration of water and habitat for aquatic plants and animals. There are also human lives which depend on them for water such as household, industry and agriculture. At any scale, for both farms and watersheds, urbanization, agriculture, industry impacts and climate change contribute to the ubiquitous decline of freshwater ecosystems [1].

There are many stressors undermining fresh water constraint in Malaysia, particularly semi-rural and agriculturally active areas such as Sawah Ring, Tangkak. The pollution of water bodies with a higher concentration of nutrients, sendiments and chemical contaminants in agriculture lead to eutrophication, turbidity, they are due the high use of fertilizers and pesticides, as well as deficient treatment if waste waters [2]. The chemicals disturb the chemical and biological balance of aquatic ecosystems, often resulting in loss of biodiversity and impairment of ecosystem functions. Physicochemical parameters such as pH, dissolced oxygen, biochemical oxygen demand, temperature and turbidity have been the predominant focus of water quality monitoring in Malaysia as well as many other countries [3]. However, as important as they are, these represent short-term environmental changes and may not reflect the sum of biological responses to pollution over time. As a result, there has been growing interest in the use of biomonitoring devices to supplement traditional chemical assessments.

The study area, Sawah Ring Tangkak was chosen in this research since it represents a freshwater stream ecosystem. The site was chosen because it offers a range of conditions for assessing macroinvertebrate diversity and habitat, which in turn provide important information on the state of freshwater aquatic systems. These types of freshwater stream are often used as tools to study the influence that physical and chemical conditions have on biological communities in the environment. It was chosen to be a natural stream based on its' woodland setting and varying environmental factors throughout the length of the stream. The diversity of water flows, the surrounding vegetation and possible human interference make this area suitable for observing changes in water quality and their influence on the biota. These attributes ensure the quality of the observation of macroinvertebrate communities that respond to environmental perturbations.

Some aquatic macroinvertebrates such as mayflies, stoneflies, snails and aquatic beetles have gained universal acceptance in biotic surveillance for water quality [4]. These organisms also have predictable responses to environmental stimuli and differences in sensitivities towards contaminants; they are also relatively simple to collect. Although tolerant species often dominate in degraded habitat, the sensitive taxa decrease or disappear from polluted water bodies [5]. As a result, macroinvertebrate communities are reliable indicators of ecosystem health over time [6]. A more complete and ecologically relevant characterization of aquatic systems can be achieved by including biological indicators such as macrozoobenthos in combination with physicochemical data [7]. We increase our understanding of how pollution affects biodiversity and the functioning of ecosystems as well as water chemistry by integrating the two data sets.

As such, this study aims to examine the influence of water quality in Sawah Ring and diversity of macroinvertebrates in Tangkak. It also aims to offer a comprehensive assessment of the health of freshwater ecosytems and feedback into improved environmental management.

2. Materials and Methods

The study was conducted at Sawah Ring, Tangkak (2˚13'50"N , 102˚40'54"E). The area consists of paddy fields with an interconnected network of irrigation channels. Three sampling sites were established within the study area and designated as Sites 1, Sites 2 and Sites 3. Sampling activities were conducted along the irrigation channels and each site was treated as an independent sampling location for water quality and macroinvertebrate data collection. All sampling sites were located within the same paddy field system.

2.1 Water Sampling and In-Situ Measurement

Water sampling and in-situ measurements were performed at the chosen sampling locations along a stream located near Sawah Ring Tangkak. This process was performed in order to know the physical and chemical properties of the water for assessing its quality. In situ measurements were performed at every sampling point using digital water testing multiparameter meter. The salinity, electrical conductivity, dissolved oxygen, pH and water temperature were determined. Measurements were made directly on site to avoid any effects from handling or transport of the samples and to get an accurate result. During the development of WQI for a stream, many factors have to be evaluated and monitored [8]. Dissolved oxygen (DO) is the amount of oxygen in water which is not chemically combined with other elements and is usually reported as milligrams of oxygen per unit volume of water. DO is temperature dependent. The more astringent effect, the more oxygen the water can hold [8].

2.2 Macroinvertebrates Sampling

A selected locations in the Sawah Ring Tangkak stream were also monitored with respect to macroinvertebrate sampling in order to determine their diversity and compositions. These inhabitants served as biological indicators of relative resistance to changes in water quality. The method kick sampling, used particularly in shallow freshwater streams was adopted for the sample collection. One hand net was set downstream at each site and the substrate of the stream was carefully disturbed by kicking. This action detached macroinvertebrates from the sediment so water flow carried them into the net. Macroinvertebrate sampling was conducted over a period of two weeks. After collection, macroinvertebrates were placed in a vial and taken back to the lab for identification and analysis. Macroinvertebrates were manually sorted using forceps under adequate lighting and a stereomicroscope to ensure accurate observation of morphological features. Identification was carried out to the appropriate taxonomic level, typically up to the family level, using standard identification keys and reference materials. The identified organisms were counted and recorded to determine their abundance at each sampling site. The data obtained were used to calculate macroinvertebrate diversity indices, which were later analysed in relation to water quality parameters to assess the ecological condition of the stream.

2.3 Water Quality Index

The DOE's WQI formula was used to calculate the WQI for the Sawah Ring Tangkak. The several sub-indexes (SIs) that make up the WQI equation which are determined using the best-fit relationship. Different weights are applied to the water quality characteristics. A stream's overall water quality index (WQI) is significantly impacted by the assigned weight, which represents the importance of a water quality characteristic for a certain usage. [9] The Water Quality Index was calculated using the equation below.

$$WQI = (SI_{DO} \times 0.30) + (SI_{pH} \times 0.25) + (SI_{Temp} \times 0.15) + (SI_{Cond} \times 0.15) + (SI_{Sal} \times 0.15)$$

Where :
WQI = Water Quality Index
SIDO = sub-Index Dissolved Oxygen
SIpH = sub-Index pH
SITemp = sub-Index Temperature
SICond = sub-Index Conductivity
SISal = sub-Index Salinity

2.4 Shannon-Weiner Index

Macroinvertebrate data were analysed by calculating diversity indices, such as the Shannon–Wiener Diversity Index, to assess biological diversity at each site. These indices provide information on species richness and evenness within the macroinvertebrate community [10].

$$H' = -\sum (p_i \ln p_i)$$

Where :
H′ = Shannon–Wiener diversity index
p_i= proportion of individuals belonging to the ***i***th species
ln = natural logarithm

$$p_i = n_i / N$$

Where :
ni = number of individuals of species ***i***
N = total number of individuals of all species

3. Results and Discussion

Based on the formula of Water Quality Index, the Table 1 below shows the data collected were calculated and identified the class of water quality.

Table 1 Result of Water Quality Index Calculation

SITE	SIDO	SIpH	SITemp	SISal	SICond	WQI	Class
Tali Air 1	82.4	60.9	91.48	96	91.8	81.84	II
Tali Air 2	79.8	60.6	90.28	96	91.8	80.8	II
Tali Air 3	81.9	60.4	89.68	96	91.8	81.3	II

As observed in Table 1, Tali air 1 had WQI of 81.84. This indicates that the it was appropriate for traditional water treatment and the sensitive aqua animals. Tali Air 2 had a WQI of 80.8. While water quality remains in the acceptable range overall, the decline in WQI can be attributed to sawah specific irrigation return flows or agricultural runoff. Finally, Tali Air 3 obtained a WQI of 81.3 indicating moderate but regulated impact from agricultural purposes. The value of Water Quality Index (WQI) for all sampling sites at Sawah Ring was between 80.80 and 81.84 and all sampling stations belonged to Class II water quality classification based on the Malaysian DOE classification. This shows that the water quality in the study area is, for the most part, of good quality and suitable for conventional treatment technology, recreational use with body contact and protection of aquatic life [11]. Although the study area lies in the paddy growing belt that is often associated with agricultural influx of fertilizers and pesticides, the WQI values are consistently observed to have fluctuated within in Class II except for few instances. This indicates that agrarian activities in the Sawah Ring were not critical to catastrophic decrease of water quality overall at avenue forest waters during period of observation. The relatively constant WQI among all stations also suggests a slight variation in water quality across the paddy field drainage system. Given this, the fact that all sites are classified as Class II demonstrate that the water body is still in a mass balance situation to support biological functions and aquatic life. For example, Azrina et al. (2006) reported that rivers draining agricultural catchments such as the Langat River often remain within Class II, despite receiving nutrient and sediment inputs from surrounding land use. Similarly, Baharudin et al. (2021) observed that rivers in agricultural and aquaculture catchments commonly exhibit Class II water quality, indicating that moderate agricultural activities do not necessarily cause severe water quality degradation.

Result of Macroinvertebrates Diversity in Family Level was shown in Table 2 as below.

Table 2 Result of Macroinvertebrates Diversity in Family Level

FAMILY	TALI AIR 1	TALI AIR 2	TALI AIR 3
Chironomidae	5	4	6
Baetidae	4	7	5
Plecoptera	8	5	5
Stylommatophora	5	5	0
Scirtidae	0	0	5
Libellulidae	5	3	2
Aeshnidae	4	5	1
Dytscidae	2	4	5
Ephemerellidae	3	7	7
Culicidae	2	4	4
Heptageniidae	2	3	3
Caenidae	2	4	3
Calopterygidae	1	3	1
ABUNDANCE	49	54	47
FAMILY RICHNESS	12	12	12

Table 2 resulting in a recorded total of 12 families from 6 orders at each site family level richness was consistent among all sampling locations. However, total abundance differed strikingly among sites which the highest was recorded at Tali Air 1 (49 individuals) , followed by Tali Air 2 (54 individuals) and Tali Air 3 with 47 individuals. The higher abundance of the species at Tali Air 1 than at other sites appears to be related to better habitat conditions and lower abundance at other sampling sites may be due to difference in habitat structure in the paddy drainage system. *Chironomidae, Baetidae, Ephemerellidae* and *Heptageniidae* families were the most abundant families in the macroinvertebrate community composition and were knowns as indicators of the relative good status water quality. Ephemeroptera families presence demonstrates that the stream can support pollution-sensitive fauna, in agreement with class II WQI [12]. At the same time, according to Lenat and Resh (2001), the occurrence of pollution-tolerant groups such as Culicidae and Chironomidae suggests the influence of paddy-related agricultural activities, including organic and nutrient inputs, without causing severe water quality degradation13].

The Table 3 below show the Result of Shannon-Weiner Index (H').

Table 3 Result of Shannon-Weiner Index (H')

Site	Total Abundance (N)	Shannon–Wiener Index (H′)
Tali Air 1	49	2.33
Tali Air 2	54	2.44
Tali Air 3	47	2.36

Table 3 shown that Shannon-Wiener index values varied minimal between sites, despite WQI values showing little variance. This means that the distribution and evenness of macroinvertebrate communities may be impacted by local habitat characteristics and agricultural pressures typical of paddy areas, even while overall water quality remained within the same class [14]. Paddy cultivation runoffs may represent an input of nutrients and also of organic matter without necessarily decreasing at the same time the general quality of water, which can favour tolerant group such as Chironomidae and Culicidae [13]. In general, the findings demonstrate a suitable Class II water quality which sustains a moderate macroinvertebrate diversity in the Sawah Ring Tangkak paddy area with good ecological relationship between physicochemical water quality and biological markers.

4. Conclusion

The Water Quality Index (WQI) assessment and physicochemical variables were applied in this study to explore the effect of water quality on macroinvertebrate diversity. Water quality parameters such as dissolved oxygen (DO), pH, temperature, salinity and conductivity were analysed in the selected sampling stations. Class II (good and clean water quality) is in harmony with the WQI values, which reflects the overall water quality of the research area. It might still relieve some degree of environmental stress, but the stream's Class II condition means it should typically be healthy for both aquatic life and recreational use. Tali Air 1 represented the best site because it has the highest WQI value approach the level of the conventional water treatment and ecologically metro given to sensitive aquatic organisms. This condition was mirrored in the macroinvertebrate community structure samples during the survey. The presence of the taxa moderately tolerant may allude that water quality should be good enough to maintain biodiversity but not pristine enough to accommodate large quantities of super sensitive individuals. In addition, as only the family level of the macroinvertebrates was detected, it may have restricted our capacity to recognize stronger ecological responses that could be displayed at genus or species resolution. Moreover, only a limited number of sampling sites within the paddy drainage system were considered and may not accurately represent the spatial variability of environmental parameters across the study site. Furthermore, some recommendations are introduced for improving developing methods for assessing water quality and managing freshwater ecosystems in future. Future studies should also consider the periodic and long-term surveillance of physicochemical variables and macroinvertebrate abundance in order to capture seasonal variation and chronic environmental signals that may affect river health.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Nurul Shahiera Atieka Yunus, Furzani Pa'ee;* ***data collection:*** *Nurul Shahiera Atieka Yunus, Hurulain Silmina Hamdi;* ***analysis and interpretation of results:*** *Nurul Shahiera Atieka Yunus;* ***draft manuscript preparation:*** *Nurul Shahiera Atieka Yunus, Furzani Pa'ee, Hurulain Silmina Hamdi. All authors reviewed the results and approved the final version of the manuscript.*

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