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Integrated Approaches in Water Quality Monitoring for River Health Assessment: Scenario of Malaysian River

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Abstract

Current practice of determining river water quality in Malaysia is based mainly on physicochemical components. Perhaps, owing to the lack of information on habitat requirements and ecological diversity of aquatic macroinvertebrates and on unearthy taxonomic key of benthic macroinvertebrates in this region makes it less popular than conventional methods. The study took place in three rivers in the state of Johor, Southern Peninsula of Malaysia, which exhibited different degrees of disturbances and physical properties, namely Sungai Ayer Hitam Besar, Sg Berasau, and Sg Mengkibol. Benthic macroinvertebrates were sampled using rectangular dipnet with frame dimension 0.5 m × 0.3 m. Although physicochemical elements such as water temperature, pH, and dissolved oxygen (DO) were measured using a YSI Professional Plus handheld multiparameter instrument, other parameters such as biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), total suspended solid (TSS), and ammoniacal nitrogen (NH₃N) were tested using the procedure of APHA Standard Method. The study found that the status of water quality varies among the three rivers. A multivariate analysis, the canonical correspondence analysis (CCA), was applied to elucidate the relationships between biological assemblages of species and their environment using PAST (version 2) software. The present findings reveal that human-induced activities are the ultimate causes of the alteration in macroinvertebrate biodiversity.

Keywords: benthic macroinvertebrate, ecosystem health, anthropogenic impact, water quality monitoring, biological assessment

1. Introduction

Water is a natural resource that is vital to all life-forms. Although nearly 70% of the world is covered by water, only 2.5% of the total is freshwater. The rest is ocean-based saline water. However, only 1% of the freshwater is easily accessible, with much of it trapped in glaciers and snowfields. In tandem with the growing global population and improvement of living standards, the increasing demand for freshwater has been said to overshadow the concerns of the warming effect of climate change [1].

Since time immemorial, rivers have played a major role in the development of human society, serving as transport routes and as a vital supply of water for domestic and agricultural use, while yielding an important source of protein for human consumption. Hence, it is not surprising that many major towns and cities are situated on the banks of rivers. For example, early urban settlements such as Uruk, Eridu, and Ur, established at the dawn of human civilization about 6000 years ago (4000 BC) in Mesopotamia and Babylon, were built in the fertile valley irrigated by the Tigris and Euphrates rivers [2].

2. Scenario of river in Malaysia

Rivers have similarly played an important role in the growth of towns and cities in Malaysia, with early settlements springing up along river banks and estuaries [3]. Many major cities and towns in such locations include Kuala Lumpur, Kuala Terengganu, Alor Setar, Kuantan, Kota Bharu, Kuching, and Melaka City [4, 5]. The discovery of tin deposits in the flood plains and river valleys also encouraged settlements to mushroom in these areas, leading to a booming tin-mining industry in the 1800s till 1980s, which made the country the largest producer of tin in the world.

Malaysia has grown rapidly over the last three decades, transforming from a rural economy based on agriculture and tin mining to an export-based, manufacturing economy. In the eighteenth century and the first half of the nineteenth century, large areas of land were cleared for coffee and sugarcane cultivation. This was followed by large-scale land clearing for rubber plantations, making Malaya the world's largest producer of natural rubber. In recent years, much of the rubber growing lands has been converted to oil palm cultivation, while further new areas have been cleared for this crop. Unfortunately, rapid changes of land use, especially of forested land and food crops to plantations as well as urban development, have triggered river erosion, surface runoff, and sedimentation of rivers, resulting eventually in overstressed river systems. River basins are frequently facing problems arising from flooding. Many rivers are gradually losing their ability to supply fresh water, and as a result, these rivers are now mainly used for transportation [6].

In Malaysia, the sources of raw fresh water are rivers, storage dams, and groundwater. Rivers supply 90% of the nation's water supply, providing water for various uses such as domestic, agricultural and industrial processes, power generation, besides serving as waterways for

transport and communication. Aquatic harvests from rivers are also an important source of food. However, as the country develops, water pollution is becoming more serious, affecting the function of the river system as a source of raw water supply. Although raw water supply is not yet depleted, clean water that can be safely consumed by humans is becoming hard to come by.

The major causes of water pollution in Malaysia include effluent from wastewater treatment plants, discharge from agro-based industries and livestock farming, land clearing activities, and domestic sewage [7]. Rivers in both urban and rural areas are experiencing the same problems. Although environmental issues in Malaysia raise serious concerns, the measures taken to address the problem thus far have been fragmented and inadequate. An integrated and holistic approach that is required is now gaining recognition, and this is reflected in the government's latest policies.

3. River-related issues and river management in Malaysia

As a responsible authority for ensuring the sustainability of integrated river basin and water resources management, the Department of Irrigation and Drainage (DID) under the Ministry of Natural Resources and Environment (NRE) upheld the Integrated River Basin Management (IRBM) concept more than 10 years ago. IRBM, a subset of Integrated Water Resources Management (IWRM), is an effective method or approach to achieve the objectives of the IWRM-based river basin. In other words, IRBM is the management of river basin as an entity, not as a series of isolated individual rivers. It is geared towards integrating and coordinating policies, programs, and practices in addressing water and water-related issues. It also requires the improvement of professional and financial practices as well as legislative, managerial, and political capacity on water-related issues. The One State One River Program (1N1S), launched by DID in 2005, was an extension of the Love Our Rivers Campaign with the slogan "SungaiKu Hidupku" ("My river, My life"). This program is one of the pilot projects for the implementation of the IRBM concept. In this program, DID and the state governments selected 13 rivers, one river for each state. Among the main criteria of the river selection was that the polluted rivers should be running through major cities in the country. The main goals of the 1N1S were to achieve and maintain the status of clean and vibrant river within Class IIB of water quality by 2015 [8]. Under the RMK-9, a sum of RM57.5 million was allocated to each state, while in the RMK-10, an allocation of RM26 million was provided for a period of 2 years (2011–2012) for 13 selected rivers.

The results showed that the program had achieved some measure of success, especially in terms of improved water quality from Class V to Class III in some rivers, namely Sungai Petani, Kedah; Sungai Galing, Pahang and Sungai Pinang, Pulau Pinang. In addition, Sungai Kinta in Perak achieved an improvement in water quality index (WQI) from Class III to Class IIB. However, the water quality for Sungai Hilir, Terengganu and Sungai Penchala, Kuala Lumpur remain unchanged [8]. Those river restoration programs have not only shown positive effects and significantly improved the quality of water, but also enhanced amenities and

riverside landscape. Nevertheless, the positive effects of the measures on riverine biota are rarely observed or documented. Sungai Melaka, for example, has shown tremendous changes in water quality, from heavily polluted to slightly polluted after undergoing several rehabilitation efforts. However, in terms of faunal diversity and aquatic life, only tolerant and hardy species such as the tilapia fish have been found to inhabit the river. A similar situation also occurs in two rehabilitated rivers in Johor, namely Sungai Sengkuang and Sungai Sebulong, where only hardy, non-economic fish species have been observed.

However, taking into consideration the physicochemical aspects alone are not sufficient to indicate a healthy ecosystem as a whole. In fact, this does not guarantee health of aquatic life because it does not directly reflect the biological responses to pollution. Although physicochemical evaluation might be appropriate to particular circumstances at the time of sampling, it does not provide an insight into the effects of pollution on habitat and aquatic life. Aquatic communities respond to ecosystem changes in various ways. The distribution and abundance of certain species and changes in their behavioral, physiological, and morphological of individual organisms indicate whether that habitat has been adversely altered. High biodiversity of aquatic species and the presence of sensitive species are good signs of a healthy stream. Nature of the river as a collection point for water flowing from every corner reflects the health of the surrounding area. Therefore, any changes or modification on riparian vegetation and surrounding landscape may subsequently alter the composition and functional structure of aquatic life inhabiting it. Healthy water body shows ecological integrity, which represents the natural or undisturbed area. Ecological integrity is a combination of three components, namely chemical, physical, and biological integrities. When one or more of these components are degraded, the health of the water body is affected, and in most cases, aquatic life living in it will reflect the degradation. According to Gordon et al. [9], stream health measurement takes into consideration the water quality, habitat availability and suitability, energy sources, hydrology, and the biota themselves.

In order to achieve a comprehensive evaluation of healthy water bodies, biological assessment tool should be carried out simultaneously with the standard physicochemical method. Biological assessment, the primary tool to evaluate the biological condition of a water body, comprises surveys and other direct measurements through biological communities such as plankton, periphyton, microphytobenthos, macrozoobenthos, aquatic macrophytes, and fish. Among all, benthic macroinvertebrates are the most favored in freshwater monitoring and are widely used to evaluate the water body health and condition [10, 11]. The advantages of using biological indicators, particularly macroinvertebrates, are biological communities that reflect the overall ecological quality and provide a broad measurement of fluctuating environmental conditions. In addition, the result of biological monitoring is reliable and relatively inexpensive compared to toxicity testing [12]. Liebmann (1962) quoted that the history of biological monitoring methods for assessing water quality began more than a century ago by Kolenati (1848) and Cohn (1853) both quoted by [13]. However, such studies in Malaysia are still very limited and started relatively late with the earliest documented was in the early 90s [14, 15]. After year 2000, interest on this topic is gaining attention and grows, and example of studies can be seen in [16–20]. In the year 2009, DID in collaboration with Universiti Sains Malaysia

produced a Guideline for Using Macroinvertebrates for Estimation of Streams Water Quality. The guideline provides simple, inexpensive, and easy approach to estimate water quality through the identification of freshwater macroinvertebrates. This government's effort is an initial step to the development of such studies in Malaysia and proving biological methods in the study of water quality began to be accepted.

4. Description of study area

This study focused on the description of the existing ecological environment of three rivers with different environmental gradient ecosystem, *viz.* Sg Ayer Hitam Besar (forest reserve), Sg Berasau (logged area), and Sungai Mengkibol (urban and rehabilitated rivers). Three main processes explored in this study were consisted of physical characteristics (general characteristics that are important in influencing the river's aquatic ecology such as channel forms, instream habitats, substrates, riverbank vegetation, and structure; additional habitat attributes such as anthropogenic alterations to the river were briefly described), biological characteristics (focusing on the composition and abundance of macroinvertebrates species) and chemical characteristics (documentation of existing conditions related to commonly observed water quality parameters). The study also investigated the correlation between the physicochemical attributes and variations in the macroinvertebrates assemblages.

4.1. Sg Ayer Hitam Besar

Sg Pontian Besar drains a total area of 362.047 km² to the Straits of Malacca. The main tributaries are Sg Ayer Hitam Besar and Sg Rambutan. The Sg Ayer Hitam Besar subcatchment is situated between Ulu Pontian and Kampung Seri Gunung Pulai settlement area. This river has a length of 11.2 km with a width of 35 m, before joining the main river and end up at the Straits of Malacca. The study was conducted at the Pulai Waterfall in Gunung Pulai Forest Reserve, in the southwestern part of Johor. Located within an 8-ha protected forest reserve, this former water catchment area for Singapore serves an important function as an area for habitat and biodiversity protection, recreation, tourism, research, and education. Gunung Pulai is a hill dipterocarp forest type on granite-based soil; its peak is about 700 m above sea level. The Gunung Pulai Forest Reserve is divided into 27 compartments to facilitate administration and management. However, only two compartments, namely Compartment 9 for recreational pursuits and Compartment 7 for educational purposes, are open to the public.

4.2. Sg Berasau

Sg Berasau is located in the Kota Tinggi District, about 42 km northeast of Johor Bahru. With an area of 54 km², this river basin is a sub-basin of Sungai Ulu Sedili Besar river basin. The study area was a first-order river situated about 8 km from the Kota Tinggi-Jemaluang main road and within the Ulu Sedili Forest Reserve. The sampling areas could be reached only by 4WD through forest plantations managed by Aramijaya Sdn. Bhd., which granted the study team access to the area for this study. Sg Berasau is surrounded by a permanent forest reserve.

However, there is active logging in the area planted with *Acacia mangium*, a tree species of the pea family, Fabaceae. *Acacia mangium* is suitable as raw material for sawn timber, and wood-chips in the pulp and paper industry, and reconstituted wood for the furniture industry. In the Asia–Pacific region, Japan is among the larger importers of wood chips, while the pulp and paper industry finds markets in Taiwan and South Korea. Based on the macro-EIA for forest management units (FMU) in Johor, Sg Berasau supports a variety of fish species such as Terbul, Sebarau, Baung, Seluang, and Tapah.

4.3. Sg Mengkibol

Sg Mengkibol is a second-order river located within the Endau watershed. This river receives flows from Sg Melantai before joining Sg Semberong. This river basin is approximately 185 km² width and 20 km long. The study area is located in the middle section of Sg Mengkibol, starting from the Sg Mengkibol Riverine Park until the wet market. From December 2006 until January 2007, Malaysia experienced large-scale flood events that affected most of the state of Johor. This phenomenon was caused by extremely high rainfall attributed to Typhoon Utor that made landfall in the Philippines and Vietnam. A series of massive floods hit the states of Malacca, Pahang, and Negeri Sembilan, with Johor as the worst hit state. Among the major towns affected by the floods were Batu Pahat, Johor Bahru, Kluang, Kota Tinggi, Mersing, Muar, Pontian, and Segamat. Consequently, the Department of Irrigation and Drainage (JPS) allocated RM2 million to deepen Sg Mengkibol at its banks for flood mitigation in low-lying residential areas [21].

5. Sampling procedure and data collection

Most of that data used for analyses in the study were primary data obtained from sampling and laboratory analyses. Data of benthic macroinvertebrate assemblage and water quality assessment were obtained from *in situ* analyses and further analyses in the laboratory. River habitat and morphology data were measured on-site in field surveys. On the other hand, secondary data such as land use, rainfall data, and stream catchment maps were obtained from several agencies such as the Department of Environment, Department of Drainage and Irrigation, Department of Survey and Mapping and local authorities.

5.1. Benthic macroinvertebrate

The multihabitat approach of USEPA's Rapid Bioassessment Protocol (RBP) was adopted for this study as it was suitable for sampling a wide variety of stream types [22]. In this study, a rectangular dipnet with 500- μ m mesh attached to a 0.5 m \times 0.3 m frame and a long pole were used for this purpose. For multiple habitats, the habitat types were sampled in proportion to their relative surface area within the sampling reach. A total of 20 sample units were collected from all major habitat types by kicking the substrates or jabbing with a dipnet within a sampling station to obtain a composite of 60 sample units in total. The samples were washed and any detritus present was removed on-site as it would be impractical to wash large samples in the laboratory. Following this, benthic materials were sieved and rinsed before preservation

in 70% ethanol. The sample containers were labeled to show all the essential information, including date and sampling location. Preprinted labels were preferably used using marker pens as ethanol would remove writing. Moreover, labeling on container lids was avoided in case they were interchanged. In laboratory, benthic macroinvertebrates were rinsed thoroughly in 500 µm-mesh sieves to remove preservative and sediment, while remaining debris was visually inspected and discarded. During the separation process, the samples were soaked for about 15 min in tap water to hydrate the preserved organisms and prevent them from floating on the water surface during sorting. The samples were then spread over an enamel tray and sorted out into major taxa. All organisms were identified to the lowest practical level using a dissecting microscope and taxonomic Key from Yule and Yong [23].

5.2. Water quality

Water quality assessment data were obtained by two methods, namely *in situ* and laboratory analyses. *In situ* measurements were made on temperature, pH, conductivity, and dissolved oxygen (DO) by using a YSI Professional Plus handheld multiparameter instrument. Meanwhile, other parameters such as biochemical oxygen demand (BOD₅), total suspended solid (TSS), ammoniacal nitrogen (NH₃N), and chemical oxygen demand (COD) were measured in the laboratory based on the Standard Methods for the Examination of Water and Wastewater [24]. Both *in situ* readings and water samples were collected from the same location. Water samples were collected in 1-L polyethylene bottles and chilled in a cold box filled with ice cubes (4°C) to minimize the metabolism of organisms contained in the water. The water samples were labeled in a manner similar to that used for the benthic samples.

The water quality index (WQI) was calculated to indicate the level of pollution and the corresponding suitability for use according to the National Water Quality Standards for Malaysia (NWQS). Water quality class was determined based on the water quality index (WQI), ascertained by the six parameters, *viz.* pH, DO, BOD₅, COD, TSS, and NH₃N, according to the DOE formula (1):

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

where SI is the subindex of the respective water quality parameters which is used to calculate the WQI (Table 1). The WQI classification based on water use is shown in Table 2.

Subindex for DO (in % saturation)

| | |
|---|------------------|
| SIDO = 0 | for $x \leq 8$ |
| SIDO = 100 | for $x \geq 92$ |
| $SIDO = -0.395 + 0.030x^2 - 0.00020x^3$ | for $8 < x < 92$ |
| <i>Subindex for BOD</i> | |
| SIBOD = $100.4 - 4.23x$ | for $x \leq 5$ |

Subindex for DO (in % saturation)

| | |
|---|-----------------------|
| $SIBOD = 108 \times \exp(-0.055x) - 0.1x$ | for $x > 5$ |
| <i>Subindex for COD</i> | |
| $SICOD = -1.33x + 99.1$ | for $x \leq 20$ |
| $SICOD = 103 \times \exp(-0.0157x) - 0.04x$ | for $x > 20$ |
| <i>Subindex for NH₃-N</i> | |
| $SIAN = 100.5 - 105x$ | for $x \leq 0.3$ |
| $SIAN = 94 \times \exp(-0.573x) - 5 \times x - 2 $ | for $0.3 < x < 4$ |
| $SIAN = 0$ | for $x \geq 4$ |
| <i>Subindex for SS</i> | |
| $SISS = 97.5 \times \exp(-0.00676x) + 0.05x$ | for $x \leq 100$ |
| $SISS = 71 \times \exp(-0.0061x) - 0.015x$ | for $100 < x < 1000$ |
| $SISS = 0$ | for $x \geq 1000$ |
| <i>Subindex for pH</i> | |
| $SpH = 17.2 - 17.2x + 5.02 \times 2$ | for $x < 5.5$ |
| $SpH = -242 + 95.5x - 6.67 \times 2$ | for $5.5 \leq x < 7$ |
| $SpH = -181 + 82.4x - 6.05 \times 2$ | for $7 \leq x < 8.75$ |
| $SpH = 536 - 77.0x + 2.76 \times 2$ | for $x \geq 8.75$ |

Table 1. Best fit equations for the estimation of various subindex values.

| Class | Uses |
|-----------|--|
| Class I | Conservation of natural environment Water supply I—practically no treatment necessary Fishery I—very sensitive aquatic species |
| Class IIA | Water supply II—conventional treatment required Fishery II—sensitive aquatic species |
| Class IIB | Recreational use with body contact |
| Class III | Water supply III—extensive treatment required Fishery III—common, of economic value and tolerant species; livestock drinking |
| Class IV | Irrigation |
| Class V | None of the above |

Table 2. Water classes and uses.**5.3. Characterization of river habitat**

A visual-based habitat assessment based on the USEPA habitat assessment survey was carried out simultaneously with the biological sampling. Several features in habitat assessment include a general description of the site, a physical characterization and water quality assessment, and also a visual assessment of instream and riparian habitat quality. Physical characterization comprised documentation of general land use, description of the stream origin and

type, and a summary of the riparian vegetation features that included measurements of instream parameters such as width, depth, flow, and substrates. The observed channel dimensions were carried out in the survey stretch, located either in the presence of riffle or at a suitable shallow section of the river. Channel dimension measurements were taken according to the river habitat survey (RHS) method.

5.4. Streamflow gauging

Streamflow gauging was conducted to measure the flow rate of the study area. The equipments used in this study were flow meter, measuring tape, staff level, hammer, and ropes/cables. The Cole Parmer Model BS 11000 flow meter used in this study was equipped with a propeller to allow it to rotate according to the velocity of the water. The mean section method was used to measure the river discharge using the flow meter and other tools, whereby cross-sectional area of the river was divided into several subsections. Stream velocity was measured at depths of 0.6d, 0.2d, and 0.8d depending on the need, where d represents the variable of depth from the water surface. This method was used to obtain the average velocity of the represented river. The general hydraulic formula for river discharge is as follows (2)

$$Q = AV \quad (2)$$

where Q is discharge (volume/unit time-e.g. m³/s, also called cumecs), A is the cross-sectional area of the stream (e.g. m²), and V is the average velocity (e.g. m/s).

6. Results and discussion

6.1. Benthic macroinvertebrate compositions

Overall, a total of 1081 fauna were recorded from Sg Ayer Hitam Besar. On the other hand, 610 individuals were caught from Sg Berasau, while sampling from Sg Mengkibol documented 1008 individuals. This brings the total number of macroinvertebrates assemblage based from all sampling events of 2699 individuals. Common net-spinners larvae from caddisfly family dominate the research finding in Sg Ayer Hitam Besar, contributing approximately one-third of the total samples (30.52%). Some intolerant taxa represented by Plecopteran families were seen widely distributed in the study area. They are Perlidae (242 individual) and Chloroperlidae (194 individual). Interestingly, Decapods (Palaemonidae) has been found widely distributed with relatively high abundance and dominated in every sampling session. On the other hand, mollusks were found in very low composition restricted to Physidae and Pleuroceridae (Table 3). Trichoptera represents the percentage of the most abundant and adaptive species with the most dominant family of Hydropsychidae. This higher number is believed to be associated with the presence of algal biomass [25]. This insect tends to live in sheath made from organic debris and mineral fragments and makes the surface of the substrate as their habitat. This insect larvae are also often attached to rocks,

facing the flow and feed on the particles trapped in their nets [26]. Several groups of aquatic insects favored rocky substrate as it offers habitat for protection and oviposition [27]. In this present study, sufficient numbers of oviposition sites were observed, including plenty of rocky substrates and riverbank vegetations, which could explain the high abundance of caddisfly larvae in this area.

| Order | Family | Abundance | Percentage (%) |
|---------------|-------------------|--------------|----------------|
| Decapoda | Palaemonidae | 153 | 14.15 |
| | Potamidae | 5 | 0.46 |
| Ephemeroptera | Heptageniidae | 57 | 5.27 |
| | Ephemeridae | 3 | 0.28 |
| Plecoptera | Perlidae | 242 | 22.39 |
| | Capniidae | 3 | 0.28 |
| | Chloroperlidae | 194 | 17.95 |
| Trichoptera | Hydropsychidae | 305 | 28.21 |
| | Limnephilidae | 12 | 1.11 |
| | Polycentropodidae | 6 | 0.55 |
| | Leptoceridae | 7 | 0.65 |
| Coleoptera | Elmidae | 60 | 5.55 |
| | Pyralidae | 6 | 0.56 |
| Odonata | Calopterygidae | 1 | 0.09 |
| | Lestidae | 2 | 0.19 |
| | Gomphidae | 3 | 0.28 |
| | Libellulidae | 16 | 1.48 |
| Gastropoda | Pleuroceridae | 1 | 0.09 |
| | Physidae | 4 | 0.37 |
| Hemiptera | Veliidae | 1 | 0.09 |
| | Total | 1,081 | 100 |

Table 3. Benthic macroinvertebrate compositions in Sg Ayer Hitam Besar.

Decapoda exhibited the highest distribution with an abundance of 343 individual in Sg Berasau. Both families, Palaemonidae and Potamidae, contributed more than half (56.23%) from the total amount. Caridean prawn (Palaemonidae) were found in all sampling events with large numbers compared to others (291 individual). The second group which had the highest distribution was Odonata, with an abundance of 153 individual. Gomphidae, which

belongs to Anisoptera suborders, were the second largest taxa found, consisting of 91 individuals. The least dominant families in Sg Berasau were Capniidae, Sialidae, and Pyralidae, contributing 0.16% each from total percentage (Table 4). Freshwater prawns of the genus *Macrobrachium* are free-living decapod crustaceans, present in almost all permanent water bodies. They inhabit a wide variety of habitat even in extreme condition, where waters can reach pH 3.3, and stagnant pool with daytime temperature may reach 35°C [28]. Their feeding habits are variable, with some are scavengers or being detritivorous [29]. As such, they are very important in recycling organic matter in the environment. The inclusion of organic matter into water bodies due to logging activities in Sg Berasau is beneficial to shrimp, as can be seen from the abundance of these organisms. However, they are prone to human disturbance and development and become extinct. This happened in Sg Gombak, whereby the populations of *Atyopsis* species are now very rare due to rapid development, resulting in water pollution.

| Order | Family | Abundance | Percentage (%) |
|---------------|-----------------|----------------|----------------|
| Decapoda | Palaemonidae | 291 | 47.70 |
| | Potamidae | 52 | 8.52 |
| Ephemeroptera | Heptageniidae | 30 | 4.92 |
| | Ephemerellidae | 18 | 2.95 |
| | Baetidae | 13 | 2.13 |
| | Leptophlebiidae | 2 | 0.33 |
| | Potamanthidae | 3 | 0.49 |
| | Plecoptera | Perlidae | 11 |
| Plecoptera | Capniidae | 1 | 0.16 |
| | Nemouridae | 8 | 1.31 |
| | Leuctridae | 2 | 0.33 |
| | Perlodidae | 2 | 0.33 |
| | Chloroperlidae | 4 | 0.66 |
| | Odonata | Calopterygidae | 17 |
| Lestidae | | 3 | 0.49 |
| Gomphidae | | 91 | 14.92 |
| Libellulidae | | 42 | 6.89 |
| Gastropoda | Pleuroceridae | 8 | 1.31 |
| Hemiptera | Belostomatidae | 2 | 0.33 |
| | Nepidae | 2 | 0.33 |
| Megaloptera | Sialidae | 1 | 0.16 |
| Coleoptera | Hydrophilidae | 6 | 0.98 |
| | Pyralidae | 1 | 0.16 |
| | Total | 610 | 100 |

Table 4. Benthic macroinvertebrate compositions in Sg Berasau.

Sampling of macrobenthic assemblages from Sg Mengkibol consists of moderately intolerant to very tolerant families. Odonates are on top of the list with highest abundance (448 individuals). Chironomidae or blood worm dominated the overall findings with cumulated percentage 22.32%. Gastropods, physidae, are in the second place with slight difference of cumulated percentage (21.92%). Odonates represented by Lestidae and Libellulidae also donated a relatively high number of 260 individuals. Interestingly, sensitive taxa were found in this study area, although the percentage is very low. They are mayflies and stoneflies (Table 5). Fly larvae can be found in various aquatic habitat and survived in most conditions. According to Yule [30], Chironomidae is probably the most diverse and abundant group of all stream macroinvertebrates. Chironomus, for example, were widely distributed in polluted areas [20, 31]. Hemoglobin pigment helps *Chironomus* spp. to adapt to unfavorable condition, since hemoglobin helps to sustain aerobic metabolism under low oxygen conditions [32]. Most fly larvae eat dead or dying plant and animal materials.

| Order | Family | Abundance | Percentage (%) |
|---------------|----------------|--------------|----------------|
| Decapoda | Palaemonidae | 20 | 1.98 |
| Ephemeroptera | Ephemerellidae | 1 | 0.10 |
| | Baetidae | 1 | 0.10 |
| Plecoptera | Leuctridae | 15 | 1.49 |
| | Perlodidae | 1 | 0.10 |
| Coleoptera | Psephenidae | 2 | 0.20 |
| Odonata | Calopterygidae | 60 | 5.95 |
| | Lestidae | 149 | 14.78 |
| | Gomphidae | 77 | 7.64 |
| | Libellulidae | 111 | 11.01 |
| | Aeshnidae | 41 | 4.07 |
| | Coenagrionidae | 10 | 0.99 |
| Gastropoda | Pleuroceridae | 3 | 0.30 |
| | Physidae | 221 | 21.92 |
| | Viviparidae | 4 | 0.40 |
| Hemiptera | Naucoridae | 35 | 3.47 |
| | Nepidae | 1 | 0.10 |
| Hirudinea | Hirundinidae | 28 | 2.78 |
| Diptera | Chironomidae | 225 | 22.32 |
| | Syrphidae | 3 | 0.30 |
| | Total | 1,008 | 100 |

Table 5. Benthic macroinvertebrate compositions in Sg Mengkibol.

6.2. River habitat survey

The Sg Ayer Hitam riverbed comprises more than 70% of natural structures such as cobble (riffles), large rocks, fallen trees, logs, and branches. These optimal conditions allow colonization, refugia, feeding/ spawning sites for aquatic faunal. Both Sg Ayer Hitam Besar and Sg Berasau consist of all four velocity/depth regime present in their study reach. The occurrence of slow-deep, slow-shallow, fast-deep, and fast-shallow velocity patterns reflects of habitat diversity and ability of stream to provide and maintain balance aquatic habitat. No channel alteration or dredging works present at studied reach in both rivers. Sg Ayer Hitam Besar showed an optimal condition of vegetative protection, as it covers more than 90% of streambank surface with native vegetation including trees, understory shrubs, or non-woody macrophytes. An optimal condition of vegetative zone serves as a buffer to pollution and nutrient input to the stream runoff, other than erosion control. Meanwhile, around 50–70% of the streambank surface is covered by riparian vegetation in Sg Berasau. Logging activities leave an obvious disruption as cropped vegetation/ bare soil potentially prone to high potential of streambank erosion during heavy downpour (30–60%).

Meanwhile, Sg Mengkibol exhibits an unsatisfactory habitat quality. Historically, Sg Mengkibol was hit by massive flood event in late 2006. In relation to deal with the incident over and over again, upgrading the river system for flood mitigation project has been carried out. Among the works are dredging and sediment disposals, as well as strengthening the river channel. As a result, variety of natural structure less than desirable due to frequent disturbed of epifaunal substrate. Compared to Sg Ayer Hitam Besar and Sg Berasau, shallow pools are more prevalent than deep pools at these rivers. Percentage of deposition of sediments in the Sg Mengkibol is approximately 50–80%, composing of gravel, sand, or fine sediment on the old and new bar. Increasing level of sediment deposition is an indication of instability and changing environment, thus unsuitable for many organisms. Deepening and dredging works as a part of river rehabilitation and restoration process have changed the shape of the stream channel drastically. More than 80% of stream reach has been straightened with the construction of anti-erosion measure in both sides of the banks. Straightened channel decreases the stream length 1–2 times shorter than its natural state. Channel sinuosity provides diverse habitat and fauna, as well as being able to handle surges as a result of storm. The construction of slope stabilization is carried out to reduce the amount of erosion that is likely to occur. Nevertheless, those artificial structures prevent plants from growing on streambanks. Therefore, the natural habitat for aquatic organism is limited. Riparian zone serves as a buffer to prevent the entrance of nutrients and pollutants directly into rivers. However, for urban river, riparian vegetative zone width is usually <6 m, due to extensive use of impervious surfaces. Therefore, it increases the volume of runoff and decreases groundwater recharge.

6.3. Water quality index (WQI)

A water quality index representing a gradation number describes the overall water quality in particular location and time based on several water quality parameters. The use of this index is not intended specifically for human health or aquatic life regulation, but provides simple guidance on water quality based on some important parameters. In Malaysia, the assessment

and classification of water quality status are based on the water quality index (WQI) and the National Water Quality Standards (NWQS), which eventually grouped into certain classes. Index developed for Malaysia, the WQI is ascertained by six parameters, *viz.* pH, DO, BOD₅, COD, TSS and NH₃N. As summarized in **Figure 1**, overall mean WQI for Sg Ayer Hitam Besar was at Class I, indicating as an excellent quality. The mean values for each sampling event were ranged 90.67–97.00. Based on this index, Class I is defined as naturally very clean and preserved river. Its water resources are suitable as drinking water with minimal treatment. In terms of ecology, habitats are able to accommodate very sensitive aquatic species. Different situation is observed for Sg Berasau, although surrounded by a natural environment, land use activities such as deforestation have greatly affected the ecosystem health. Its effect can be seen through water quality status, which categorized this river into Class II (Clean). Based on general rating scale of WQI, Class II of water resources still can be used as a source of drinking after conventional treatment method. It is also suitable for recreational use with body contact. On average, the mean values of WQI in Sg Berasau are between 75.00 and 89.33. Result of this study coincides with the finding from [17] which proves that logging activities which comply with prescribed standards still have an adverse impact on the riverine ecosystem even in a small proportion. On the other hand, Sg Mengkibol exhibits a moderately clean river status. Eight out of ten sampling events showed water quality for this river was in Class III (slightly polluted). This type of river status requires an extensive treatment as a drinking water supply. This river also accommodates certain fish species that are more tolerant and low in economic value such as catfish (*Clarias batrachus*) and tilapia (*Tilapia mossambica*) [33].

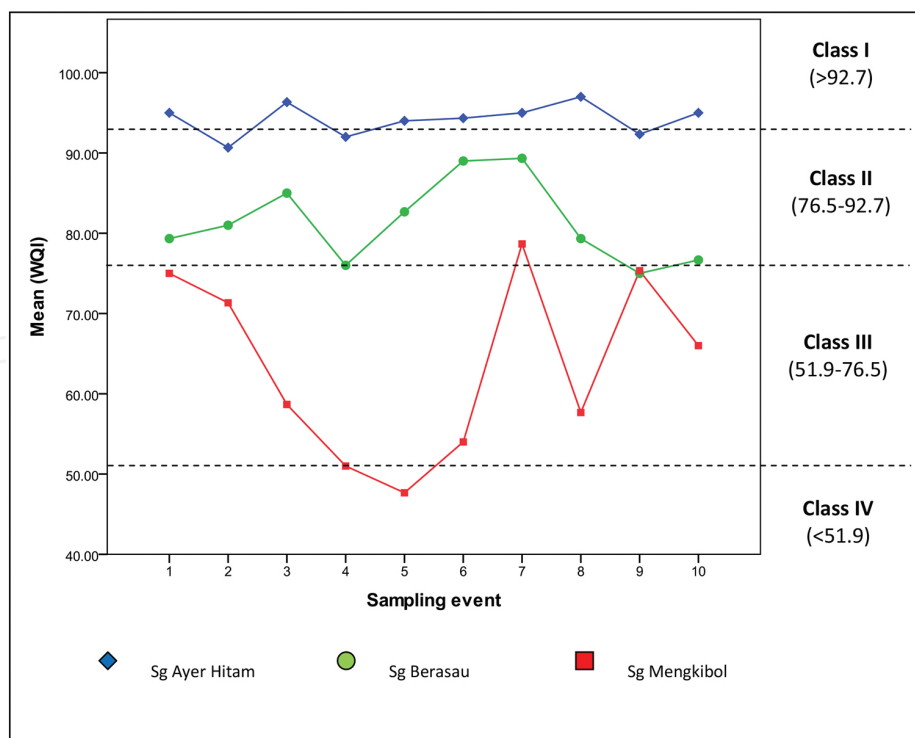


Figure 1. WQI values for all sampling sites.

6.4. Influence of hydrological, physicochemical, and habitat characteristics on the biological assemblage

In this section, a multivariate method, the canonical correspondence analysis (CCA), was applied to elucidate the relationships between biological assemblages of species and their environment using PAST (version 2) software. The CCA ordination biplot illustrated the relationship between several hydrological, physicochemical parameters, and distribution of the aquatic macroinvertebrates. The first two axes derived from CCA model accounted for 88.57% of the macroinvertebrates–environmental variations. CCA demonstrated that axis 1 was strongly correlated with DO, habitat quality (epifaunal substrate and vegetative protection), whereas COD, BOD₅, NH₃N, temperature, and velocity were negatively correlated with it (Table 6). Several taxa associated with three pollution-sensitive orders, EPT, showing good adaptation features and presenting highest score on the first axis. They consist of order Ephemeroptera (Heptageniidae, Ephemeridae), Plecoptera (Capniidae, Perlidae, Chloroperlidae), and Trichoptera (Hydropsychidae, Polycentropodidae, Leptoceridae, Limnephilidae). Low habitat quality, deterioration of DO and elevated concentration of nutrient and organic pollutant, suspended particulate, and temperature were positioned on the negative side of the first axis and were associated with moderate to tolerant taxa such as Odonata (Gomphidae, Libellulidae, Calopterygidae, Lestidae, Coenagrionidae, Aeshnidae), Hemiptera (Nepidae, Naucoridae), Coleoptera (Psephenidae), Gastropoda (Physidae, Planorbidae, Viviparidae), Diptera (Chironomidae, Syrphidae, Simuliidae, Tipulidae, Culicidae) and Hirundinidae (Hirundinidae). The second axis was positively related to TSS and pH. In particular, these species taxa (Pleuroceridae, Perlodidae, and Palaemonidae) showed moderate preference for velocity, water temperature, rainfall precipitation, and less vegetative cover. However, this group showed dependence on high suspended particulate and alkalinity.

| Variable | Axis 1 | Axis 2 |
|----------------------------------|--------|--------|
| Temperature | -0.891 | -0.534 |
| pH | 0.281 | 0.953 |
| DO | 0.995 | 0.035 |
| BOD | -0.977 | -0.280 |
| COD | -0.978 | -0.260 |
| TSS | -0.102 | 0.952 |
| NH ₃ N | -0.849 | -0.410 |
| Rainfall | 0.679 | -0.424 |
| Velocity | -0.682 | 0.639 |
| Epifaunal | 0.968 | 0.057 |
| Vegetative | 0.905 | -0.307 |
| Eigenvalue | 0.842 | 0.447 |
| Percentage of variance explained | 57.85 | 30.72 |

Table 6. Summary statistic for the canonical correspondence analysis (CCA) relating aquatic macroinvertebrate–environmental variables (11 variables).

7. Conclusion

Rivers in Tropical Asia is closely related to the effect of seasonal flow imposed by unpredictable monsoon and seasonal rainfall [34, 35]. Several studies have analyzed the changes of benthic community dictated by seasonal rainfall [36–38], including those in Peninsular Malaysia [39–41]. In general, rainfall pattern in Malaysia is much influenced by wind flow pattern during the seasonal period. To some extent, it is also influenced by local topography. The present study indicated that seasonal rainfall has not significantly affected the distribution of benthic communities in the four studied rivers. This study is in line with the findings from Refs. [33, 42]. The anthropogenic impacts were more significant than the seasonal rainfall. However, the EPT populations were seen correlated to seasonal variation, as been reported earlier by Suhaila et al. [40] in Gunung Jerai Forest Reserve. According to Ref. [43], these types of species react quickly to the changes in environment.

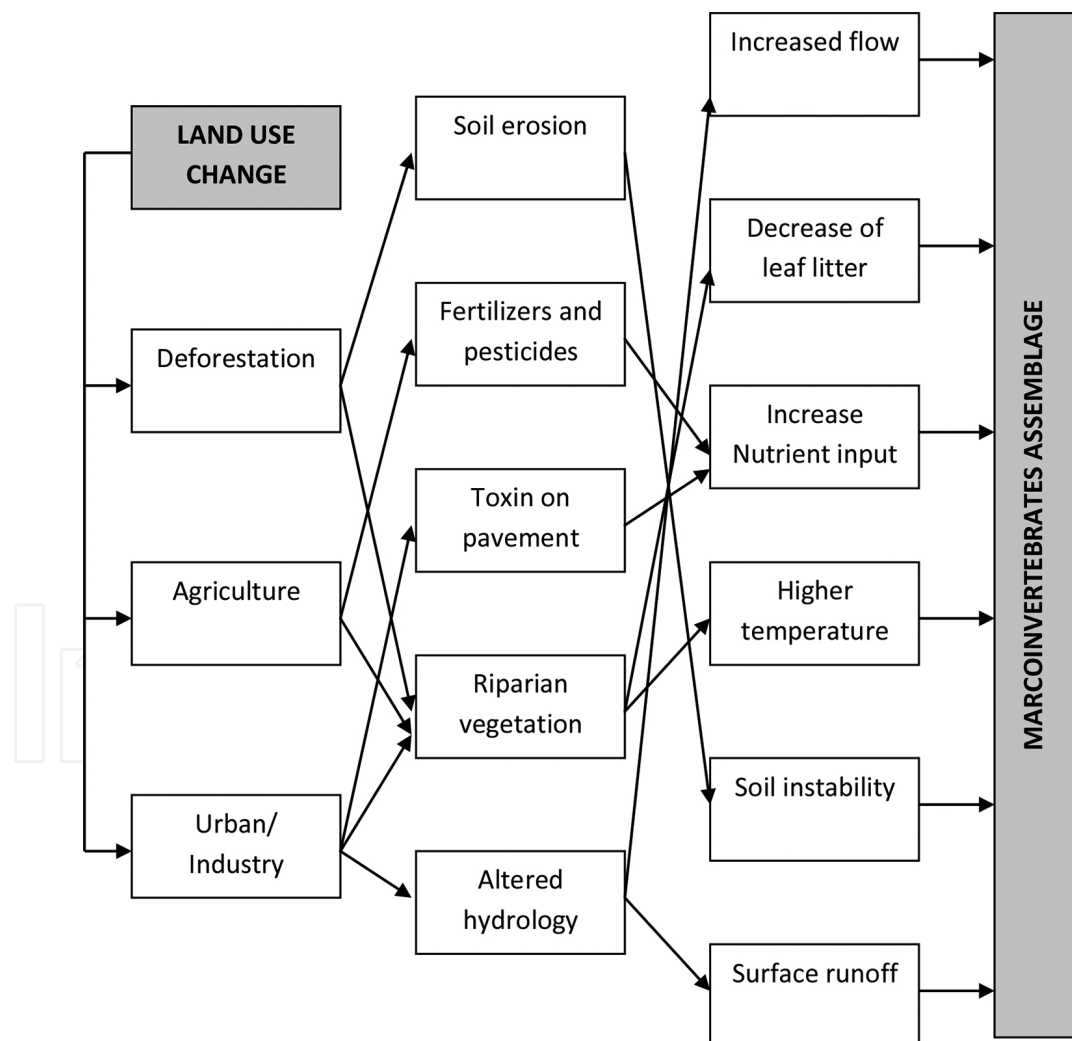


Figure 2. Illustrative schematic of the potential interactions between the threats, impact, and the response to the stream macroinvertebrate assemblage.

The present findings reveal that human-induced changes in natural habitat are the ultimate causes explaining the alteration in macroinvertebrates biodiversity. There is no doubt that anthropogenic disturbance impacted the structure of macroinvertebrate communities, either in the tropics or in the temperates [44–47]. Land use change is an integration of various human activities that negatively impact the river ecosystem. Among which, flow variability and sediments transport into the river by impervious surface and drainage in urban areas, stream channelization, agriculture, and deforestation. All of these threats will be manifested in changes in flows, benthic habitat conditions, and riffle-pool integrity. **Figure 2** presents an illustrative example of how macroinvertebrate communities can respond to land use change through a chain of indirect effects that lead to changes to the macroinvertebrate assemblage in both taxa richness and relative abundance.

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