MALAYSIAN JOURNAL OF SCIENCE
MJS
ISSN 1394-3065

Regular Issue

Malaysian Journal of Science 43(1): 72-85 (March 2024) https://mjs.um.edu.my

APPLICATION OF BENTHIC MACROINVERTEBRATES AS POTENTIAL BIO-INDICATORS IN MALAYSIAN'S RIVERS: GAP AND BIBLIOMETRIC ANALYSES

Nadeesha Dilani Hettige[1c], Rohasliney Hashim[2a]*, and Ahmad Abas Kutty[3b]

Abstract: The literature on reliable indices, suitable bio-indicators, taxonomic level, frequency of measurements, and replications on benthic macroinvertebrates remains scarce in Malaysia. In addition, no review study was conducted using bibliometric analysis related to this discipline. Thus, this review aimed at gap and bibliometric analysis of publications on benthic macroinvertebrates as potential biological indicators. Sixty-six relevant scientific research papers from 2011 to 2022 were selected from the different databases. Then, descriptive and inferential statistical analyses were performed to assess the most reliable potential bio-indicators for river assessment and monitoring. Visualized statistics regarding bibliographic coupling analysis of authors, journal proceedings, and organizations were analyzed. The findings revealed that publications on invertebrates had no significant relationship in the last ten years ($r = 0.241$; $p > 0.05$). Most publications on macroinvertebrates in Malaysian rivers were found in the Scopus database (53.57%). Therefore, research articles must be published in journals included in the Journal Citation Report (JCR) to improve their quality further. Besides, benthic macroinvertebrates are commonly identified only up to the family level (47%) due to incomplete tropical benthic macroinvertebrates identification keys. As such, using environmental DNA methods with the power of next-generation sequencing has come in handy in bio-indicator species identification. Among the potential bio-indicators found in Malaysian rivers are Chironomidae (9.11%), Baetidae (8.87%), and Hydropsychidae (8.62%). Based on the approaches utilized in analyzing benthic macroinvertebrates as bio-indicators, in-depth research such as bioassay and toxicology tests is necessary to realize the potential bio-indicators fully. Many studies focused on recreational rivers in Peninsular Malaysia. Therefore, research studies would be expanded to urban rivers and rivers in Sabah and Sarawak. Also, to overcome the limitation of the single biotic index, developing a multimetric index to evaluate the water quality by selecting many river basins is essential. Bibliographic analysis showed that the Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, made the greatest total link strength. The Serangga Journal published the highest number of research articles. Finally, utilizing advanced technologies is recommended to address Malaysia's lack of potential bio-indicator studies.

Keywords: *Bio-indicators, bio-indices, biomonitoring, freshwater pollution, and macroinvertebrate*

1. Introduction

Streams and rivers are among the most endangered ecosystems globally due to anthropogenic activities, which can directly or indirectly harm river environments (Ekka et al., 2020). Traditionally, physicochemical parameters are used to evaluate the quality of running water in streams worldwide (Aazami et al., 2015), including in Malaysia. However, this method is cost-intensive, time-consuming, and dependent on particular instruments. Similarly, physicochemical parameters fluctuate over time and only show environmental conditions at the moment of measurement (Aazami et al., 2015; Dorji, 2016). Hence, if no long-term physicochemical parameters with good spatial coverage are available, it does not accurately signify a clear picture of the health of the river ecosystem.

Biological monitoring is imperative in evaluating the environmental health of aquatic ecosystems (Parmar et al., 2016; Yusop et al., 2017). Algae, fish, aquatic plants, and invertebrates serve as bio-indicators in bioassessment (Barbour et al., 1999). In brief, bio-indicators are living organisms generally utilized to assess the health of natural ecosystems (Parmar et al., 2016) due to their capacity to respond to pollutants present in the ambient environment (Kumari & Paul, 2020). Also, they can act as an index of measure or a model that categorizes aquatic ecosystem health (Manickavasam et al., 2019). In particular, benthic macroinvertebrates are considered useful bio-indicators for environmental changes in many aquatic ecosystems (Belal et al., 2016) due to their high biodiversity, minimal mobility, relatively long life cycle, bottom-dwelling nature, and immense sensitivity to environmental changes (Flores & Zafaralla, 2012; Jun et al., 2012; Tampus et al., 2012; Dacayana et al., 2013; Sharma et al., 2013; Selvanayagam & Abril, 2016). To date, the utilization of

Authors information:
[a]Department of Environment, Faculty of Forestry and Environment, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, MALAYSIA. E-mail: rohasliney@upm.edu.my[2]
[b]Department of Earth Science and Environment, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi Selangor, MALAYSIA. E-mail: abas@ukm.edu.my[3]
[c]Department Environmental Studies Division, National Aquatic Resource Research and Development Agency (NARA), Crow Island, Colombo 15, SRI LANKA. E-mail: nadeeshahettige83@gmail.com[1]
*Corresponding Author: rohasliney@upm.edu.my

Received: August 22, 2022
Accepted: April 5, 2023
Published: March 31, 2024

DOI:https//doi.org/10.22452/mjs.vol43no1.7
Malaysian Journal of Science 43(1): 72-85 (March 2024)

benthic macroinvertebrates as bio-indicators has garnered significant attention in global river monitoring programs, including those in Malaysia (Gallacher, 2001; Resh, 2007; Narangarvuu et al., 2014; Tan & Beh, 2015).

Initially, stream biomonitoring studies predominantly employed single indices, such as ecological indices, to assess water quality status. These included the Shannon diversity index (Shannon, 1948), Margaleaf diversity index (Margalef, 1958), Simpson's diversity index (Simpson, 1949), Biological Monitoring Working Party (BMWP) in 1976 (Armitage et al., 1983), and Family Biotic Index (Hilsenhoff, 1988). However, this concept is an inadequate measure of overall ecological integrity because the cause-effect relationships of indicator organisms are not fully established and are often confusing (Barbour et al., 1999). Hence, multimetric indices have been developed as an alternative bio-assessment approach to reflect all types of degradation and cumulative impacts at the ecosystem level (Barbour et al., 1999). This approach held the potential for wide-ranging application in the assessment of stream ecosystems, as it involved various types of measurement and provided comprehensive comparative information relative to pre-determined criteria derived from non-impacted reference conditions (Klemm et al., 2002).

Toxicity testing is one of the methods that can be used to select bio-indicators. The main goal of toxicity testing is to monitor or predict the effects of single compounds, elements, or mixtures on the long-term health of individual organisms, populations, communities, and ecosystems. Researchers have found plants, plankton, and benthic macroinvertebrates as bio-indicators of water pollution in the aquatic environment. For example, Mazur et al. (2016) identified *Lymnaea stagnalis* as a highly sensitive bio-indicator capable of detecting even minimal levels of environmental stressors. Esposito et al. (2018) found *Leptodictyum riparium* to be a bio-indicator of toxic metal pollution. The significance of toxicity testing lies in its efficiency, which eliminates the need to conduct tests on numerous available pollutants (Peyravi *et al*., 2020).

A total of 189 river basins are found in Malaysia: 89 are located in Peninsular Malaysia, 78 in Sabah, and 22 in Sarawak (Diya et al., 2015). One of the earliest publications about biomonitoring in Malaysian rivers was reported by Bishop in 1973. This study comprehensively analyzed physical, chemical, and biological features, including algae, benthic invertebrates, and some vertebrates like fishes in the Gombak River, Selangor. Subsequently, the interest in river water quality monitoring using benthic macroinvertebrates has grown since 2010. The trend is a result of the limited prior studies and available data in Malaysian ecosystems, specifically the absence of physicochemical data. This scarcity has heightened the interest in utilizing benthic invertebrates (Arsad et al., 2012). However, most studies mainly focused on diversity, biotic indices application, water quality monitoring, and land use patterns to conduct biomonitoring (Al-Shami et al., 2011a; Md Rawi et al., 2014; Al-Shami et al., 2017; Shafie et al., 2017). In contrast, few studies have explored the role of benthic macroinvertebrates as bio-indicators to assess the water quality of rivers and streams (Azrina et al., 2006). Presumably, the river classifications are related to water quality levels based on the species composition of macroinvertebrates. Hence, some studies have developed river classification using macroinvertebrates for the Malaysia River (Arsad et al., 2012; Ghani, 2016). Also, few papers have reviewed this topic, and no systemic review has been done on benthic macroinvertebrates in Malaysia's rivers.

Bibliometric analysis is a statistical method used to assess the characteristics and significant development trends of a given research subject based on published research (Guo et al., 2019). This analytical approach has been applied to evaluate various aquatic organisms for water quality monitoring (Zyoud et al., 2014) and is applicable to quantify and characterize the global scientific production of Taxus-related research (Zyoud et al., 2014). Therefore, this study extends the application of bibliometric analysis to systematically review scientific publications on benthic macroinvertebrates as potential bio-indicators in Malaysian rivers. A novel aspect of this research involves integrating the science mappings approach, including bibliographic coupling analysis for authors, journal proceedings, and organizations, to visualize information related to benthic macroinvertebrates as bio-indicators in Malaysian rivers.

2. Materials and Methods

Statistical Analysis for Literature Approach

This review was conducted in January 2023 using resources extracted from journals and conferences from 2011 to 2022 in Scopus's primary scientific database and several other databases based on Universiti Putra Malaysia (UPM) subscription (Emerald Insights, Nature Journal, Oxford Journal, and Science Direct) for 12 years. The keywords used were "benthic macroinvertebrates, benthos, aquatic insects, and bio-indicators" in rivers, Malaysia. Since this study analyzed selected potential bio-indicator groups, only articles discussing potential bio-indicators in streams and rivers were included. Furthermore, articles published in Malay where bio-indicators are discussed were also included. Meanwhile, articles that did not mention benthic macroinvertebrates as bio-indicators were removed from the study scope. Abstracts and other documents (reviews, books, and book chapters) were also excluded because these are not primary literature. Moreover, the thesis was also excluded due to its unavailability in the selected databases. Out of the 205 papers, only 66 were evaluated for this review.

First, descriptive statistics were used to assess the trends and approaches, such as published journals, taxonomic identification, and study area. Then, the Pearson correlation was carried out to determine the time series trends in publications related to benthic macroinvertebrates and potential bio-indicators only for benthic macroinvertebrates. Also, selected research papers were searched via Journal Citation Report (JCR) to determine whether the journal's name is recorded as Q ranking based on JCR (Q1, Q2, Q3, and Q4).

The geographical locations of the studies, the frequency of measurements (i.e., number of sampling during the study period)

DOI:https//doi.org/10.22452/mjs.vol43no1.7
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conducted by the researchers, replication variables used in their studies, taxonomic identification of identified potential bio-indicators, and methodological information used by the authors were summarized in this review paper. The dominant potential bio-indicators were determined based on the number of papers reported using the benthic macroinvertebrates families. The study areas for rivers, namely recreational, forested streams, urban or polluted rivers, and different land use areas, were categorized based on the information provided in the research paper.

Visualized Analysis

VOSviewer (Leiden University, Leiden, The Netherlands) was used to visualize and analyze the literature. The software was used for bibliographic coupling analysis for authors, journals, proceedings, and organizations. The total link strength of the authors was determined through the bibliographic coupling analysis of the authors. The total link strength represents the frequency of simultaneous appearances of two items in publications. Also, the bibliographic coupling analysis for journals and proceedings established the minimum threshold value of 155 and the total link strength for both journals and proceedings. Moreover, the total link strength of organizations was determined through bibliographic coupling analysis. In cases where the VOSviewer database contained duplicate author names and similar terms, a thesaurus file was created and used to combine the identical information.

3. Results and Discussion

Results

Research Trends

Figure 1 illustrates the percentage of publications related to benthic macroinvertebrates and potential bio-indicators of benthic macroinvertebrates in Malaysian streams for 12 years. There has been a surge in the use of benthic macroinvertebrates to evaluate Malaysia's river quality since 2011, with several peaks in 2013 and 2020. Meanwhile, benthic macroinvertebrates as potential bio-indicators started trending in 2011, recording the highest percentage in 2020. However, there is no significant relationship between the number of publications on benthic macroinvertebrates and the last 12 years (2011 to 2022) ($r = 0.241$: $p > 0.05$).

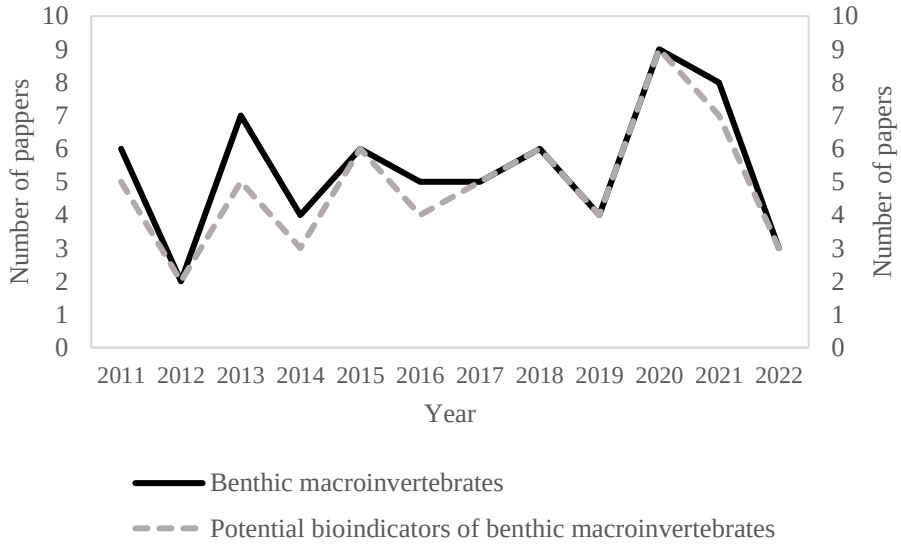

Figure 1. Time series plot for overall published papers on benthic macroinvertebrates and potential bio-indicators of benthic macroinvertebrates from 2010 to 2022.

Published Journals and Proceedings (Bibliographic Information)

Based on Figure 2, the Serangga Journal (Scopus indexed) published the highest number of papers. The second-highest papers were published in Sains Malaysiana (Journal Citation index: Q4), IOP Conference Series: Earth and Environmental Science, Sains Malaysiana, and Journal of Sustainability Science and Management. A total of five journals published in these databases were authored by researchers from Malaysian universities, namely Universiti Putra Malaysia (Pertanika Journal of Tropical Agricultural Science, and Pertanika Journal Science and Technology), Universiti Kebangsaan Malaysia (Serangga), and Universiti Sains Malaysia (Sains Malaysiana, and Tropical Life

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Sciences Research). In addition, Jurnal Teknologi published two research papers on aquatic ecology. Many previous studies that identified potential benthic macroinvertebrates as biological indicators were published in high-impact journals, with the highest percentage (53.57%) recorded in Scopus index journals, followed by Journal Citation Report (JCR) index journals (25.00%), including Q1 and Q2. Moreover, approximately 14.29% of papers on this research area were published in other indexed journals, and about 7.14% of papers included proceedings. Meanwhile, only eight research papers related to potential bio-indicators were published in conference proceedings, notably the IOP Conference Series: Earth and Environmental Science Proceedings.

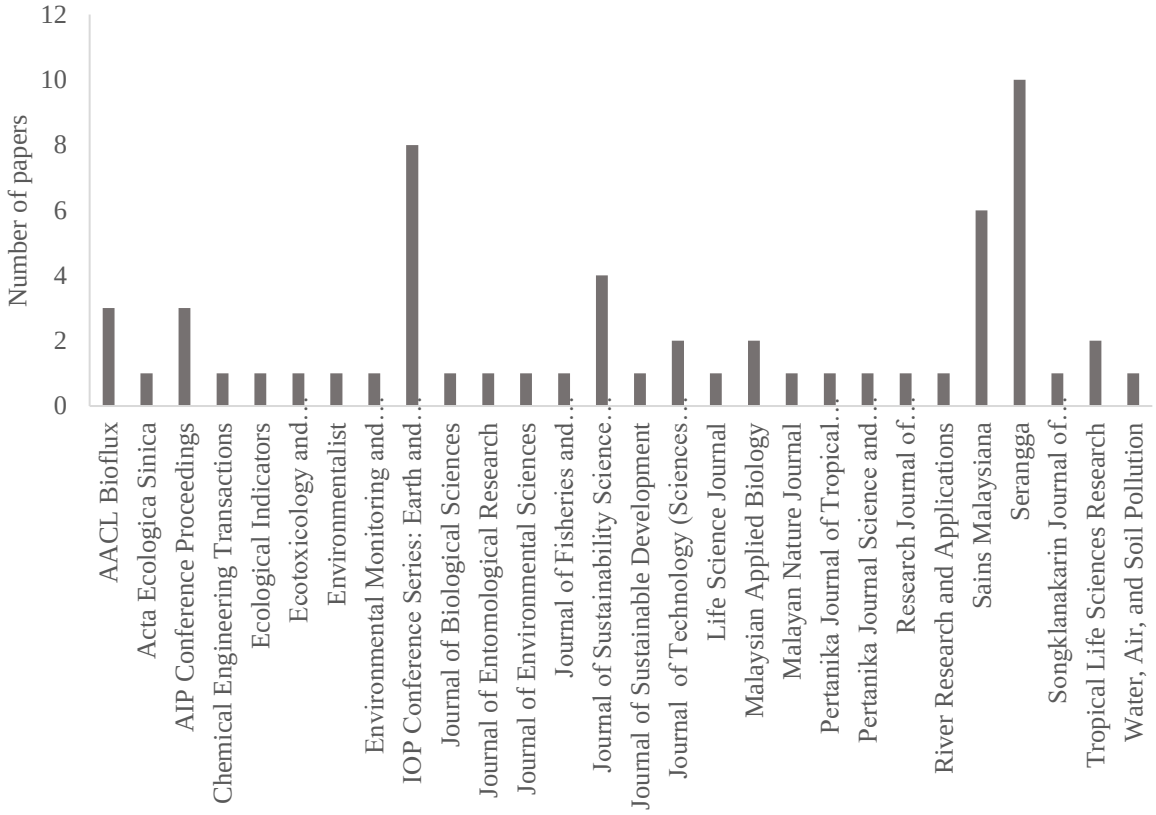

Figure 2. The number of published papers on benthic macroinvertebrates as potential bio-indicators.

There are two languages used by Malaysian researchers when they published their research: Malay and English. The Malay language was used in local journals, with 8.47% of publications related to potential bio-indicators. However, most research articles (91.53%) were published in English.

Geographical Locations of The Studies, Frequency of Measurement, and Replication

Most studies related to this discipline were conducted in Peninsular Malaysia (Table 1), and few were carried out in Sabah (five studies), while none were found in Sarawak.

Table 1. Geographical locations of the studies in Peninsular Malaysia with the year

State	River	River type	Year
Kedah	Tupah River	Forested	2012
	Selama River	Forested	2013
	Rivers of Gunung Jerai Forest Reserve	Forested	2017, 2019
	Rivers at various elevations of Gunung Jerai forest reserve	Forested	2019
	Perangin River	Recreational	2020
	Urian Perangin River		2020
Terengganu	Two freshwater streams of Hulu Terengganu	Recreational	2011
	Ikan River	Recreational	2015
	Three streams of Terengganu	Forested	2018
	Mendak River	Recreational	2019

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Kelantan	Dawai and Dekong rivers	Forested	2014
	Recreational rivers	Recreational	2018
	Lata Janggut Recreational Area	Recreational	2020, 2021
Perak	Rivers in the Bukit Merah catchment area	Forested	2017
	Air terjun Lata Kinjang	Recreational	2018
Penang	Juru River Basin	Urban	2011, 2012
	Pauh River, Cameron Highlands	Forested	2015
	Air Terjun River	Recreational	2018
	Sayong River	Recreational	2021
	Jeriau River	Recreational	2022
Selangor	Semenyih River	Urban	2011
	Penchala River	Urban	2013
	Congkak River	Recreational	2013
	Langat River	Urban	2014
	Selangor River	Urban	2020, 2022
Johor	Berasau River	Forested	2015
	Tropical forest streams in Gunung Pulai	Recreational	2015
	Johor River		2017
	Asah River in Pulau Tioman	Recreational	2018
	Pontian Besar, Ulu Sedili Besar, Endau, and Skudai rivers	Recreational and Urban	2019
	Bantang River	Recreational	2019
	Kawal River	Recreational	2021
Negeri Sembilan	Kongkoi River	Different land use area	2013
Pahang	Lata Meraung Waterfall	Recreational	2015
	Janda Baik River	Recreational	2018
	Jeriau River, Bukit Fraser		2022
Melaka	Asahan Waterfall	Recreational	2016

The highest percentage of studies focused on recreational rivers (36%), followed by forested streams (24%) and urban or polluted rivers (20%) in Malaysia (Figure 3).

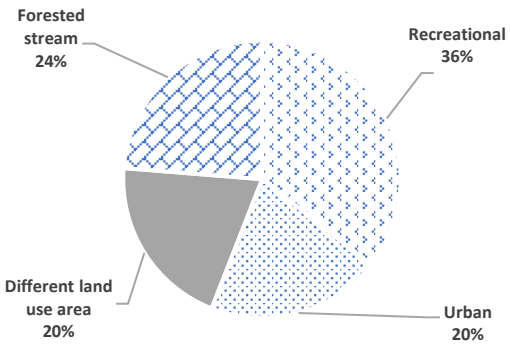

Figure 3. Study areas for potential bio-indicators research in Malaysian rivers.

Regarding the frequency of measurements (i.e., number of sampling during the study period), several researchers conducted (30.19%) only one sampling for biomonitoring of a particular river, while the other 18.87% did not state the frequency of measurements for their study. However, these researchers included the duration of their study. Meanwhile, approximately 22.64% of researchers conducted six samplings within a one-year study period. On the other hand, most studies did not mention the number of replicates used for their sampling (52.63%). However, several studies specified three (42.11%), five (3.51%), and six replicates (1.75%) of sampling to increase the precision of the study.

3.1.4 Taxonomic Identification of Identified Potential Bio-Indicators and Methodological Information

Most studies on Malaysian rivers used benthic macroinvertebrates at the family level (47%) due to incomplete identification of tropical benthic macroinvertebrates, especially in Southeast Asia. However, some studies achieved identification up to the genus level (29%), and a smaller proportion managed to identify them down to the species level (10%), as depicted in Figure 4.

DOI:https//doi.org/10.22452/mjs.vol43no1.7
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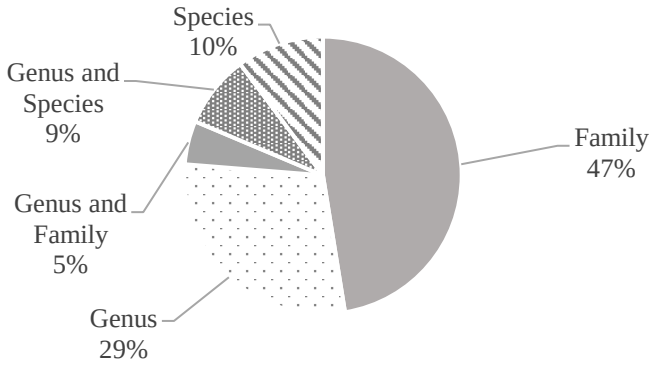

Figure 4. Resolution of taxonomic identification of benthic macroinvertebrates in reviewed studies.

According to Figure 5, a total of 22 families, namely Atyidae, Baetidae, Caenidae, Coenagrionidae, Chironomidae, Elmidae, Ephemerellidae, Euphaeidae, Gomphidae, Heptageniidae, Hydrophilidae, Hydropsychidae, Leptophlebiidae, Libellulidae, Perlidae, Potamanthidae, Simuliidae (Arthropoda), Hirudinidae, Lumbriculidae, Naididae, Turbificidae (Annelida), and Physidae (Mollusca) were identified as potential bio-indicators in Malaysian rivers. Chironomidae (9.11%) was identified as the dominant potential bio-indicator, followed by Baetidae (8.87%) and Hydropsychidae (8.62%). The examples of bio-indicators and relevant pollution identified from the previous studies are presented in Table 2.

Table 2. The bio-indicators identified with particular reference to the type of pollution

Common group	Bio-indicators	Type of pollution	Reference
Arthropoda	Atyidae	Clean water	(Kutty et al., 2017)
	Baetidae	Clean water	(Farah Safiah et al., 2020)
	Caenidae	Clean water	(Aweng et al., 2012)
	Coenagrionidae	Moderate pollution	(Al-Shami et al., 2014)
	Chironomidae	Urban pollution	(Al-Shami et al., 2013)
	Elmidae	Clean water	(Ahmad et al., 2013)
	Ephemerellidae	Clean water	(Azmi et al., 2018)
	Euphaeidae	Clean water	(Md Rawi et al., 2014)
	Gomphidae	Sensitive to pollution	(Suhaila et al., 2016)
	Heptageniidae	Clean water	(Hamid et al., 2016)
	Hydrophilidae	Clean water	(Mustaqim-Alias & Ahmad, 2013)
	Hydropsychidae	Clean water	(Nurhafizah-Azwa & Ahmad, 2018)
	Leptophlebiidae	Clean water	(Hettige et al., 2020)
	Libellulidae	Moderate pollution	(Al-Shami et al., 2011a)
	Perlidae	Clean water	(Mustaqim-Alias & Ahmad, 2013)
	Potamanthidae	Clean water	(Azmi et al., 2018)
	Simuliidae	Clean water	(Mohd Rasdi et al., 2012)
Annelida	Hirudinidae	Urban pollution	(Rak et al., 2011)
	Lumbriculidae	Urban pollution	(Hettige et al., 2020)
	Naididae (*Nais elinguis*)	Heavy metal pollution	(Othman et al., 2012).
		Urban pollution	(Rak et al., 2011)
	Turbificidae	Urban pollution	(Hettige et al., 2020)
Mollusca	Physidae	Urban pollution	(Mahazar et al., 2013)

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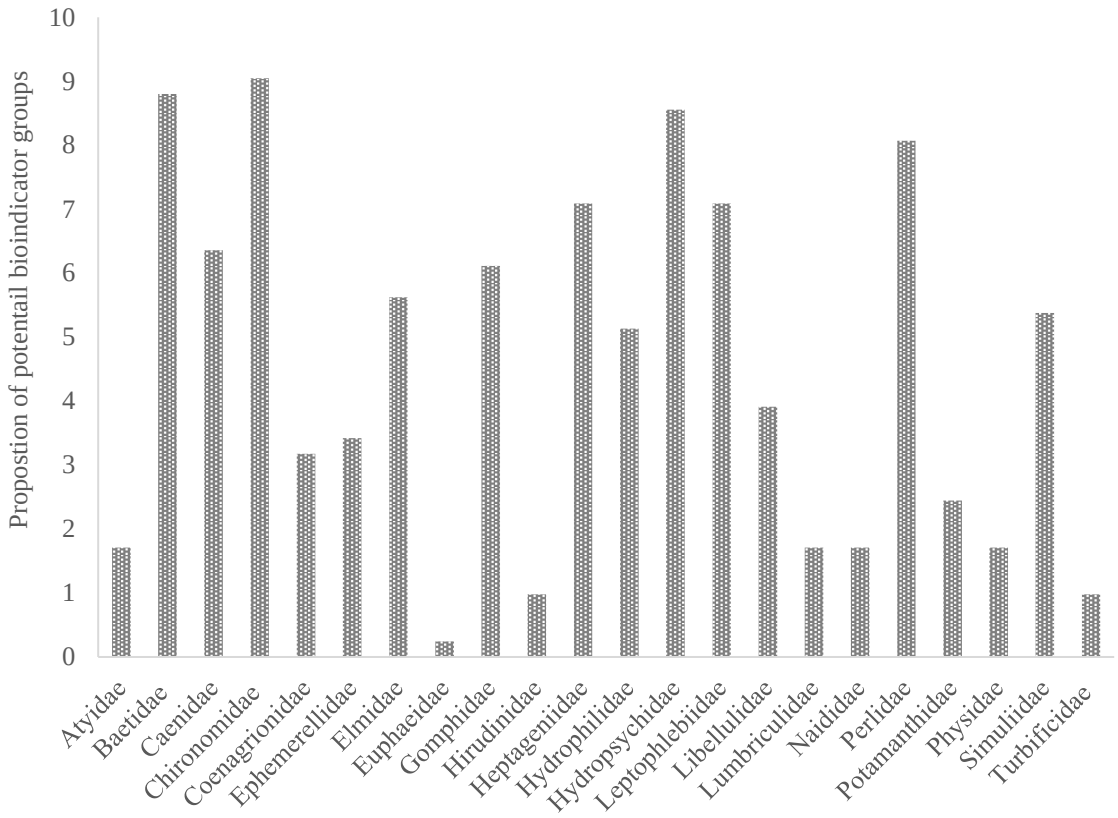

Figure 5. Benthic macroinvertebrate families were identified as potential bio-indicators.

Authors utilized many approaches in the analysis of benthic macroinvertebrates as bio-indicators. Based on Figure 6, the multivariate statistical analysis (28.99%) is currently the most popular option for these studies, followed by ecological indices (21.79%), biotic indices (20.29%), diversity indices (14.49%), diversity (8.70%), and genotoxicity (5.80%). Biotic and diversity indices (ecological indices) are commonly used in analyzing benthic macroinvertebrates. Out of all the reliable bio-indices, the biological monitoring working party (BMWP) (33.3%) is the most frequently used bio-indices, besides the Family Biotic Index (FBI) (17.33%) and Average Score Per Taxon (ASPT) (16.00%). Meanwhile, the Shannon-Weiner diversity index (29.49%) and the Margalef index (16.67%) are the most frequently used when considering diversity indices.

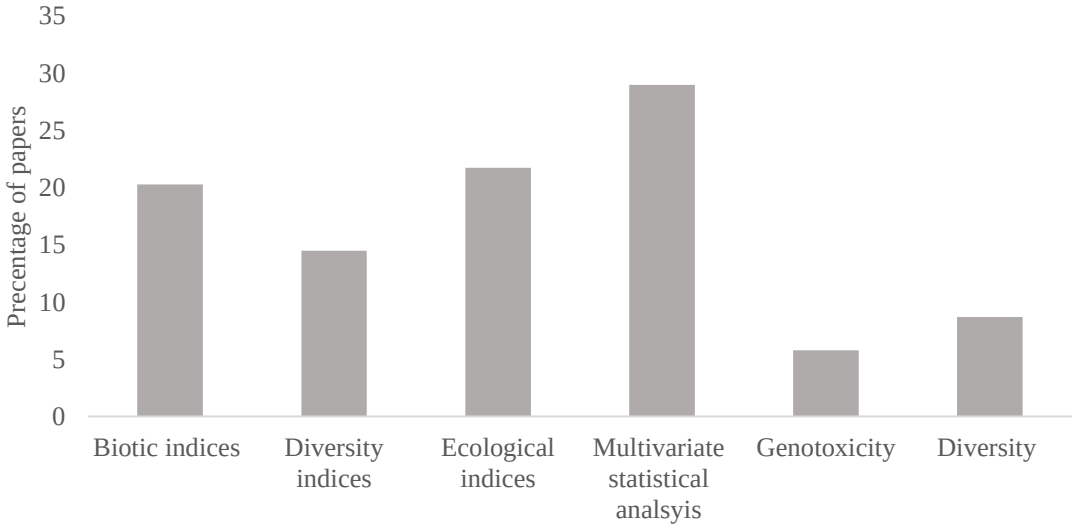

Figure 6. Approaches used in potential bio-indicators studies.

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Visualized Analysis

Bibliographic Coupling Analysis

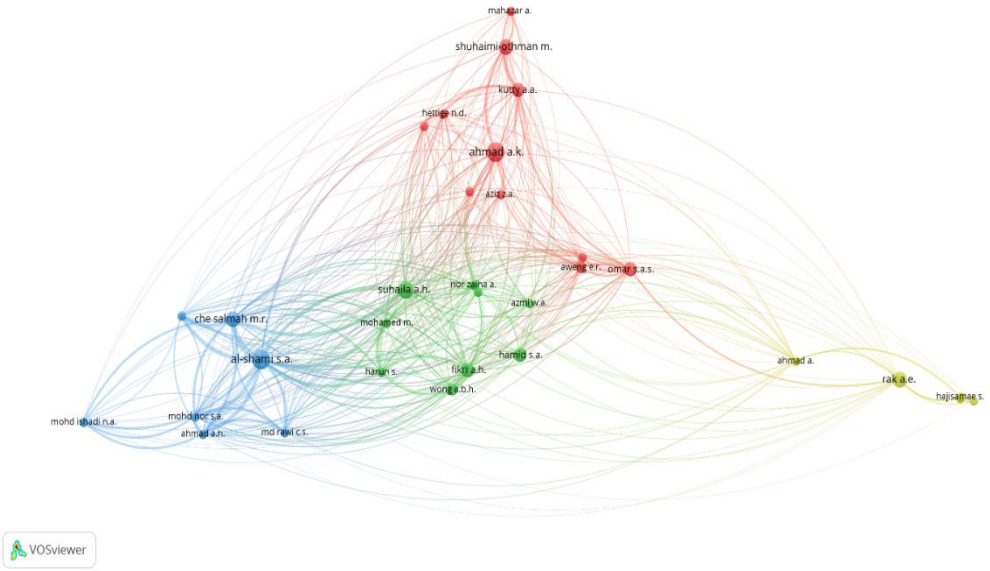

Figure 7. Bibliographic coupling analysis of authors.

Thirty-three authors were identified with a minimum threshold of two publications from a single author (Figure 7). The top three authors with the greatest total link strength were Al-Shami, S. A. (n = 1880), Suhaila, A. H. (n = 655), and Ahmad, A.K. (n = 461).

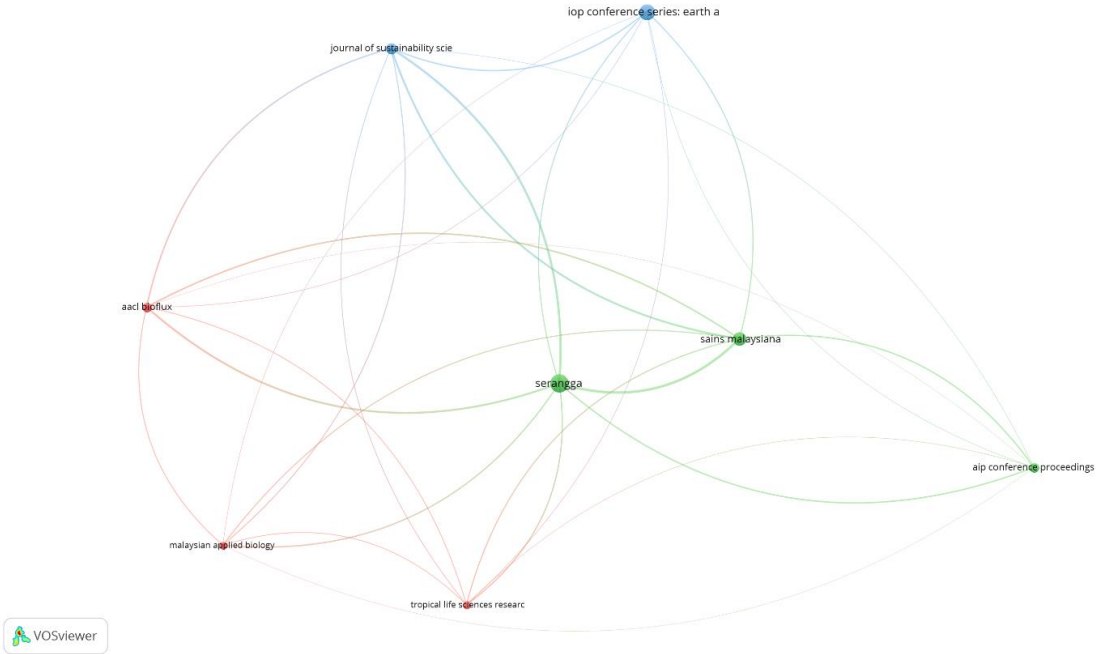

Figure 8. Bibliographic coupling analysis of journals and proceedings.

Of the 30 journals, 8 meet the minimum threshold of two (Figure 8). The top three journals with the greatest total link strength were Serangga Journal (n = 173), Sains Malaysiana (n = 145), and IOP Proceeding Conference Series: Earth and Environmental Science (n = 44).

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Figure 9. Bibliographic coupling analysis of organizations.

The top three organizations with the greatest total link strength were the Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah (n = 143), the School of Biological Science, Universiti Sains Malaysia (n = 71), and the Department of Technology and Natural Resources, Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia (39) (Figure 9).

Discussion

The application of benthic macroinvertebrates as bio-indicators has received much scientific attention for continuous pollution monitoring due to the limitation posed by physicochemical parameters as a monitoring tool in freshwater ecosystems. An assessment of the literature on macroinvertebrates as bio-indicators in Malaysian rivers reveals a consistent upward trend over the years. As a result, many studies now concentrate on the health assessment of streams and rivers using benthic macroinvertebrates as bio-indicators in Malaysia, albeit many research gaps remain in this discipline. The papers were mainly published in leading periodicals with relevant scopes, including research on freshwater ecology. In addition, many papers with different studies were published in journals, e.g., Serangga and Sains Malaysiana.

Moreover, the reviewed findings also showed that the identification of macroinvertebrates primarily relies on morphological characteristics. Based on descriptive statistics, most studies in Malaysian rivers use benthic macroinvertebrates at the family level due to incomplete identification of tropical benthic macroinvertebrates, especially in Southeast Asia. Therefore, identifying up to the species level is vital to separate benthic macroinvertebrates based on their sensitivity to pollution. However, no studies have reported the use of molecular methods, such as Environmental DNA sequencing, to support or facilitate the identification of benthic macroinvertebrates in Malaysian rivers. Therefore, gaps still exist in the identification of benthic macroinvertebrates.

Many bio-indicator studies focused on microscopic identifications, along with biotechnology and toxicology analysis. Toxicity testing was also used to identify suitable organisms as bio-indicators, such as Oligochaeta. Only one toxicity test has been reported with Naididae (aquatic Oligochaeta) in Malaysia (Othman et al., 2012). This study identified *Nais elinguis* as a bio-indicator for heavy metal pollution, but this research did not conduct biomonitoring. Thus, in-depth research such as bioassay and toxicology tests are needed to realize the potential of Naididae as bioindicators fully. Besides, a genotoxicity study was conducted on *Chironomus kiiensis* in the Juru River (Al-Shami et al., 2013). The study revealed that sediments polluted by industrial wastes exhibit a more pronounced and immediate adverse genetic impact compared to urban pollution. As such, including molecular and genetic techniques is imperative in benthic macroinvertebrate studies in Malaysian rivers.

Biomonitoring is mainly categorized into four main approaches: single metrics, multimetric, multivariate, and models. Biological indices primarily consider the tolerance score of specific benthic macroinvertebrates (Blakely et al., 2014), which provides a clear idea about the bio-indicator taxa. However, in some southeast countries, taxa like Protoneuridae do not have tolerance values in the Family Biotic Index (FBI) due to the adaptation of the FBI by researchers from other countries to suit the context of their geographical regions. Hence, the development of a multimetric index using benthic macroinvertebrates is essential. For instance, Arman et al. (2019) developed a Malaysian water quality index based on aquatic

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invertebrates specific to four different catchments in Johor State, Malaysia. Therefore, developing a multimetric index based on the benthic macroinvertebrates with an extensive nationwide database is also necessary. This initiative would benefit many bio-indicator studies within the local context, with a comprehensive collection of taxa throughout Malaysia.

Many studies conducted in Peninsular Malaysia were based on the geographical extent of studies. However, there were limited studies in Perak, Melaka, and Negeri Sembilan. On top of that, biomonitoring studies in rivers and streams of Sabah and Sarawak are still lacking; thus, species richness and ecology of aquatic invertebrates remain unknown in these regions. Yong & Yule (2004) stated similar findings. Also, many studies have been conducted on Peninsular Malaysia recreational rivers. Benthic macroinvertebrates' distribution varies based on geological location, elevation, and habitat condition (Mohd Rasdi et al., 2012; Min & Kong, 2020). Researchers in Peninsular Malaysia often select a mostly polluted river (e.g., Juru River, Penang) (Al-Shami et al., 2011a; Al-Shami et al., 2011b). Thus, there is a crucial need to direct future research towards urban rivers, given the limited understanding of the diverse impacts on the conditions of benthic macroinvertebrates in this specific river type.

In addition, most studies have focused on a one-time frequency of occurrence. Consequently, much sampling is required to obtain accurate data on invertebrates' life cycles and better represent benthic macroinvertebrates. Furthermore, multiple replicates substantially improve the data's precision and allow more minor changes to be detected. Therefore, conducting a minimum of three replicates is recommended to obtain reliable measures for ecological monitoring (Mavrič et al., 2013).

Bibliographic maps provide a valuable aid in the investigation of bibliographic coupling. To ensure a thorough analysis, focusing on the top three authors and journals of significance is recommended. This approach helps to analyze the relationships among each author, the journals, and the impact of their research in this field. The bibliographic coupling also highlights the most productive journals and their connections in this study area. This study is the first to present the primary paths of bibliographic coupling research besides examining the bibliographies of authors, journals, and organizations. The results of the primary path analysis indicate a future research trend, which involves consolidated analysis based on diverse citation structures and textual similarity.

4. Conclusions

This review has revealed the bias and gaps in scientific publications for future research needs in bio-indicators studies. The Atyidae, Baetidae, Caenidae, Coenagrionidae, Chironomidae, Elmidae, Ephemerellidae, Euphaeidae, Gomphidae, Heptageniidae, Hydrophilidae, Hydropsychidae, Leptophlebiidae, Libellulidae, Perlidae, Potamanthidae, Simuliidae (Athropoda), Hirudinidae, Lumbriculidae, Naididae, Turbificidae (Annelida), and Physidae (Mollusca) were identified as the most popular potential biological indicator species in Malaysian streams and rivers due to their presence in the most favorable environmental conditions in aquatic ecosystems. Several recommendations were given to overcome the research gaps in studies on benthic macroinvertebrates as potential bio-indicators, such as modeling and developing the multimeric index. Besides, species identification is scarce in Malaysia compared with other Asian countries. Identifying taxa up to the species level is difficult due to the lack of taxonomic expertise; hence, the eDNA barcoding method with the power of the next-generation sequencing technique can be applied to overcome this limitation.

Also, there is an urgent need for new studies to address the limited bioassay and toxicology tests in identifying certain benthic macroinvertebrates as potential bio-indicators. Moreover, since little attention is given to benthic macroinvertebrate studies in Sabah and Sarawak, studies in these geological locations are most pertinent. Lastly, proper coordination among government agencies and private organizations is crucial in developing benthic macroinvertebrate studies, especially in preparing a database that includes all publications related to benthic macroinvertebrates. Furthermore, this science mapping approach appears to be the first bibliographic analysis of Malaysian research on potential bio-indicators of benthic macroinvertebrates in streams and rivers.

5. Recommendations for Wayforward

- In order to disseminate their research widely and reach a diverse audience, researchers worldwide rely on publishing their findings in a variety of high-impact journals, both locally and internationally. To effectively communicate their knowledge to a global audience, they must use English as the primary language while publishing their research.
- Bibliographic analysis is a highly effective method for evaluating the status and trends of current research. Through bibliographic coupling analysis of journals and proceedings, we have discovered that the two Malaysian journals with the greatest total link strength were also the top two with the highest total link strength. Further analysis of authors and organizations revealed that the three authors with the most publications were affiliated with the three institutions that made the most significant contributions. This research highlights the value of bibliographic analysis for understanding research trends and identifying key players in a given field.
- It is imperative to enhance the accessibility of the macroinvertebrate database to facilitate its utilization by other researchers. Such an action will unlock new avenues for research and application in freshwater management and conservation.
- Developing a multimetric index is an effective method to classify the various impacts of pollution. Such indices can encompass a wide range of information and data, which are then condensed into a single figure, making it easier to understand and compare the different pollution levels.

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The resulting index can provide valuable insights into pollution's severity and help guide efforts to mitigate its adverse effects.

7. Acknowledgments

The authors would like to acknowledge Universiti Putra Malaysia for providing permission to submit this review paper. Finally, the authors would like to thank the Sri Lanka Council for Agricultural Research Policy (SLCARP) and National Aquatic Resource Research and Development Agency (NARA), Crow Island, Colombo 15, Sri Lanka, for Nadeesha's postgraduate scholarship grant and study leave, respectively.

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