

INTEGRATING BIOLOGICAL ASPECTS INTO RIVER WATER QUALITY RESEARCH IN MALAYSIA: AN OPINION

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Abstract: Assessment on rivers and streams water quality should incorporate aspects of chemical, physical, and biological. The objective of this paper was to review the current primary concerned aspects and practiced method in river water quality research in Malaysia. The present day, method of determining river water quality in Malaysia is based mainly on physical and chemical parameters. Concentration on chemical and physical parameters is particularly surprising in judging natural waters where the main aim is often preservation of biological amenities. Numerous studies have indicated biological method has many advantages over chemical and physical method such as, cheaper, easier, less time consuming, reliable, and can give indications of water quality for a long period of time. We do not advocate to abandoning physical and chemical assessments, rather, we note the inadequacy of the assessments to give complete information on river water quality. Therefore, Malaysia should start to anticipate and integrate the biological aspects into water quality studies, and extensively make use of them to improve water quality monitoring in Malaysia. Successfulness on this will enhance water quality monitoring and management in Malaysia.

Keywords: Biological aspects, Malaysia, River monitoring, Water quality.

INTRODUCTION

Water quality research had gone more than 100 years and cover physical, chemical, and biological aspects of water quality. All these aspects had profound impact on aesthetical and usability to consumers, they are linked and inseparable to ensure water quality kept at utmost (Viswanathan et al., 2010; Meybeck et al., 1996). Rivers and streams are very important natural environment and linked to human lives, animals, and vegetations (Wu et al., 2010; Haase and Blodgett, 2009; Ghani, 2006).

Nowadays, the numbers of unpolluted streams are decreasing rapidly, parallel to rapid development process by man's (Niemczynowicz, 1999). Perhaps that is the main reason why it had being considered by Malaysian professional as the main ecological problem in Malaysia when Silverman and Silverman (2000) conduct their survey back then. Description of development impact on natural environment in Malaysia had been discussed since 1970th by Aiken and Moss (1976), although their studies are only based on several case studies on different areal scale

in Peninsular Malaysia, their arguments are supported by strong fact. Former Director-general of Department of Irrigation and Drainage in Malaysia (Jabatan Pengairan dan Saliran Malaysia) also known as JPS or DID, Dato' Paduka Ir. Hj. Keizrul bin Abdullah in his speaking at the East Asia Regional Seminar on River Restoration in Kuala Lumpur in 2003 says, "we have exploited our rivers beyond sustainable level, and in many places, what is left is degraded river system. Rivers become polluted and devoid of aquatic life as it gets silted up and cannot perform its function as a drainage channel" (Star, 2003). A recent study by Arsad (2009) revealed, most of the rivers in Malaysian cities still possess the problem related to water pollution, and it had been identified to be caused by alteration on physical properties of the rivers. Coupled with bad land use practice and loss of riparian areas along the river corridors, the effects are much greater than we could expect (DID, 2009).

Development activities such as industrialization (Leung and Sell, 1982; Mangarillo et al., 2005), agricultural (Shamsudin, 1999; Vemula et al., 2004; Willardson, 1985; Espinosa-Villegas et al., 2005; Johns and Watkins, 1989), urbanization (Metsäranta et al., 2005; He et al., 2007; Gilbert, 2010; Weber et al., 2004) and channelization are well known to introduce stress to rivers and streams in watershed. The activities lead to nutrient enrichment to the rivers and streams by runoff pollutants (Yusop et al., 2005) such as pesticides, toxic element (e.g. arsenic and chromium) (Abdullah and Nainggolan, 1991; Salim et al., 2009) and fertilizer (Dukes and Evans, 2006; Nazahiyah et al., 2007), as well as discharged effluent from wastewater treatment plants (Lung, 1986; Fulazzaky et al., 2010) and discharged of untreated wastewater or sullage from residential areas (Mamun et al., 2009; Lee et al., 2008). Chen et al. (2004), Arsdale et al. (2003) and Barbour et al. (1996) stated that, development activities could cause reduction on biological functionality especially to the aquatic ecosystem and ecological values of the river compared to the time when it still in pristine condition. Coupled with bad antisocial habit such as wastes littering, the effects on the river water quality are known to be negatives (Jennings et al., 2009; Arsad, 2009). Appropriate management and monitoring technique is therefore required to control and further offset the negative effects (Bowen, 1998; Deutschman and Leach, 1998; DID, 2009).

Rivers and streams are usually expose to loads of polluting substances that come from point sources such as sewers and effluent from wastewater treatment plants (Petersen et al., 2005), as well as from diffuse discharge sources such as surface water runoffs (McLeod et al., 2006; Petersen et al., 2005; Earles et al., 2008; Gurr and Nnadi, 2009; Lefkowitz

et al., 2009). In order to evaluate the quality of running waters, chemicals and physicals (physicochemical) parameters such as *biological oxygen demand, chemical oxygen demand, organics and nitrogenous substance, suspended solids, alkalinity, temperature, electrical conductivity*, and *dissolved oxygen* are then assessed and evaluated. However, physicochemical analyses cannot yield enough information on the whole health of the river ecosystem (Viswanathan et al., 2010). In some cases, chemical analyses may fail to detect the presence of certain contaminant due to dilution phenomenon; hence, integration of bioindicator is necessary to complete the information (Conti, 2008).

It is a concern in this paper to discuss more on biological aspects of river water quality. In this context, aquatic biological communities such as benthic macroinvertebrates, water plants, and fish are the objects of safeguard action and at the same time they are the markers for the healthiness of the water bodies. Although there are numbers of aquatic bioindicator, focus of this paper is primarily on the use of benthic macroinvertebrates as bioindicator for rivers and streams water quality monitoring.

The review reported in this paper was carried out to: (a) review the current practiced methods of determining river water quality in Malaysia. (b) discuss the use of biological methods for assessing river water quality. (c) suggest future direction for integrating biological aspects and implementing biological methods into river water quality studies in Malaysia.

Biological methods for assessing rivers and streams water quality have many attractions. For example, biological community can integrate many different environmental factors over a long period of time, hence able to demonstrate environmental changes of the surrounding area (Wu et al., 2010; Hathaway and Hunt, 2010; Karr and Chu, 1999; Strobl and Robillard, 2008), and because the biological community demonstrate ecological integrity as a whole (Viswanathan et al., 2010), direct evaluation on the overall quality of the water bodies is possible (Boonsoong et al., 2009; DID, 2009).

Unfortunately, the biological aspects of water quality are often received little consideration in river water quality research relative to physical and chemical aspects (James and Evison, 1979; Karr, 1991), where most national standards for assessment of river water quality only includes physical and chemical indicator relevant to specific pollutants and stressors (Boonsoong et al., 2009). This had also being a trend in Malaysia where most river water quality studies are only focusing on physical and chemical parameters (e.g. Ghani et al., 2009; Abdullah and Nainggolan, 1991; Lee et al., 2006; Latiff et al.,

2009; Nazahiyah et al., 2007; Salim et al., 2009; Yunus and Nakagoshi, 2004; Deris, 2009; Suratman et al., 2009; Sarmani, 1989; Yusof et al., 1999; Yusop et al., 2005; Fulazzaky et al., 2010) with largely neglecting the biological parameters.

In selecting the appropriate bioindicator for freshwater quality monitoring, more knowledge are needed about the identification of species, how biological diversity is distributed, and what are the trends observed on short-term to long-term biodiversity changes. In many tropical countries (including Malaysia), there are lakes and rivers lacking even the most basic research on fauna and flora (Lévêque, 1998). Yule and Sen (2004) stated, the freshwater fauna of tropical regions is poorly known, yet the tropics hold a large share of the world's freshwater resources and some extreme and unusual habitats. This should be taken as an opportunity for scientist, especially biologist in Malaysia to explore and commence extensive research to study the surrounding environment ecosystem in Malaysia broadly for better understanding the science of bioindicator which then can be utilizes for monitoring the ecosystem in Malaysia. Undoubtedly, successfulness in doing this will further hone our knowledge on bioindicator especially on benthic macroinvertebrates in Malaysia.

In late 1970, a study by Sladecék (1979) revealed, every aquatic organism can serve as indicator for its habitat. What required is; we must first know its environmental requirement, and then we will be able to assess the water quality of its habitat according to its presence, and in some cases even according to its absence (Sommaggio, 1999). Benthic invertebrate community in rivers and streams of Malaysian regions may contain a variety of biota including bacteria, protists, rotifers, bryozoans, worms, crustaceans, aquatic insect larvae, mussels, clams, crayfish, and other forms of invertebrates (Yule and Sen, 2004). Aquatic invertebrates are found in or on a multitude of microhabitats including plants, woody debris, rocks, interstitial spaces of hard substrates (gravel), and soft substrates (sand and muck). The habitats of invertebrate communities exist at all vertical strata including the water surface, water column, bottom surface, and deep within the hyporheic zone. The findings by Sladecék (1979) should open up the mind of scientists and researchers in Malaysia, hence start to consider biological over the traditional physicochemical based methods in river water quality studies.

Where studies which applied biological method in river water quality research in Malaysia are still very limited, there has one study that should get our attention. A study by Salmah et al., (2006) shows, odonate (dragonflies) larval communities are able to

indicate the quality of water in its habitat. The study was done at three small rivers in Penang, northern part of Malaysia. From the study they found that, the distribution of dragonflies are higher in area with good water quality (high dissolved oxygen, low biological oxygen demand, low conductivity, and low turbidity) compared to area with bad water quality (low dissolved oxygen, high biological oxygen demand, high conductivity, and high turbidity). This relatively simple indication for water quality is a promising finding on the ability and validity of the biological method to be integrated into river water quality studies and monitoring in Malaysia. With further research and deeper understandings, biological method could soon have appropriate place in river water quality research in Malaysia.

Benthic macroinvertebrates, particularly aquatic insect larvae and crustacean, had been widely used as indicator of the health and condition of waterbodies (e.g. Gewurtz et al., 2003; Haase et al., 2004; Meng et al., 2009; Barton, 1989; Conti, 2008; James and Evison, 1979; Iliopoulou-Georgudaki et al., 2003; Leonardsson et al., 2009; Canfield et al., 1996; Dlamini et al., 2010; Wu et al., 2010). Many fish species rely on benthic organisms as a food source (Longhurst, 1957; Shubina, 2006; Alheit and Scheibel, 1982) either by direct browsing or by catching the benthic organisms that become dislodged and drifted downstream (Principe and Corigliano, 2006). The use of benthic macroinvertebrates to assess biological integrity of stream ecosystems has been well documented in Resh et al., (1996) and in Rosenberg and Resh (1992). On behalf of the United States Environmental Protection Agency (U.S EPA), Barbour et al. (1999) had revised the rapid bioassessment protocols with use of periphyton, benthic macroinvertebrates and fish as bioindicator. The protocols provide a practical technical reference for conducting cost-effective biological assessment of lotic systems and most suitable for streams and Wadeable rivers.

According to Sladecék (1979), the right way of utilizing the aquatic organism is to use it according to where it stays in the waterbodies: planktonic community about the water; benthic and littoral ones about the conditions on the bottom and shoreline. Combination of these is necessary because the more species under consideration the more accurate the result would be (Khan, 1990).

RIVER WATER QUALITY MONITORING IN MALAYSIA

There has 189 river basins in Malaysia and 150 of them are main river basins. About 100 of main river basins in Malaysia are situated in Peninsular Malaysia, where the other 50 are situated in Sabah and Sarawak.

Table 1: DOE water quality classification based on Water Quality Index_{Malaysia}

Sub Index & Water Quality Index	Unit	Index Range		
		Clean	Slightly Polluted	Polluted
Biochemical Oxygen Demand (BOD)	mg/l	91 - 100	80 - 90	0 - 79
Ammoniacal Nitrogen (NH ₃ -N)	mg/l	92 - 100	71 - 91	0 - 70
Suspended Solids (SS)	mg/l	76 - 100	70 - 75	0 - 69
Water Quality Index (WQI)		81 - 100	60 - 80	0 - 59

Table 2 : DOE Water Quality Index_{Malaysia} classification.

Parameters	Unit	Class				
		I	II	III	IV	V
Ammoniacal Nitrogen	mg/l	< 0.1	– 0.3	0.3 – 0.9	0.9 – 2.7	> 2.7
Biochemical Oxygen Demand	mg/l	< 1	1 – 3	3 – 6	6 – 12	> 12
Chemical Oxygen Demand	mg/l	< 10	10 – 25	25 – 50	50 – 100	> 100
Dissolved Oxygen	mg/l	> 7	5 – 7	3 – 5	1 – 3	< 1
pH	-	> 7.0	6.0 – 7.0	5.0 – 6.0	< 5.0	> 5.0
Total Suspended Solids	mg/l	< 25.0	25 – 50	50 – 150	150 – 300	> 300
Water Quality Index		> 92.7	76.5 – 92.7	51.9 – 76.5	31.0 – 51.9	< 31.0

It is estimated that there has 1800 rivers in Malaysia with total length of more than 38, 000km (DID, 2009). Currently Malaysia has 30 hydroelectric dam for power generation and water supply. Rivers and streams in Malaysia serve the purpose for agricultural, industry, water supply, transportation, aquatic habitats, water sport and recreational. Monitoring and management of rivers and streams water quality in Malaysia lies under the jurisdictions of two government agencies: The Department of Environmental in Malaysia (Jabatan Alam Sekitar Sekitar Malaysia), also known as JAS or DOE; The Department of Irrigation and Drainage in Malaysia (Jabatan Pengairan dan Saliran Malaysia), also known as JPS or DID.

Annually, DOE published Environmental Quality Report of Malaysia to reporting the environmental state of air, water, and soil in the country. In assessing and reporting the state of rivers and streams water quality, DOE uses physicochemical based methods of their own developed Water Quality Index_{Malaysia} (WQI_{Malaysia}). Table 1 shows the parameters consisted in the WQI_{Malaysia}.

There has 6 parameters (physicochemical) in WQI_{Malaysia} : Ammoniacal Nitrogen (NH₃-N), Biochemical Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Suspended Solid (SS), and pH. Assessment and valuation of these parameters produced an index value ranging from zero to one hundred. From the index value, the river water quality can then be classified into three main classes which are: clean, slightly polluted, and polluted. The WQI_{Malaysia} was developed in Malaysia by collaboration efforts between DOE and Universiti Malaya in 1985 (Arsad, 2009). Table 2 show the classification of WQI_{Malaysia} and all the subindex parameters into five classes.

WQI_{Malaysia} is the most effective way for communicating information on the state of water environment to the concern citizen and policy makers in Malaysia. Ratings from the index value reflect the overall composite influence of the water quality parameters. Calculated index for a given river and stream will determine its quality status, which later will help the respective agencies in determining the appropriate management actions.

While DOE has their focuses majorly on the quality of waters and identification of point and non-point source pollution that pollute freshwater in Malaysia, DID on the other hand has their focuses mainly on the physical and hydraulics properties of channels and drainages in Malaysia. Only quite recently, in 2009 DID have started to have their attention on water quality. That is when they made a collaboration effort with Universiti Sains Malaysia, and had successfully produce a Guideline for Using

Macroinvertebrates for Estimation of Streams Water Quality also known as *Panduan Penggunaan Macroinvertebrata untuk Penganggaran Kualiti Air Sungai*. DID have utilized Biological Monitoring Working Party Index's (BMWP) and Average Score Per Taxon Index's (ASPT) in the guideline. The BMWP and ASPT were used in the guideline because these two indexes had been widely used in Europe and many parts of the world since 1976, and they require qualitative data which are easy to collect (DID, 2009). The guideline provides simple, cheap, and easy approach for estimating the river water quality through collecting and indentifying main species of aquatic macroinvertebrates found in the waterbodies.

RIVER WATER QUALITY STUDIES IN MALAYSIA

River water quality in Malaysia was historically being evaluated by chemical specific numeric water quality standards and narrative criteria. While such criteria are based on scientific judgement about the potential for adverse effects to aquatic organisms, the causative relationship between chemicals and effect is only assumed (Ellis et al., 1997). The history of bioindicator systems for surface water quality assessment had started more than a century ago by Kolenati (1848) and Cohn (1853), both quoted in Liebmann (1962) (Depauw and Vanhooren, 1983; Iliopoulou-Georgudaki et al., 2003) who observed that organisms occurring in polluted water are different from those in clean water. Kolenati (1848) literally concluded that the absence of caddis larvae from a stream can be caused by the presence of a city upstream (Liebmann, 1960 and SladeCek, 1973), both quoted in Mol (1980) and it was a very old and the very beginning of biological method used in river monitoring study conducted in Europe. Thereafter, discussion on bioindicator had run until the recent day.

In Europe, awareness on applying biological methods for assessing river water quality had emerged over the past century, and interest on using biological method had significantly increased over the past decade. As a result, there have many studies which lesson can be drawn. Biological quality can be assessed by different kinds of organisms: diatoms, riparian and aquatic vegetation, invertebrates and fishes. Many literature on these groups and methods are available (e.g. Dutka, 1979; Sladécék, 1979; Lockwood, 1979; Hawkes, 1979; Bellinger, 1979; Collingwood, 1979; Prince, 1979; Hellawell, 1986; Persoone and De Pauw, 1979; Descy and Micha, 1988). Quite recently, references on using freshwater biomonitoring and benthic macroinvertebrate (aquatic insects, molluscs, crustaceans, and worms) in biological assessment of water quality are well documented in Rosenberg and Resh (1992), they sum

up the use of these organisms in both North America and Europe where their uses had dramatically increased in the past two decades.

In the past 25 years, numerous biomarkers have been developed with objective to apply them in environmental biomonitoring; quite recently the Water Framework Directive (WFD) of the European Union has had specified required monitoring programs to assess the achievement of good chemical and ecological status for all water bodies by 2015 (Sanchez and Porcher, 2009). Whereby in south East Asia (Thailand and Malaysia), example of studies on rivers and streams water quality monitoring with utilization of benthic macroinvertebrate can be found quite in Boonsoong et al., (2010), Boonsoong et al., (2009), Mustow, (2002), Parrong, (2002), Salmah et al., (2006), and Lee et al., (2006).

One of the most striking feature of past assessment procedures in Malaysia had been the reliance placed upon chemical and physical based methods, with relatively full neglect on biological methods. Review on water quality standards and practices in Malaysia by Idris et al. (2003) reveals, chemical parameter such as *Ammoniacal Nitrogen* ($\text{NH}_3\text{-N}$) was identified as one of the main pollutant to Malaysian rivers. In the review, they were suggesting to direct efforts on searching for others pollutant that frequently found in Malaysian rivers system. Although their suggestion would further enhance river water quality standard and practice in Malaysia, it lacks of preservation of biological amenities which primarily important to the end users (humans, animals, and vegetations) of the water.

Quite recently, Malaysia had started to integrate biological techniques for rivers and streams monitoring across the country, and this had been done by Department of Irrigation and Drainage in Malaysia (DID, 2009). However, the implementation is still too new compared to traditional physicochemical based techniques. Hence, there are a lot to be studied before users (water authority, researchers, and scientist) can comfortably rely on the biological technique for rivers and streams water quality monitoring. Until now the concentration on physicochemical parameters is still very dominant in many river water quality studies in Malaysia (e.g. Bouza-Deaño et al., 2008; Bordalo et al., 2001; Yunus and Nakagoshi, 2004; Gopinath and Tamjjs, 2008; Latiff et al., 2009). The concentration on physical and chemical based methods is particularly surprising in judging natural waters where the main aim is often the preservation of biological amenities.

In Malaysia, studies on river water quality with relations to bioindicator had started relatively quite late compared to European countries, as the earliest and well documented one was in 1990 when Khan

(1990) conducted a case studies in Linggi River Basin, Malaysia (tropical river basin); to assess water pollution using diatom community structure and species distributions. Khan found a marked variation in species association exists between the unpolluted and polluted stations. Later, Khan (1991) expanded the studies where he had investigated the effects of urban and industrial wastes on species diversity of diatom community in tropical river, Malaysia. Interests on this topic indicate a growth when Yap (1997) made a preliminary attempt to classify Malaysian river using biological indices: Shannon-Weaver diversity index and Saprobic system, concept of Kolkwitz and Marsson. Yap found that, the Shannon-Weaver diversity index appeared to give interesting and interpretable classification results compared to the Saprobic system index. Only quite recently in year 2000, application of biological method in river water quality studies started to increase, and example of the studies can be seen in Al-Shami et al., (2010b, 2010a), Azrina et al., (2006), Lee et al., (2006), Maznah and Mansor, (2002), and Salmah et al., (2006).

In year 2000, Maznah and Mansor (2002) conducted a study on diatom community with relation to river water quality. The results shows that, certain diatom species are affected by the degree of water quality in the study area, thus the diatom community could be use as a bioindicator to measure the impacts of river pollution. A recent study by Al-Shami et al. (2010b) also agrees that, pollutants discharged into river can cause negatives impact on the aquatic macroinvertebrates (e.g. Diptera: Chairomidae). These two studies are very excellent example and give us a solid proof that, biological indicators (aquatic macroinvertebrate) can be use in Malaysia for assessing and evaluating the streams and rivers water quality. Therefore, biological methods are compelling and reliable to be integrated as a tool for river water quality monitoring in Malaysia (tropical climate country). The time is now that, Malaysia should start to appreciate the biological methods, hence scientists and researchers start to incorporate and manipulate every advantages and benefits of biological method into river water quality research agendas in Malaysia.

ADVANTAGES OF BIOLOGICAL ASPECTS

A typical question arises each time ones try to decide between biological method over physicochemical method in water quality analysis: Why biological water analysis at all? Or more precisely: Why biological water analysis besides all other possibilities water analysis? And this means the biological analysis must offer important advantages over physical and chemical based method, otherwise its uses could not be justified.

The use of biological methods may be justified by the following discussions. Biological assessment (or bioassessment) techniques have been developed to enhance the existing chemical-specific standards by providing direct measure of ambient aquatic habitats and overall biological integrity of a waterbodies (Wong and Dixon, 1995; Usepa, 1991). Better than chemical and physical criteria alone, biological criteria link human actions with their impacts on waterbodies and societal goals which are expressed as designated uses (Karr and Yoder, 2004). Perhaps, one of the bright sides of bioassessment techniques is it can be used across a range of biological systems, from the ecosystem down to the molecular level (Ellis et al., 1997).

One of the important values of biological indicators is that, they gives direct answer on the suitability of the water for supporting aquatic lives and for agricultural uses, and to some extent it shows the suitability of the water for direct consumes by humans. The advantages of river water quality monitoring with the use of bioindicator is that, biological communities are able to reflects the overall ecological quality and integrate the effects of different stressors by providing broad measures of their impact and ecological measurements of fluctuating environmental condition. According to Iliopoulou-Georgudaki et al. (2003), overall routine monitoring of river water quality using biological communities is reliable and relatively inexpensive compared to the cost of assessing toxicant pollutants.

Galassi et al. (1993) shows another advantage of using biological method over chemical and physical method as they found biological method offers complete characterization of all parent compounds and their metabolites by employing aquatic organism on the basis of their toxicity. They also reveal, biological method could save time due to its simplicity compared to physicochemical based method. A study by Tittizer and Kothe (1979) found biological analyses yield relevant information on the quality condition of the waterbodies with relatively modest requirements and very quickly. They also found biological analyses provide information which cannot be obtained by other methods.

The crux of the matter in river water quality monitoring using biological community lies in finding a reliable biological indication for water pollution which at the same time independent to natural variations in the environment. The selection of proper bioindicator can provide additional benefits through their uses in causal analysis of impaired water and measurement of ecosystem (Barbour and Paul, 2010). Fortunately, now there are many studies from which lessons can be drawn (e.g. Slooff and Zwart, 1983; Hawkes, 1979; Sladécék, 1979; Tittizer

and Kothe, 1979); Sladécék had made elaboration on continental system for the assessment of river water quality; Hawkes had found how to use aquatic invertebrates as indicator for river water quality; and Tittizer and Kothe had shown the possibilities and limitations of biological method in water analysis.

With increased interests in biological surveillance, different data processing methods were tried. Since 1848 until early 1980, fifty different methods for biological water analysis have been developed (quoted in Depauw and Vanhooren (1983)). However the number is likely to have been continuing increased thereafter as U.S EPA advancing their steps in biological monitoring in 1990 with the development of Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition (Barbour et al., 1999).

In an ideal situation, the quality of running waters should be assessed on the basis of physical, chemical and biological parameters in order to get the complete spectrum of information for appropriate water management. However, such assessment needs much more times and expenses than assessment on the biological parameters alone (Iliopoulou-Georgudaki et al., 2003), which as it is widely accepted, can give reliably about all the information (Dolédéc and Statzner, 2010).

A vast number of studies could cause fragmentation of methods and results, especially if the new developed methods are not shareable and linkable to methods from the past or future to come. When abundance of methods had been developed, question is, does the developed method level with one another? Can we just use one particular method instead of another? The answer is yes; in late 1970, a study by Tittizer and Kothe (1979) had proved that the applicability of intercalibration between methods developed earlier in 1976, which means it is possible to develop a comparative measuring system that allows the conversion of water pollution values from one type of measuring unit to another type of measuring unit. But, can the result from different methods be linked with one another? Is the result shareable? Houston et al. (2002) reveals that, data or assessment information could be shared among agencies even though there was a difference in methods and metric results. This shows that biological assessment is not sensitive to some changes in the method (Borja et al., 2008) thus offering flexibility to match with local condition and geographical area.

CHALLENGE OF BIOLOGICAL ASPECTS

A study by Duran et al. (2003) reveals biological and chemical results are in good agreement with respect

to water quality in stream. However, it is undeniable that biological methods also suffer from disadvantages of failing to provide a numerical basis for remedial action (James and Evison, 1979). One of the primary goals of bioindicator research is to identify species or other taxonomic units that would reliably indicate disturbances in the environment and reflects the responses of other species or the overall biodiversity. According to Sladécék (1979) biologist must be able to classify many species of aquatic organisms and be able to get specialist to identify for the unknown ones. This is quite a big challenge especially in Malaysia where the country has limited resource of essentials information and experts to identify and classify native species of aquatic organisms.

In monitoring rivers and streams water quality, concerned parameters are largely on physicochemical parameters of the water itself. The use of bioindicator is as a tool for predicting the ranges of physicochemical compounds contained in the water based on the tolerant values of the referred macroinvertebrate. Recent study by Al-Shami et al. (2010b) at rice field in Penang, Malaysia found that the community of macroinvertebrate (Diptera: Chironomidae) which was used as referred biological indicator did not significantly affected by physicochemical parameters such as pH, dissolved oxygen, daytime water temperature, total suspended solids, phosphate, and sediments total organic matter. Instead, the community would follow the dynamic changes of the habitat area including agronomic practices, patterns of water availability, and phases of plant growth. The finding appears to be a good indication for which biological indicator could also be linked to agricultural practices. However, this finding is actually revealing the disadvantage of biological method on reflecting the assessed water quality, by which the finding could actually cause a doubt on the suitability of bioindicator to reflect the state of water quality especially when one of the main objectives of biological based method is to act as substitute of the more accurate physicochemical based methods.

Khan (1990) found that the biological method (with use of diatom community) cannot give a marked variation between unpolluted and moderately polluted river, thus caused a doubt on reliability of biological method especially when the river which ones try to assess is in fairly clean state. So there has a limited ability for biological method to distinguish the types and degree of pollutions. Later, Khan (1991) found that the changes in species diversity can be related to changes in diatom community structure and thereby changes in water quality, however due to complexity to interpret the results he concluded that,

the diatom community cannot be used as an index of water quality.

There is no perfect bioindicator and selecting the most suitable one depends to a great extent on the goal of the survey (Rainio and Niemelä, 2003). Therefore, in order to get full view of the surrounding water quality, assessment on multiple species are needed because there is no single species in habitat composition of the community can reflect complex information (Sladécék, 1979). Before a particular aquatic organism being selected as bioindicator for rivers and streams water quality monitoring, there must had been a sufficient research to determine its suitability to be indicator. Until the particular organism being extensively studied, it should be used with caution (Rainio and Niemelä, 2003). Disadvantages of biological methods in lacking to provide numerical basis compared to physicochemical based methods should not be deemed as a dead end for implementing it in water quality monitoring. Instead, it should be seen as a challenge for scientists to commence thorough research on biological methods, hence foster the successfulness of biological methods in river water quality research in Malaysia.

FUTURE DIRECTION

Agendas in management of rivers and streams in Malaysia require collaborations effort between government agencies, research institutions, scientist, and all the stakeholders. Holistic approach is favour in the agendas. Therefore future direction on river water quality research in Malaysia should integrate biological methods in the agendas. Whether biological method should be use as alternatively or complementary approach for streams water quality monitoring in Malaysia, should be further investigated. The parallelism and relationship between bioindicator and water quality index established in Malaysia should be further studied to fully understand the science between these two different based methods. Understanding on the relationship will help to clear doubt pertaining biological methods over physicochemical based methods. The validity of biological methods for assessing river water quality in Malaysia require years of implementation to fully understand the information offered by the method (DID, 2009). In advance research, biological methods could be applied to assess the recovery quality of river and streams related projects (e.g. river restoration projects), especially when there has many river restoration project going on in Malaysia: Sungai Pinang, Pulau Pinang; Sungai Melaka, Melaka; Sungai Tebrau, Johor; Sungai Skudai, Johor; Sungai Segget, Johor; and Sungai Muda, Kedah.

CONCLUSION

In conclusion, assessment on river water quality lies on delicate interface between physical, chemical and biological. Biological based methods have significant advantages over traditional analysis of physicochemical based methods. Besides providing information on the bioavailability of contaminants, it simplifies the physicochemical analysis, eliminating the problem in the assessment of very low levels contaminants. It also prevents the risk of misinterpretations which can be caused by sudden fluctuations in the environmental parameters at the time of sampling, thus providing a measurement over time on the level of environmental contaminations. However, we do not advocate abandoning physical and chemical assessments rather we note the inadequacy of the assessments which unable to give complete information on the river water quality in complex ecosystem. Long history path of biological methods had produced many lessons that are very useful and beneficial for Malaysia. It is now that, Malaysia should extensively make use of them to improve river water quality monitoring in Malaysia especially in term of biological aspects and for further research to be started. Biological and physicochemical qualities are inextricably tied to the viability of water resources availability and resilience. Integrating biological based methods and physicochemical based methods into water resources research agendas is essential for sustainable of water resources. Therefore, vibrant and holistic water resources research agendas must account for interdependencies between the quality and quantity of water. The water quality aspect in the agenda must be sustainable and should include consideration on finding and developing a viable system of regulation and incentive to promote interest on biological methods. Succession in integrating the biological methods in river water quality research agenda will contribute to one step further towards sustainability of the water resources in Malaysia and in the world.

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REFERENCES

- [1] Abdullah, P. and Nainggolan, H. (1991), 'Phenolic water pollutants in a Malaysian River basin', *Environmental Monitoring and Assessment*, 19 (1), 423-431.
- [2] Aiken, S. R. and Moss, M. R. (1976), 'Man's Impact on the Natural Environment of Peninsular Malaysia: Some Problems and Human Consequences', *Environmental Conservation*, 3 (04), 273-283.
- [3] Al-Shami, S., Salmah, Md. R. C., Hassan, A. A., and Nor, M. S. A. (2010a), 'Temporal distribution of larval Chironomidae (Diptera) in experimental rice fields in Penang, Malaysia', *Journal of Asia-Pacific Entomology*, 13 (1), 17-22.
- [4] Al-Shami, S., Salmah, Md. R. C., Hassan, A. A., and Nor, M. S. A. (2010b), 'Morphological Deformities in Chironomus spp. (Diptera: Chironomidae) Larvae as a Tool for Impact Assessment of Anthropogenic and Environmental Stresses on Three Rivers in the Juru River System, Penang, Malaysia', *Environmental Entomology*, 39 (1), 210-222.
- [5] Alheit, J. and Scheibel, W. (1982), 'Benthic harpacticoids as a food source for fish', *Marine Biology*, 70 (2), 141-147.
- [6] Arsad, A. (2009), 'Development of River Restoration Plan for Upstream Tributary of Sungai Pulai Based on Water Quality and Land Used Activities.', (Universiti Teknologi Malaysia).
- [7] Arsdale, R. V., Waldron, B., Ramsey, N., Parrish, S., and Yates, R. (2003), 'Impact of River Channelization on Seismic Risk: Shelby County, Tennessee', *Natural Hazards Review*, 4 (1), 2-11.
- [8] Azrina, M. Z., Yap, C. K., Ismail, A. R., Ismail, A., and Tan, S. G. (2006), 'Anthropogenic impacts on the distribution and biodiversity of benthic macroinvertebrates and water quality of the Langat River, Peninsular Malaysia', *Ecotoxicology and Environmental Safety*, 64 (3), 337-347.
- [9] Barbour, M. and Paul, M. (2010), 'Adding value to water resource management through biological assessment of rivers', *Hydrobiologia*, 651 (1), 17-24.
- [10] Barbour, M. T., Stribling, J. B., Gerritsen, J., and Karr, J. R. (1996), *Biological criteria: Technical guidance for streams and small rivers (Revised Edition)*, ed. G.R. Jr. Gibson (Washington, D.C.: U.S. Environmental Protection Agency, Office of Water).
- [11] Barbour, M. T., Gerritsen, J., Snyder, B. D., and Stribling, J. B. (1999), *Rapid Bioassessment Protocols for Use in Streams*

- and Wadeable Rivers: Periphyton, Benthic Macroinvertebrate and Fish, Second Edition (Washington, D.C.: US. Environmental Protection Agency, Office of Water).
- [12] Barton, D. R. (1989), 'Some Problems Affecting the Assessment of Great Lakes Water Quality Using Benthic Invertebrates', *Journal of Great Lakes Research*, 15 (4), 611-622.
- [13] Bellinger, E. G. (1979), 'The response of algal populations to changes in lake water quality', in A. James and L. Evison (eds.), *Biological Indicators of Water Quality* (Chichester: John Wiley & Sons), 1-27.
- [14] Boonsoong, B., Sangpradub, N., and Barbour, M. (2009), 'Development of rapid bioassessment approaches using benthic macroinvertebrates for Thai streams', *Environmental Monitoring and Assessment*, 155 (1), 129-147.
- [15] Boonsoong, Boonsatien, Sangpradub, Narumon, Barbour, Michael T., and Simachaya, Wijarn (2010), 'An Implementation plan for Using Biological Indicators to Improve Assessment of Water Quality in Thailand', *Environmental Monitoring and Assessment*, 165 (1), 205-215.
- [16] Bordalo, A. A., Nilsumranchit, W., and Chalermwat, K. (2001), 'Water quality and uses of the Bangpakong River (Eastern Thailand)', *Water Research*, 35 (15), 3635-3642.
- [17] Borja, A., Dauer, D. M., Díaz, R., Llansó, R. J., Muxika, I., Rodríguez, J. G., and Schaffner, L. (2008), 'Assessing estuarine benthic quality conditions in Chesapeake Bay: A comparison of three indices', *Ecological Indicators*, 8 (4), 395-403.
- [18] Bouza-Deaño, R., Ternero-Rodríguez, M., and Fernández-Espinosa, A. J. (2008), 'Trend study and assessment of surface water quality in the Ebro River (Spain)', *Journal of Hydrology*, 361 (3-4), 227-239.
- [19] Bowen, J. D. (1998), 'Using Eutrophication Modeling to Predict the Effectiveness of River Restoration Efforts', in Donald F. Hayes (ed.), (40382 edn., 100; Denver, Colorado, USA: ASCE), 117-117.
- [20] Canfield, T. J., Dwyer, J. F., Fairchild, J. F., Haverland, P. S., Ingersoll, C. G., Kemble, N. E., Mount, D. R., Point, T. W. La, Burton, A. G., and Swift, M. C. (1996), 'Assessing Contamination in Great Lakes Sediments Using Benthic Invertebrate Communities and the Sediment Quality Triad Approach', *Journal of Great Lakes Research*, 22 (3), 565-583.
- [21] Chen, J. C., Chang, N. B., Chen, C. Y., and Fen, C. S. (2004), 'Minimizing the Ecological Risk of Combined-Sewer Overflows in an Urban River System by a System-Based Approach', *Journal of Environmental Engineering*, 130 (10), 1154-1169.
- [22] Collingwood, R. W. (1979), 'The effect of algal growth on the quality of treated water', in A. James and L. Evison (eds.), *Biological Indicators of Water Quality* (Chichester: John Wiley & Sons), 1-19.
- [23] Conti, M. E. (2008), 'Biomonitoring of freshwater environment.', in M.E. Conti (ed.), *Biological Monitoring: Theory & Applications* (Southampton: WIT Press), 47-73.
- [24] DePauw, N. and Vanhooren, G. (1983), 'Method for biological quality assessment of watercourses in Belgium', *Hydrobiologia*, 100 (1), 153-168.
- [25] Deris, O. (2009), 'Effects of Rimbaka Forest Harvesting Technique on Stream Water Quality and Soil Physical Properties', (Universiti Putra Malaysia).
- [26] Deutschman, M. R. and Leach, M. (1998), 'Water Quality of the Clearwater River - Effect of Nonpoint Sources and a Strategy for Improvement', in Donald F. Hayes (ed.), (40382 edn., 100; Denver, Colorado, USA: ASCE), 142-142.
- [27] DID, Department of Irrigation and Drainage Malaysia (2009), *Panduan Penggunaan Makroinvertebrata untuk Penganggaran Kualiti Air Sungai*, ed. Department of Irrigation and Drainage Malaysia (Kuala Lumpur, Malaysia: Jabatan Pengairan dan Saliran Malaysia) 116.
- [28] Dlamini, V., Hoko, Z., Murwira, A., and Magagula, C. (2010), 'Response of aquatic macro-invertebrate diversity to environmental factors along the Lower Komati River in Swaziland', *Physics and Chemistry of the Earth, Parts A/B/C*, In Press, Corrected Proof.
- [29] Dolédec, S. and Statzner, B. (2010), 'Responses of freshwater biota to human disturbances: Contribution of J-NABS to developments in ecological integrity assessments.', *Journal of the North American Benthological Society*, 29, 286-312.
- [30] Dukes, M. D. and Evans, R. O. (2006), 'Impact of Agriculture on Water Quality in the North Carolina Middle Coastal Plain', *Journal of Irrigation and Drainage Engineering*, 132 (3), 250-262.
- [31] Duran, M., Tüzen, M., and Kayım, M. (2003), 'Exploration of biological richness and water quality of stream Kelkit, Tokat-Turkey', *Fresenius Environmental Bulletin*, 12 (4), 368-375.

- [32] Dutka, B. J. (1979), 'Microbiological indicators, problems and potential of new microbial indicators of water quality', in A. James and L. Evison (eds.), *Biological Indicators of Water Quality* (Chichester: John Wiley & Sons), 1-24.
- [33] Earles, T. A., Lorenz, W. F., Koger, W. L., and Trujillo, M. Y. (2008), 'Nonpoint Source Phosphorus Trading in the Cherry Creek Reservoir Watershed in Colorado', *Journal of Irrigation and Drainage Engineering*, 134 (5), 589-597.
- [34] Ellis, S.G., Deshler, S.T., and Miller, R. (1997), 'Characterizing Fish Assemblages in the Willamette River, Oregon, Using Three Different Bioassessment Techniques', in A. Laenen and D. A. Dunnette (eds.), *River Quality: Dynamics and Restoration* (Florida: CRC Press), 347-364.
- [35] Espinosa-Villegas, C. O., Just, C. L., and Schnoor, J. L. (2005), 'Sustainable Watershed Management: Impacts of a 30-Year Historical Record of Water Quality of the Iowa River', in Glenn E. Moglen (ed.), (40763 edn., 178; Williamsburg, Virginia, USA: ASCE), 149-149.
- [36] Fulazzaky, M., Seong, T., and Masirin, M. (2010), 'Assessment of Water Quality Status for the Selangor River in Malaysia', *Water, Air, & Soil Pollution*, 205 (1), 63-77.
- [37] Galassi, S., Mingazzini, M., and Battagazzore, M. (1993), 'The use of biological methods for pesticide monitoring', *The Science of The Total Environment*, 132 (2-3), 399-414.
- [38] Gewurtz, S. B., Lazar, R., and Douglas, H. G. (2003), 'Biomonitoring of Bioavailable PAH and PCB Water Concentrations in the Detroit River Using the Freshwater Mussel, *Elliptio complanata*', *Journal of Great Lakes Research*, 29 (2), 242-255.
- [39] Ghani, P. H. A., Yusoff, M. K., Manaf, L. Abd., and Daud, M. B. (2009), 'Ammonium Ion Trend in Selected Malaysian River', *World Applied Sciences Journal*, 6 (3), 442-448.
- [40] Ghani, P.H.A. (2006), 'Water Resources at a Glance', in T.H.C. Patrick (ed.), *IMPAK - Laws to Protect River and Sea Pollution* (Putrajaya, Malaysia: Department of Environment, Ministry of Natural Resources and Environment).
- [41] Gilbert, E. A. (2010), 'Comparison of Water Quality Data to Determine Effects of Urbanization on the Flint River, Madison County, Alabama', in Richard N. Palmer (ed.), (41114 edn., 371; Providence, Rhode Island: ASCE), 3-3.
- [42] Gopinath, R. B. and Tamjis, M. R. (2008), 'Water Quality in Healthcare', *International Journal of Environmental Technology and Management*, 9 (1), 125 - 140.
- [43] Gurr, E. and Nnadi, F. (2009), 'Non-Point Source Nutrient Loading in an Urban Watershed', in Steve Starrett (ed.), (41036 edn., 342; Kansas City, Missouri: ASCE), 140-140.
- [44] Haase, C. S. and Blodgett, K. D. (2009), 'The Nature Conservancy's Mississippi River Program: Sustainable Conservation of a Working River that Works', in Steve Starrett (ed.), (41036 edn., 342; Kansas City, Missouri: ASCE), 610-610.
- [45] Haase, P., Lohse, S., Pauls, S., Schindehütte, K., Sundermann, A., Rolauuffs, P., and Hering, D. (2004), 'Assessing streams in Germany with benthic invertebrates: development of a practical standardised protocol for macroinvertebrate sampling and sorting', *Limnologica - Ecology and Management of Inland Waters*, 34 (4), 349-365.
- [46] Hathaway, J. M. and Hunt, W. F. (2010), 'Statistical Evaluation of Factors Affecting Indicator Bacteria in Urban Stormwater Runoff', *Journal of Environmental Engineering*.
- [47] Hawkes, H. A. (1979), 'Invertebrates as indicators of river water quality', in A. James and L. Evison (eds.), *Biological Indicators of Water Quality* (Chichester: John Wiley & Sons), 1-45.
- [48] He, H., Zhou, J., Wu, Y., Yu, Q., Zhang, W., and Xie, X. (2007), 'Estimating Water Quality Pollution Impacts Based on Economic Loss Models in Urbanization Process in Xi'an, China', *Journal of Urban Planning and Development*, 133 (3), 151-160.
- [49] Hellowell, J. M. (1986), *Biological indicators of freshwater pollution and environmental management* (Nature; Amsterdam: Elsevier).
- [50] Houston, L., Barbour, M. T., Lenat, D., and Penrose, D. (2002), 'A multi-agency comparison of aquatic macroinvertebrate-based stream bioassessment methodologies', *Ecological Indicators*, 1 (4), 279-292.
- [51] Idris, A., Mamun, A. A., Azmin, W. N. W., and Amin, M. S. M. (2003), 'Review of water quality standards and practices in Malaysia.', *Pollution Research*, 22 (2), 145-155.
- [52] Iliopoulou-Georgudaki, J., Kantzaris, V., Katharios, P., Kaspiris, P., Georgiadis, Th, and Montesantou, B. (2003), 'An application of different bioindicators for assessing water quality: a case study in the rivers Alfeios and Pineios (Peloponnisos, Greece)', *Ecological Indicators*, 2 (4), 345-360.

- [53]James, A. and Evison, L. (1979), *Biological Indicators of Water Quality*, eds A. James and L. Evison (Chichester: John Wiley and Sons).
- [54]Jennings, A. A. (2009), 'Zinc Pollution Potential of Consumer Battery Litter', *Journal of Environmental Engineering*, 135 (9), 815-823.
- [55]Jennings, A. A., Hise, S., Kiedrowski, B., and Krouse, C. (2009), 'Urban Battery Litter', *Journal of Environmental Engineering*, 135 (1), 46-57.
- [56]Johns, G. E. and Watkins, D. A. (1989), 'Regulation of Agricultural Drainage to San Joaquin River', *Journal of Irrigation and Drainage Engineering*, 115 (1), 29-41.
- [57]Karr, J. R. (1981), 'Assessment of biotic integrity using fish communities', *Fisheries*, 6, 21-27.
- [58]Karr, J. R. (1991), 'Biological Integrity: A Long-Neglected Aspect of Water Resource Management', *Ecological Applications*, Vol. 1 (No. 1), 66-84.
- [59]Karr, J. R. and Chu, E. W. (1999), *Restoring Life in Running Water Better Ecological Monitoring: Better Biological Monitoring* (Washington, D.C.: Island Press).
- [60]Karr, J. R. and Yoder, C. O. (2004), 'Biological Assessment and Criteria Improve Total Maximum Daily Load Decision Making', *Journal of Environmental Engineering*, 130 (6), 594-604.
- [61]Khan, I. S. A. N. (1990), 'Assessment of Water Pollution using Diatom Community Structure and Species Distribution — A Case Study in a Tropical River Basin', *Internationale Revue der gesamten Hydrobiologie und Hydrographie*, 75 (3), 317-338.
- [62]Khan, I. S. A. N. (1991), 'Effect of Urban and Industrial Wastes on Species Diversity of The Diatom Community in A Tropical River, Malaysia', *Hydrobiologia*, 224 (3), 175-184.
- [63]Latiff, Ab. A. Ab., Karim, A. T. Abd., Muhamad, A., Hashim, N. H., and Yung-Tse, H. (2009), 'Study of metal pollution in Sembrong River, Johor, Malaysia', *International Journal of Environmental Engineering*, 1 (4), 383 - 404.
- [64]Lawrence, R. J. (2003), 'Human ecology and its applications', *Landscape and Urban Planning*, 65 (1-2), 31-40.
- [65]Lee, M. S., Chen, T. Y., Kao, C. M., Hung, J. L., and Chen, C. Y. (2008), 'Development of Watershed Management Strategies for the Chiang-Chun River Basin, Taiwan', *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management*, 12 (1), 47-52.
- [66]Lee, Y. H., Lee, N. C., Robert, B. S., and Mani, O. (2006), 'The Water Quality of Several Oxbow Lakes in Sabah, Malaysia and its Relation to Fish Fauna Distribution', *Journal of Biological Sciences*, 6 (2), 365-369.
- [67]Lefkowitz, J., Westphal, K., Walker, J., and Mercer, G. (2009), 'The Economic and Environmental Significance of Nonpoint Source Abatement in Large Watersheds', in Steve Starrett (ed.), (41036 edn., 342; Kansas City, Missouri: ASCE), 257-257.
- [68]Leonardsson, K., Blomqvist, M., and Rosenberg, R. (2009), 'Theoretical and practical aspects on benthic quality assessment according to the EU-Water Framework Directive - Examples from Swedish waters', *Marine Pollution Bulletin*, 58 (9), 1286-1296.
- [69]Leung, P. S. K. and Sell, N. J. (1982), 'Effect of the paper industry on water quality of the lower fox river', *JAWRA Journal of the American Water Resources Association*, 18 (3), 495-502.
- [70]Lévêque, C. (1998), 'Biodiversity and management of inland aquatic ecosystems', *Revue des Sciences de l'Eau (Journal of Water Science)*, 11, 211-221.
- [71]Lockwood, A. P. M. (1979), 'The response of estuarine organism to changes in water quality', in A. James and L. Evison (eds.), *Biological Indicators of Water Quality* (Chichester: John Wiley & Sons), 1-40.
- [72]Longhurst, A. R. (1957), 'The Food of the Demersal Fish of a West African Estuary', *Journal of Animal Ecology*, 26 (2), 369-387
- [73]Lung, W. S. (1986), 'Assessing Phosphorus Control in the James River Basin', *Journal of Environmental Engineering*, 112 (1), 44-60.
- [74]Mamun, A. A., Alam, M. Z., Idris, A., and Sulaiman, W. N. A. (2009), 'Untreated Sullage From Residential Areas - A Challenge Against Inland Water Policy In Malaysia.', *Pollution Research*, 28 (2), 279-285.
- [75]Mangarillo, J. T., Rees, P. L. S., Westphal, K., and Walsh, T. (2005), 'Basin-Scale Methodology for Evaluating Relative Impacts of Pollution Source Abatement', in Glenn E. Moglen (ed.), (40763 edn., 178; Williamsburg, Virginia, USA: ASCE), 4-4.
- [76]Maznah, W. O. W. and Mansor, M. (2002), 'Aquatic pollution assessment based on attached diatom communities in the Pinang River Basin, Malaysia', *Hydrobiologia*, 487 (1), 229-241.
- [77]McLeod, S. M., Kells, J. A., and Putz, G. J. (2006), 'Urban Runoff Quality Characterization and Load Estimation in

- Saskatoon, Canada', *Journal of Environmental Engineering*, 132 (11), 1470-1481.
- [78] Meng, W., Zhang, N., Zhang, Y., and Zheng, B. (2009), 'Integrated assessment of river health based on water quality, aquatic life and physical habitat', *Journal of Environmental Sciences*, 21 (8), 1017-1027.
- [79] Metsäranta, N., Kotola, J., and Nurminen, J. (2005), 'Effects of urbanization on runoff water quantity and quality: Experiences from test catchments in Southern Finland', *International Journal of River Basin Management*, 3 (3), 229 - 234.
- [80] Meybeck, M., Kuusisto, E., Makela, A., and Malkki, E. (1996), 'Water Quality', in J. Bartman and R. Ballance (eds.), *Water Quality Monitoring: A practical guide to the design and implementation of freshwater quality studies and monitoring programmes* (London, UK.: E & FN Spon), 9-32.
- [81] Mol, A. (1980), 'The role of the invertebrate fauna in the biological assessment of water quality', *Aquatic Ecology*, 14 (3), 222-223.
- [82] Mustow, S. E. (2002), 'Biological monitoring of rivers in Thailand: use and adaptation of the BMWP score', *Hydrobiologia*, 479 (1), 191-229.
- [83] Nazahiyah, R., Yusop, Z., and Abustan, I. (2007), 'Stormwater quality and pollution loading from an urban residential catchment in Johor, Malaysia. ', *Water Science and Technology*, Volume 56 (Issue 7), 1-9.
- [84] Niemczynowicz, J. (1999), 'Urban hydrology and water management - present and future challenges', *Urban Water*, 1 (1), 1-14.
- [85] Parnrong, S. (2002), 'A review of Biological Assessment of Freshwater Water Ecosystems in Thailand', (Hat Yai, Thailand: Mekong River Commission – Environment Program).
- [86] Petersen, T. M., Rifai, H. S., Suarez, M. P., and Stein, A. R. (2005), 'Bacteria Loads from Point and Nonpoint Sources in an Urban Watershed', *Journal of Environmental Engineering*, 131 (10), 1414-1425.
- [87] Prince, D. R. H. (1979), 'Fish as indicators of river water quality', in A. James and L. Evison (eds.), *Biological Indicators of Water Quality* (Chichester: John Wiley & Sons), 1-23.
- [88] Principe, R. E and Corigliano, M. d. C. (2006), 'Benthic, drifting and marginal macroinvertebrate assemblages in a lowland river: temporal and spatial variations and size structure', *Hydrobiologia*, (553), 303–317.
- [89] Rainio, J. and Niemelä, J. (2003), 'Ground beetles (Coleoptera: Carabidae) as bioindicators', *Biodiversity and Conservation*, 12 (3), 487-506.
- [90] Resh, V. H., Carter, J. L., Myers, M. J., and Hannaford, M. J. (1996), 'Macroinvertebrates as biotic indicators of environmental quality', in F. R. Hauer and G. A. Lamberti (eds.), *Methods in Stream Ecology* (San Diego, CA: Academic Press).
- [91] Rosenberg, D. M. and Resh, V. H. (1992), *Freshwater Biomonitoring and Benthic Macroinvertebrates*, eds D. M. Rosenberg and V. H. Resh (New York, NY: Chapman & Hall).
- [92] Salim, N. A. A., Wood, A. K., Yusof, A. M., Hamzah, M. S., Elias, M. S., and Rahman, S. A. (2009), 'A study of arsenic and chromium contamination in sediments of freshwater bodies', *Fresenius Environmental Bulletin*, 18 (9), 1618-1623.
- [93] Salmah, Md. R. C., Tribuana, S. W., and Hassan, A. A. (2006), 'The population of Odonata (dragonflies) in small tropical rivers with reference to asynchronous growth patterns', *Aquatic Insects: International Journal of Freshwater Entomology*, 28 (3), 195 - 209.
- [94] Sanchez, W. and Porcher, Jean-Marc (2009), 'Fish biomarkers for environmental monitoring within the Water Framework Directive of the European Union', *TrAC Trends in Analytical Chemistry*, 28 (2), 150-158.
- [95] Sarmani, S. B. (1989), 'The determination of heavy metals in water, suspended materials and sediments from Langat River, Malaysia', *Hydrobiologia*, 176-177 (1), 233-238.
- [96] Shamsudin, L. (1999), 'The Blue Green Algal Bloom in the Nearshore Waters of Cukai Bay Facing the South China Sea', *Environmental Monitoring and Assessment*, 59 (2), 123-134.
- [97] Shubina, V. (2006), 'Caddis flies (Trichoptera) in the benthos and food of fish from streams of the Pechora-Ilych State Biosphere Reserve, the northern Urals', *Russian Journal of Ecology*, 37 (5), 352-358.
- [98] Silverman, G. S. and Silverman, M. K. (2000), 'Research Article: Perceptions of Environmental Problems by Malaysian Professionals', *Environmental Practice*, 2 (04), 299-310.
- [99] SladéCék, V. (1979), 'Continental Systems for the Assessment of River Water Quality', in A. James and L. Evison (eds.), *Biological Indicators of Water Quality* (Chichester, Great Britain: John Wiley and Sons), 1-33.
- [100] Slooff, W. and Zwart, D. (1983), 'Bio-indicators and chemical pollution of surface waters', *Environmental Monitoring and Assessment*, 3 (3), 237-245.

- [101] Sommaggio, D. (1999), 'Syrphidae: can they be used as environmental bioindicators?', *Agriculture, Ecosystems & Environment*, 74 (1-3), 343-356.
- [102] Star, I. (2003), 'Checking Troubled Water', *The Star Online* (18 Feb 2003)
- [103] Strobl, R. O. and Robillard, P. D. (2008), 'Network design for water quality monitoring of surface freshwaters: A review', *Journal of Environmental Management*, 87 (4), 639-648.
- [104] Suratman, S., Awang, M., Loh, A. L., and Tahir, N. M. (2009), 'Water Quality Index Study in Paka River Basin, Terengganu', *Sains Malaysiana*, 38 (2), 125-131.
- [105] Tittizer, T. and Kothe, P. (1979), 'Possibilities and Limitations of Biological Methods of Water Analysis', in A. James and L. Evison (eds.), *Biological Indicators of Water Quality* (Chichester, Great Britain: John Wiley and Sons), 1-21.
- [106] Tolkamp, H. and Gardeniers, J. (1988), 'The development of biological water quality assessment in The Netherlands', *Aquatic Ecology*, 22 (1), 87-91.
- [107] USEPA, United States Environmental Protection Agency (1991), 'Biological Criteria: State Development and Implementation Efforts', (Washington, D. C.: U. S. Environmental Protection Agency, Office of Water Regulations and Standards).
- [108] Vemula, V. R. S., Mujumdar, P. P., and Ghosh, S. (2004), 'Risk Evaluation in Water Quality Management of a River System', *Journal of Water Resources Planning and Management*, 130 (5), 411-423.
- [109] Viswanathan, S., Voss, K. A., Pohlman, A., Gibson, D., and Purohit, J. (2010), 'Evaluation of the Biocriteria of Streams in the San Diego Hydrologic Region', *Journal of Environmental Engineering*, 136 (6), 627-637.
- [110] Weber, D., Sturm, T. W., and Warner, R. (2004), 'Impact of Urbanization on Sediment Budget of Peachtree Creek', in Gerald Sehlke, Donald F. Hayes, and David K. Stevens (eds.), (40737 edn., 138; Salt Lake City, Utah, USA: ASCE), 430-430.
- [111] Weng, C. N. (2005), 'Sustainable management of rivers in Malaysia: Involving all stakeholders', *International Journal of River Basin Management*, 3 (3), 147 - 162.
- [112] Willardson, L. S. (1985), 'Basin-Wide Impacts of Irrigation Efficiency', *Journal of Irrigation and Drainage Engineering*, 111 (3), 241-246.
- [113] Wong, P. T. S. and Dixon, D. G. (1995), 'Bioassessment of water quality', *Environmental Toxicology and Water Quality*, 10 (1), 9-17.
- [114] Wu, H. C., Chen, P. C., and Tsay, T. T. (2010), 'Assessment of nematode community structure as a bioindicator in river monitoring', *Environmental Pollution*, 158 (5), 1741-1747.
- [115] Yap, S. Y. (1997), 'Classification of a Malaysian river using biological indices: a preliminary attempt', *The Environmentalist*, 17 (2), 79-86.
- [116] Yule, C. M. and Sen, Y. H. (2004), *Freshwater Invertebrates of the Malaysia Region*, eds C. M. Yule and Y. H. Sen (Kuala Lumpur, Malaysia: Academy of Sciences Malaysia).
- [117] Yunus, A. and Nakagoshi, N. (2004), 'Effects of seasonality on streamflow and water quality of the Pinang River in Penang Island, Malaysia', *Chinese Geographical Science*, 14 (2), 153-161.
- [118] Yusof, A., Salleh, S., and Wood, A. (1999), 'Speciation of inorganic arsenic and selenium in leachates from landfills in relation to water quality assessment', *Biological Trace Element Research*, 71-72 (1), 139-148.
- [119] Yusop, Z., Tan, L. W., Ujang, Z., Mohamed, M., and Nasir, K. A. (2005), 'Runoff Quality and Pollution Loadings from A Tropical Urban Catchment', *Water science and technology*, vol. 52 (9), 125-132

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