DEVELOPMENT OF MALAYSIAN WATER QUALITY INDICES USING AQUATIC MACROINVERTEBRATES POPULATION OF PAHANG RIVER BASIN, PAHANG, MALAYSIA

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By

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LIST OF ABBREVIATION AND SYMBOLS

asl	=	Above Sea Level
BOD	=	Biological Oxygen Demand
CCA	=	Canonical Correspondence Analysis
COD	=	Chemical Oxygen Demand
DOE	=	Department of Environment
l	=	Liter
m	=	Meter
ms^{-1}	=	meter per second
mg	=	Milligram
mg/L	=	milligram per liter
NH_4-N	=	Ammonium-nitrogen
ppm	=	Part per million
SE	=	Standard Error
SPSS	=	Statistical Package for Social Science
TDS	=	Total Dissolve Solid
TSS	=	Total Suspended Solid
µm	=	Micrometer
ρ	=	Spearman’s Correlation Coefficient

PEMBANGUNAN INDEKS KUALITI AIR MALAYSIA MENGGUNAKAN POPULASI MAKROINVERTEBRATA AKUATIK LEMBANGAN SUNGAI PAHANG, PAHANG, MALAYSIA

ABSTRAK

Di dalam kajian ini, satu data makroinvertebrata dan parameter air yang besar telah dikumpulkan dari 50 cabang sungai di Lembangan Sungai Pahang (PRB). Pada mulanya, prestasi tiga penyampel; jaring berbingkai D dan segi empat sama dan penyampel Surber, telah diuji untuk mengumpulkan makroinvertebrata akuatik di tiga sungai. Variasi Relatif (RV) makroinvertebrata yang rendah telah dikumpulkan oleh jaring segi empat sama di dua sungai (15% and 19%), dan ini menunjukkan kecekapan yang tertinggi berbanding penyampel yang lain. Walaupun jaring segi empat sama memerlukan masa yang lebih lama untuk memproses setiap sampel (18.31 min), ia mencatatkan kepelbagaian makroinvertebrata yang paling tinggi ($Alpha_{purata}$ = 13.5). Oleh sebab itu, jaring segi empat sama telah dipilih untuk mengumpul data makroinvertebrata untuk perbandingan prestasi indeks biotik dan menerbitkan nilai toleransi (TV) makroinvertebrata tersebut. Sebelas indeks biotik telah dipilih untuk dibandingkan prestasi mereka; Indeks Biotik Famili (FBI), Pemantauan Biologi Parti Kerja (BMWP), BMWP-Thai, BMWP-Viet, Purata Skor Per Takson (ASPT), ASPT-Thai, ASPT-Viet, HKHBios, Sistem Pemarkahan Afrika Selatan Versi 5 (SASS5), Indeks SingScore dan Indeks EPT. Kepelbagaian dan kelimpahan makroinvertebrata dan seterusnya prestasi indeks biotik didapati tidak dipengaruhi oleh musim hujan dan kering (Mann-Whitney, $P > 0.05$). Diantara semua indeks, FBI dan semua indeks BMWP cenderung untuk mengklasifikasikan kebanyakan sungai mempunyai kualiti air yang lebih baik, ASPT-Thai dan ASPT-

Viet pula sederhana manakala SingScore dan EPT menunjukkan kebanyakan sungai sebagai tercemar. Didapati bahawa semua kategori kualiti air yang telah ditentukan oleh indeks biotik yang dilaraskan menggunakan WQI sebagai rujukan menunjukkan kebolehtahanan makroinvertebrata terhadap bahan-bahan pencemar. Semua indeks BMWP dan SASS5 dipengaruhi secara positif oleh pelbagai tahap DO dan pH pada musim kering dan COD di musim hujan seterusnya membuktikan kebolehpercayaan indeks-indeks ini untuk penilaian kualiti air. Di antara indeks ini, BMWP-Viet dikenalpasti sebagai indeks yang paling sesuai kerana persamaan rapat antara faunanya dengan taksa di Malaysia. TV untuk makroinvertebrata akuatik Malaysia dianggarkan dengan mengira purata berwajaran kelimpahan makroinvertebrata yang menunjukkan respon kepada NH_4-N and pH, iaitu parameter air yang paling penting untuk sungai-sungai Malaysia (dikenalpasti melalui analisis pemilihan kehadapan). TV untuk kedua-dua parameter ini dipuratakan untuk mendapat nilai tunggal akhir untuk setiap taksa (genus atau famili). Nilai-nilai ini didalam lingkungan 0 (berdayatahan) ke 10 (sensitif) dan dinamakan Nilai Toleransi Malaysia (MTV). MTV ini telah digunakan untuk menghasilkan Indeks Biotik Malaysia (MBI) dan Indeks Biotik Famili Malaysia (MFBI) dengan membahagikan jumlah terkumpul produk nilai toleransi (TV) bagi setiap takson, didarabkan dengan bilangan individu dan dibahagikan pula dengan jumlah individu di dalam sampel. Oleh kerana MBI dan MFBI tidak berbeza secara statistik (Mann-Whitney, $P > 0.05$), analisis kluster telah digunakan untuk menetapkan lima kelas kualiti air MFBI, iaitu kualiti air yang sangat baik (> 5.9), baik (4.5 – 5.8), sederhana (3.8 – 4.4), tercemar (2.7 – 3.7) dan sangat tercemar (<2.7). Sempadan kelas-kelas ini telah ditentukan dengan menggunakan analisis plot kotak. Skor MFBI dipengaruhi secara positif oleh DO, dan secara negatif oleh NH_4-N, BOD, TN dan Pb, yang mengesahkan kebolehpercayaan mereka. Kesimpulannya, MFBI adalah lebih baik daripada BMWP-My (BMWP-My dikira dengan menggunakan MTV), BMWP dan WQI. Berdasarkan kedapatan kajian ini, MFBI adalah indeks yang paling sesuai untuk digunakan di dalam penilaian air sungai di Malaysia bersama-sama dengan WQI.

DEVELOPMENT OF MALAYSIAN WATER QUALITY INDICES USING AQUATIC MACROINVERTEBRATES POPULATION OF PAHANG RIVER BASIN, PAHANG, MALAYSIA

ABSTRACT

In this study, a large macroinvertebrates and water parameters data were collected from fifty Pahang River Basin (PRB) tributaries. Initially, the efficiency of three samplers; D-frame and square nets and Surber sampler, for collections of aquatic macroinvertebrates were tested in three rivers. Low relative variation (RV) of macroinvertebrates collected by square net in two rivers (15% and 19%, respectively) indicated its highest efficiency among the samplers. Although the square net required a longer time to process each sample (18.31 min) it recorded the highest macroinvertebrate diversities ($Alpha_{average}$ = 13.5). Consequently, the square net was selected to collect macroinvertebrates for comparison of biotic index performances and the derivation of their tolerance values (TVs). Eleven biotic indices were chosen; Family Biotic Index (FBI), Biological Monitoring Working Party (BMWP), BMWP-Thai, BMWP-Viet, Average Score Per Taxon (ASPT), ASPT-Thai, ASPT-Viet, HKHBios, South African Scoring System version 5 (SASS5), SingScore and EPT Index and their performances were compared. Distribution and abundance of macroinvertebrates and hence the performance of biotic indices were not influenced by Malaysian wet and dry seasons (Mann-Whitney, $P>0.05$). Among the indices, FBI and all BMWPs tended to classify most of the rivers into better water quality, ASPT-Thai and ASPT-Viet moderately polluted while the SingScore and EPT showed most rivers had been polluted. Using WQI as a reference, it was found that adjusted water quality categories of all biotic

indices paralleled the tolerance of macroinvertebrates to pollutants. All BMWP indices and SASS5 were positively influenced by varied levels of DO and pH in dry season and COD in wet season which justified their reliability for water quality assessment. Among these indices, BMWP-Viet was identified as the most suitable due to close similarity of its macroinvertebrate fauna to Malaysian taxa. The TVs of Malaysian aquatic macroinvertebrates were estimated by computing the weighted average of macroinvertebrate abundance that responded towards NH_4-N and pH, the most important water parameters in Malaysian rivers (identified through forward selection). The TVs of these two stressors were averaged to finally obtain single TV for each taxon (genus or family). The values ranged from 0 (tolerant) to 10 (sensitive) and named as Malaysian Tolerance Value (MTV). These MTVs were used to derive the Malaysian Biotic Index (MBI) and Malaysian Family Biotic Index (MFBI) by dividing the cumulative sum of products of tolerance value (TV) of each taxon multiplied by its number of individual with the total individuals in the sample. Since the performances of the MBI and MFBI were not statistically different (Mann-Whitney, $P>0.05$), the cluster analysis was used to assign MFBI scores into 5 water quality classes, very good (> 5.9), good (4.5 – 5.8), moderate (3.8 – 4.4), bad (2.7 – 3.7) and poor (< 2.7) water quality. Their boundaries were separated using box plot analysis. The MFBI scores were positively influenced by DO, and negatively by NH_4-N, BOD, TN and Pb, which validated their reliability. Accordingly, the MFBI performed better than BMWP-My (BMWP-My calculated using MTV), BMWP and WQI. Based on the findings of this study, the MFBI was the most suitable index to be adopted in Malaysian river water assessment along with the WQI.

CHAPTER 1:

GENERAL INTRODUCTION

1.1 Background

The biodiversity of macroinvertebrates in the aquatic ecosystems including those in South East Asia is highly threatened by numerous factors related to human activities and anthropogenic disturbances. Human disturbance of the rivers in the tropics is pervasive resulting into irreversible changes in the ecosystems (Martin *et al*., 2000). Thus, hydrological changes, water pollution and habitat alterations will eventually influence the aquatic diversity and taxonomic composition (Verdonschot, 2000). For this matter, understanding the response of aquatic communities towards pollution is vital for biomonitoring programs, which may help in bioassessment of water quality (Cao *et al*., 1996).

In aquatic macroinvertebrates study, reliability of the collected data depends on the selection of the sampling protocol which is very crucial (Barbour *et al.*, 1999). Many researchers agreed that the most practical and feasible technique used to sample macroinvertebrate is by using a hand net (Chutter, 1972; Armitage, 1983; Mustow, 2002; Hoang, 2009; Ogleni and Topal, 2011). Accordingly, field scientists designed several qualitative and quantitative net-based sampling gears to collect benthic invertebrates (Merritt *et al.*, 2008). In spite of their availability, many macroinvertebrates samplers are not readily and effectively used in all types of habitats. For example, the commonly used Surber sampler (Surber, 1937) is only suitable for collection in rivers with small substrates such as cobbles or gravel. However, the application of this sampler in areas with big boulder is less suitable (Al-Shami *et al*, 2013). In Malaysia, selected sampling protocol and sampling gear has to be practical and suitable (Merritt *et al*., 2008) for sampling at various habitats of wadeable water bodies because many popular study areas have wide variety of habitats such as lake, forested streams and urban rivers. Reliable data determine the usefulness and meaningful research findings.

Since the initiation of the biotic index more than a century ago by Kolenati (1848) (De Pauw and Vanhooren, 1983), several biotic indices were developed in Europe and subsequently practiced in the United States of America for water assessment and monitoring river pollution (Ogleni and Topal, 2011). Since then, biological water quality assessment received considerable attention from scientists around the world especially in the half of the last century (Hawkes, 1997). Many countries have adopted biological assessment technique as a common method for river biomonitoring (Armitage *et al*., 1983; Cao *et al*., 1996). Meanwhile according to Bonada et al. (2006), an ideal biomonitoring tool uses a simple sampling protocol, is relatively cheap to sample, to sort and to identify the collected organisms, has large-scale applicability, has good potential to assess ecological functions and to discriminate different types of human impact and finally it is able to produce a reliable indication of changes in overall human impact.

The use of macroinvertebrate indicators provide a better yet simple approach of assessing water quality (De Pauw and Vanhooren, 1983, Hilsenhoff, 1988; Chutter, 1972; Henne et al., 2002; Chessman and McEnvoy, 1988) with large-scale applicability (Bonada *et al*., 2006). As a result, established biotic indices are applicable in rivers of many countries with or without modification of the indices (Alba-Tercedor and Sanchez-Ortega, 1988; Zamora-Muñoz *et al*., 1995; Henne *et al*., 2002). Several indices have been improved or adopted for use in countries other than the places of their developments. Among these indices, South African Scoring

System (SASS5) has been refined from highly successful earlier version of SASS (Dickens and Graham, 2002). Nepalese Biotic Score (Sharma and Moog, 1996) is an adaptation from BMWP/ASPT system. Similarly, BMWP-Thai (Mustow, 2002) and BMWP-Viet (Hoang, 2009) are adopted from Biological Monitoring Working Party (BMWP) (Armitage *et al*., 1983).

However, the increase in biotic indices in river biomonitoring triggers the question about the efficiency of the biotic indices in evaluating the water quality in foreign regions or countries. The most frequent criticisms on the use of biotic indices in river bioassessment are the variations of the macroinvertebrate communities among rivers, river basins and eco-regions. This factor is compounded by temporal variation which made the assessment by these indices less accurate at areas away from the places of their origin (Leunda *et al*. 2009). Consequently, many available literatures focus on comparing the performances of various biotic indices at many places (Semenchenko and Moroz, 2005; Ravera, 2001). However, up to this point, the comparison of the biotic indices was done either using few indices or in small localities. For example, Ravera (2001) compared the performance of the several diversity indices, one similarity index and two biotic indices in a small stream.

Most living aquatic organisms are sensitive and actively respond towards the changes in water quality or disturbances of their habitats. This important criterion has been recognized and many studies of using macroinvertebrates to assess the water quality are based on the degree of their responses towards pollutants in the water known as their tolerance values (Chutter, 1972; Hilsenhoff, 1987; Hilsenhoff, 1988; Armitage *et al*., 1983; De Pauw and Vanhooren, 1983; Lang *et al*., 1989; Lang and Reymond, 1995; Mustow, 1997; Hoang, 2009; Blakely and Harding, 2010). Tolerance values of aquatic taxa are widely used to estimate the score biotic indices because they are able to represents the actual condition of the river (Cao *et al*., 1996; Blakely and Harding, 2010). Meanwhile, other indices such as diversity indices and multivariate analyses are also useful for water quality assessment (Wright *et al*. 1998; Smith *et al*., 1999).

In Malaysia, the using macroinvertebrates as water quality indicators of pollution is yet to be applied by the river managers, mainly due to lack of suitable biotic indices for Malaysian rivers since the available indices was never been compared for their reliability. Nevertheless some Malaysian scientists had adopted water quality assessment using aquatic macroinvertebrates in assessing river health (Azrina *et al*., 2006; Yap *et al*., 2006; Nor Azwady *et al*., 2010; Wahizatul *et al*., 2011; Aweng *et al*., 2012) although all of these studies were conducted at small scales in scattered rivers in Malaysia. As one of the mega biodiversity countries in the world (MNRE, 2006), Malaysia has rich flora and fauna including the fauna of aquatic macroinvertebrates. The Malaysian aquatic macroinvertebrates taxa are unique and different especially in comparison with the taxa in temprate countries (Yule and Yong, 2004). Unfortunately, this high diversity of aquatic macroinvertebrates was not wisely utilized and incorporated in the river biomonitoring program. The Malaysian river authorities such as Department of Irrigation and Drainage (DID) depends on the chemical water analysis (WQI) since the 1980s (Zaki, 2010) and the biological aspects of water quality are often received little consideration in their river water quality research (Arsad *et al*., 2012). In Malaysia, there were studies on aquatic macroinvertebrates, but most of the researchers concentrate on the diversity and abundance of benthic fauna that occur in polluted rivers (Suhaila *et al*., 2011; Che Salmah *et al*., 2012). Although there were researches by local scientists to utilized the aquatic macroinvertebrates for river assessment and have applied many of the biotic indices such as FBI and BMWP (Azrina *et al*., 2006; Wahizatul *et al*., 2011), adopting biological indices developed in temperate countries for water quality assessment in Malaysia would be less accurate (Leunda *et al*. 2009) and thus requires some modification (Armitage *et al*., 1983; Hilsenhoff, 1988) as being practiced in Thailand (Mustow, 2002) and Vietnam (Hoang, 2010). Considering the facts that there is lacking of research on the use of biotic indices in Malaysian rivers monitoring program, using macroinvertebrate data, this study was carried out with several objectives.

1.2 Objectives of the study

1. To determine the most suitable sampling gear to be used for aquatic macroinvertebrates sampling for water quality assessment of Malaysian rivers.

2. To compare the performances of various biological indices for water quality assessment using aquatic macroinvertebrates in Malaysian rivers.

3. To determine the tolerance values for Malaysian aquatic macroinvertebrates. The tolerance values would be used in constructing the Malaysian Biotic Index (MBI) and Malaysian Family Biotic Index (MFBI)

4. To categorize the water quality of rivers based on Malaysian Biotic Index (MBI) and Malaysian Family Biotic Index (MFBI) and to validate the performance of both indices.

CHAPTER 2:

LITERATURE REVIEW

2.1 River water quality, problems and solutions

River water is regarded as the most essential natural resources worldwide and provides most of the water for human activities. For this reason, most of the human populations were established close to the rivers. Over 50% of world's population living with in 3 km from the freshwater river with population in Australia, Asia and Europe live closest to the rivers (Kummu *et al*., 2011) due to the needs of water resources. However, the establishment of human population near the freshwater body directly threatening the health of the rivers by their activities and the rivers are tend to be further affected by the anthropogenic impairments (Vörösmarty *et al*., 2010). Furthermore, the rivers are transformed through urbanization, industrialization and altered through the building of reservoirs for irrigation, dams for hydroelectric generation and interbasin transfers that maximize human access to water. These activities exposed the river systems to the pollution and unhealthy condition.

Today, the numbers of undisturbed and unpolluted rivers are decreasing rapidly, corresponding to rapid development of human community near the rivers (Niemczynowicz, 1999). This situation is considered by many researchers as the main ecological problem in many developed and developing countries in the world, including Malaysia (Silverman and Silverman, 2000). This is the main reason for the development in water quality research which inlcuded physical, chemical and biological aspects of water quality (Arsad *et al*., 2012). In the last decades, river health monitoring followed traditional approaches using predetermined chemical parameters and methodology that allowed for proper investigation of contamination sources (Debels *et al*., 2005). The technique has lead to the development of the index for river quality assessment in many countries after the first proposed water quality index (WQI) (Horton, 1965). However, using the WQI alone to assess water quality in the river has many limitations. For instance, this approach is not able to reveal the source of pollution where the source is readily discharging pollutants (Bonada *et al*., 2006).

The biomonitoring approach of river health assessment started centuries ago when Aristotle placed freshwater fish into seawater to observe their reaction (Rosenberg, 1998). More than a century ago, Kolenati (1848) and Cohn (1853) (De Pauw and Vanhooren, 1983) paid serious attention on this aspect of river assessment. Since then, more than 50 different methods for biological water quality assessment were established by scientist around the world (De Pauw and Vanhooren, 1983). These methods were developed differently to fit ecological conditions of the rivers in the temperate and tropical regions although some methods were modified for applicability in other regions. Although the biomonitoring programs were developed independently, they shared some similarities such as rapid turnaround of results, wide regional coverage and easily interpreted outputs of practical use for managers (Norris, 1995).

2.2 History of Rivers and Water Quality Management in Malaysia

Malaysia is drained by a dense network of rivers and streams with approximately 74 rivers basin located in Peninsular Malaysia, while 100 others are situated in East Malaysia (Sabah and Sarawak). Overall, there are 189 river basins in Malaysia of which 150 are main river basins. In Peninsular Malaysia, the longest Pahang River follows a course of 434 km before reaching the South China Sea. It drains a catchment area of 29 000 km² in Pahang State which is the largest river basin in Malaysia Peninsula. Other major rivers that also drain into the South China Sea are the Kelantan, Terengganu, Dungun, Endau and Sedili rivers. In East Malaysia, the longest river is the Rajang River (563 km) in Sarawak. In east Malaysia rivers basins are larger than those in peninsula Malaysia.

Status of water quality of Malaysian rivers started to capture attention of Malaysian authorities since 1970s with the establishment of the Environment Division under the Ministry of Local Government and Environment on 15 April 1975 (later was placed under the Ministry of Science, Technology and Environment in March 1976). Based on the importance of environmental protection and conservation including the water and irrigation systems in Malaysia, the Environment Division has been upgraded to the Department of Environment (DOE) on 1 September 1983 (JAS, 1995). The main function of the department is to control the water pollution and to enforce compliance with effluent standards for point sources pollution consistent with the purposes of the Environmental Quality Act 1974 (the regulation of pollution) (JAS, 1995). However, besides the DOE, the responsibility for water resources planning and development is shared by various government agencies. The Department of Irrigation and Drainage (DID) is responsible for planning, implementing and operation of irrigation, drainage and flood control projects throughout the country. The Department of Agriculture (DOA) offers advice and extension services to the farmers and the Ministry of Health (MOH) provides untreated but drinkable water to rural communities which is not served by the local water authorities. The MOH also monitors water quality at water treatment plant intakes as well as the quality of water within the distribution system for compliance with national drinking water standards. Although many legislations in the country touch on water resources, most of the existing laws are considered outdated. The Water Act of 1920 is inadequate for dealing with the current complex issues related to water abstraction, pollution and river basin management.

2.3 River Water Quality Monitoring in Malaysia

Similar to many other developing countries, Malaysia is experiencing increasing deterioration in river water quality. According to Munirah *et al*. (2011), major river pollution is coming from industrial effluent, anthropogenic waste, land clearance including logging activities, domestic sewage disposal and animal farming activities. Furthermore, the increasing population in Malaysia from 10 million in 1970s to 29 million in 2010 (DSM, 2016) is the major factor of land use changes that affect the water quality status in Malaysian rivers (Juahir *et al*., 2009). Out of189 river basins, 74 river basins are in Peninsular Malaysia, while 115 basins are in East Malaysia (75 in Sarawak and 40 in Sabah). According to DOE (2011), only 143 of these river basins are monitored and among 1064 monitoring stations, 638 (60%) were clean, 376 (35%) slightly polluted and 50 (5%) polluted (DOE, 2007).

Two agencies that are responsible for river management and water quality monitoring in Malaysia are the Department of Environment Malaysia (DOE) and Department of Irrigation and Drainage (DID). Dealing mainly with river management and monitoring source of river pollution, the agencies were provided with statutory called Environmental Quality Act (EQA) 1974. Under this act, those who are found guilty of polluting rivers in Malaysia are liable to a fine not exceeding RM 500 000 or imprison for not exceeding five years or both (EQA, 1974). Nevertheless, some agencies at the state level are responsible for river management in agriculture irrigation, such as Muda Agriculture Development Authority (MADA) in Kedah and Kemubu Agriculture Development Authority (KADA) in Kelantan.

Two primary methods are commonly used to classify the river water condition in Malaysia. They are the Water Quality Index (WQI) and the Interim National Water Quality Standards (INWQS), which are derived through measurements of physico-chemical parameters of the water. The WQI as well as the INWQS are developed based on the beneficial uses of water for human consumption (Zaki, 2010). In 1985, the Malaysian government realized the need to develop a standard to classify the rivers water according to its qualities. The government undertook a national study that involved a multidisciplinary team of researchers from several universities throughout the countries. The study was dubbed as the 'Development of Water Quality Criteria and Standards for Malaysia', focused on domestic water supply, livestock drinking, recreation, fisheries and aquatic propagation and agriculture uses (DOE, 1985). One hundred and 20 physico-chemical and biological parameters were reviewed by the research panels. Finally, INWQS was drafted (DOE, 1985) and river water was classified into six categories (Table 2.1).

Table 2.1: Classification of river water by INWQS based on suitability for human consumption

Class	Definition
I	➢ Conservation of natural environment ➢ Water Supply I – Practically no treatment necessary (except by disinfection or boiling only) ➢ Fishery I – Very sensitive aquatic species
IIA	➢ Water supply II – Conventional treatment required ➢ Fishery II – Sensitive aquatic species
IIB	➢ Recreational use with body contact
III	➢ Water supply III – Extensive treatment required ➢ Fishery III – Common of economic value, tolerant species, livestock drinking
IV	➢ Irrigation
V	➢ None of above

The data used for water monitoring were considered extensive and the physico-chemical parameters listed in INWQS were designed to be a benchmark for water-quality monitoring by the Malaysian authority. Later, a simplified indexing system coherent to parameters listed in INWQS was introduced (Zaki, 2010). It was called Water Quality Index (WQI) that was used by Malaysian authorities to analyze trends in water quality of Malaysian rivers. The purpose of the WQI is to summarize large river water quality data into a simple calculation useful for river classifications.

In comparison to INWQS, WQI only used six parameters; dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammoniacal-nitrogen (NH_3-N) and pH for its calculation (Table 2.2). The WQI adopted a simplified formula where the parameters and the weightage to each parameter were determined by a panel of experts using the data from INWQS (DOE, 1985).

Table 2.2: Water Quality Index (WQI) classification

Parameters	Unit	Classes				
		I	II	III	IV	V
NH_{4-}	mg/L	< 0.1	0.1 – 0.3	0.3 – 0.9	0.9 – 2.7	> 2.7
BOD_5	mg/L	< 1	1 – 3	3 – 6	6 – 12	> 12
COD	mg/L	< 10	10 – 25	25 – 50	50 – 100	> 100
DO	mg/L	> 7	5 – 7	3 – 5	1 – 3	< 1
pH	mg/L	> 7	6 – 7	5 – 6	<5	> 5
TSS	mg/L	< 25	25 – 50	50 – 150	150 – 300	> 300
WQI	mg/L	> 92.7	76.5 – 92.7	51.9 – 76.5	31.0 – 51.9	< 31.0

The Department of Environment, DOE published Environmental Quality Report (EQR) annually that is required under Section 3(1)(i) of the Environmental Quality Act 1974, to report the environmental status of air quality, river water quality, groundwater quality, marine and island marine water quality and pollution sources inventory. In assessing the status of rivers and streams water quality, the DOE uses the WQI where the calculation of the index not on the parameters itself but on their sub-indices. The rivers and streams water quality are finally classified into their specific classes, as shown in Table 2.3.

Table 2.3: DOE water quality classification based on Water Quality Index (WQI) (Zaki, 2010).

Parameters	Index range		
	Clean	Slightly Polluted	Polluted
Sub-index BOD	91 – 100	80 – 90	0 – 79
Sub-index NH_3-N	92 – 100	71 – 91	0 – 70
Sub-Index TSS	76 – 100	70 – 75	0 – 69
WQI	81 – 100	60 – 80	0 – 59

Although the WQI is widely used by the DOE to monitor the water quality status of rivers and streams in Malaysia, there are limitations of the index that lead to imprecise information of the water quality status (Zaki, 2010). Firstly, WQI is based on a pre-identified set of water quality constituents. During the water quality assessment, a particular station may record a good WQI score and thus considered as having clean water. However, the pollution at the station could be caused by other parameters that were not considered by the index. For example, the WQI does not consider the aquatic microorganism indicator such as coliform bacteria or heavy metal, which are usually detected in polluted water. Secondly, the WQI is generally used to describe water quality condition at specific location and time. As a result, the index only determines the short-term water quality problem.

Despite the limitation of the WQI, the water monitoring by Malaysian government authorities is commendable. Both the INWQS and WQI are good water quality benchmarking tools. Nevertheless, the problem occurs when the WQI registers a good water quality status for river impaired by parameters measured by the WQI. This may lead to improper decision by the authorities responsible for river water assessment.

2.4 Biological water monitoring study of water quality in Malaysia

Conceptually, biological monitoring of environment is a systematic method of collecting information about the status of environment using physico-chemical and biological methods (Sharma and Sharma, 2010) of an ecosystem. A river biological monitoring (biomonitoring) is comprehensive methodological approaches to evaluate the quality of river ecosystems because it provides actual state and rate of change of the ecosystems (Rosenberg and Resh, 1993). According to Li *et al*. (2010), the use of physico-chemical and biological data in the river assessment, form the basis of monitoring because they provide the complete spectrum of data for proper management of the river.

In Malaysia, river pollution was mostly caused by human disturbances through land conversion for agriculture (Al-Shami *et al*., 2006; Che Salmah *et al*., 2012; Mercer *et al*., 2013), anthropogenic activities and urbanization (Azrina *et al*., 2006; Al-Shami *et al*., 2011; Faridah *et al*., 2012) and logging and deforestation (Aweng *et al*., 2011; Che Salmah *et al*., 2014) near the rivers. Although the WQI has long been used to evaluate the water quality of polluted rivers, there are indication of growing interest among the environmental researchers to use the biological monitoring technique for river (Che Salmah *et al*., 1999) and lakes assessments (Shuhaimi-Othman *et al*., 2007). The aquatic organisms useful for river bioassessment in Malaysia were algae (Wan Maznah, 2010), fish (Taweel *et al*., 2013) and benthic invertebrates (Che Salmah *et al*., 2012). However, a more popular indicator for river biomonitoring in Malaysia was aquatic macroinvertebrates (Suhaila and Che Salmah, 2011; Suhaila *et al*., 2011; Aweng *et al*., 2012; Che Salmah *et al*., 2012; Suhaila *et al*., 2013; Ahmad *et al*., 2013). The macroinvertebrates was also widely used for biomonitoring across the region, where 60% of the developed biotic indices within the past 10 years were based on the aquatic macroinvertebrates (Uherek *et al*., 2014). This is due to the their wide ranges of adaptation (Odum, 1963) and sensitivity towards the stresses produced by pollutants (Uherek *et al*., 2014).

Although, the implementation of a biological water quality assessment is still in its juvenile stage (Arsad *et al*., 2012), there are attempts by many of the Malaysian river researchers on river bioassessment. Quite recently, few investigations addressed the roles and potential of aquatic macroinvertebrates in biological monitoring of water quality or as indicator species at local scale and a landscape scale (Che Salmah *et al*., 2014). Several studies used aquatic macroinvertebrates such as Odonata (Che Salmah *et al*., 2012), Ephemeroptera, Plecopetera and Trichoptera (EPT) (Suhaila and Che Salmah, 2011; Suhaila *et al*., 2011; Suhaila *et al*., 2013) and dipteran chironomid (Al-Shami *et al*., 2010; Al-Shami *et al*., 2011) to assess the pollution of the water bodies. However, in general, less effort has been made to use the biotic indices in assessing various aquatic environments in Malaysia. However a few researchers used the biological assessment such as Biological Monitoring Working Party (BMWP) and Average Score Per Taxon (ASPT) in relation to the distribution of aquatic macroinvertebrates (Wahizatul Afzan *et al*., 2011; Akmal *et al*., 2013). Other authors also attempted to use other indices for river bioassessment such as Ahmad Abas *et al*. 1999) (Diversity Index), Aweng *et al*. (2012) (SIGNAL), Ahmad *et al*. (2013) (EPT Index) and Sharifah Aisyah *et al*. (2014) (Family Biotic Index, FBI).

2.5 Development of tolerance value and its application across regions

One approach for interpreting biological assessment data is to group taxa according to their perceived tolerance or sensitivity to anthropogenic disturbances. Hence, the concept of tolerance values (TV) is used to assess the health of freshwater in rivers, on the basis of whether taxa from tolerant or sensitive groups are predominantly collected. The TV of a macroinvertebrate is a relative measurement of macroinvertebrates taxon's sensitivity toward organic pollution (Yuan, 2004). Historically, it provides a useful tool for assessing the biological condition of streams and rivers (Yuan, 2006). Many biotic indices currently in use are using TVs of macroinvertebrates as the basis of the indices. For example, Biological Monitoring Working Party (BMWP) (Armitage *et al*., 1983), Belgium Biotic Index (BBI) (De Pauw and Vanhooren, 1983), Family Biotic Index (FBI) (Hilsenhoff, 1988) and

SingScore (Blakely and Harding, 2010) used the TV of freshwater macroinvertebrates to evaluate the river's water quality. However, currently available TVs of macroinvertebrates are only is limited for use on certain geographical areas.

In the development of most of biotic indices, organism tolerances have been defined with respect to a single gradient of anthropogenic disturbances. For example, BMWP and FBI only consider tolerance to organic pollution and nutrient enrichment (Armitage *et al*., 1983; Hilsenhoff, 1987). These biotic indices have been used effectively to assess the rivers' health status although it can be misleading when the primary stressors differ from those used to derive the values (Yuan, 2004). Additionally, potential of the tolerance value will be greatly enhanced if they are specific to different stressors. Such potential does exist because the macroinvertebrates have different sensitivity toward different water stressors (Uherek *et al*., 2014).

The TV becomes an important component of river conditions, but in recent years, two issues have arisen regarding their reliability for river quality assessment. Firstly, the unsuitable application of TVs for organisms in regions away from where the values are originated (Yuan, 2006). For example, the TVs of BMWP taxa that were assigned to macroinvertebrates from Trent River of United Kingdom (UK) had been used in many countries. According to Bonada (2006), communities of macroinvertebrates are different across the regions. As a result, the application of BMWP in other rivers from other region requires for slight changes (Hoang, 2009). Direct application of the index in other than UK rivers would be a problem because of the possible differences in macroinvertebrates' responses to pollutants. Secondly, there is a growing interest in extending the use of TVs to diagnose the causes of river pollution (Yuan, 2006). Most biotic index studies were only able to define the organism tolerance values with respect to a single gradient of anthropogenic disturbance (Hilsenhoff, 1987; Blakely and Harding, 2010; Silolom *et al*., 2010). For example, Slooff (1983) reported in his study the potential used of macroinvertebrates to indicate the water surface pollution. Meanwhile, Chessman and McEvoy (1998) constructed indices by assemble the macroinvertebrates using sensitivity numbers targeted to a particular impact to overcome the problem of wide sensitivity of individual taxa macroinvertebrate on particular river disturbance.

2.6 Development of Biological Water Quality Indices and Their Application Around the World

2.6.1 Biological Monitoring Working Party (BMWP)

Biological Monitoring Work Party (BMWP), a scoring system of river water quality from United Kingdom (UK) (Armitage *et al*., 1983) was set up by the Department of the Environment Standing Technical Advisory Committee on Water Quality (STACWQ) of United Kingdom (UK) to propose a biological classification system for national river pollution surveys (Hawkes, 1997). The BMWP was set up by a group of eleven biologists who decided to develop a score system for river quality assessment based on benthic macroinvertebrates. BMWP has been applied in many countries, especially in developing countries because they can be employed with qualitative and family level data (Hoang, 2009). According to Semenchenko and Moroz (2005), the wide application of BMWP for river water assessment is related to its simplicity and convenience for water assessment. The system is proven to be an appropriate tool for rapid bioassessment (Mustow, 1997; Hoang, 2009) and demonstrate the highest sensitivity to water quality assessment because it is able to detect small variations in water quality (Rico *et al*., 1992).

2.6.2 Average Score Per Taxon (ASPT)

ASPT is a modification of the BMWP to correct the values obtained from a very particular fluvial conditions (Rico *et al*., 1992). It is able to reflect the substantial differences in the complement of families to be found in upland and lowland rivers whereas BMWP would not show a steady decline between both of the areas. It also provides useful means of distinguishing between sites which have similar scores but which differ in their physical and chemical characteristic (Armitage *et al*., 1983). ASPT is used as an alternative to BMWP when the faunistic scarcity is not an effect of pollution. It was also less sensitive towards sampling effort and seasonal variation. Walley and Fontama (1998) suggested the application of the APST together with BMWP for better accuracy of river assessment.

2.6.3 Family Biotic Index (FBI)

Family Biotic Index (FBI) was first employed by Hilsenhoff (1988) in streams of southern Wisconsin, North America to fulfill the need for rapid field-based water assessment approaches. The FBI was derived from Biotic Index (BI) used to detect organic pollution in river water (Hilsenhoff, 1987). More than 2000 samples were collected from rivers around Wisconsin to develop the tolerance values for the arthropods species and genera. Then the TVs were revised to establish new tolerance values for the arthropods at the family level by comparing occurrence of each family with average of BI of the streams in which they occurred in the greatest number. Thus, family level tolerance values tend to be a weighted average of tolerance values of species and genera within each family based on their relative abundance in Wisconsin (Hilsenhoff, 1988). The FBI was then compared to the BI to determine its efficiency. It was found that the FBI was more efficient and advantageous in evaluating the general status of organic pollution in the streams and very useful for river screening. Consequently, the FBI was used for rapid assessment of the river water quality.

2.6.4 BalkaN Biotic Index (BNBI)

BalkaN Biotic Index (BNBI) was developed as the result of macrozoobenthos investigation in tributaries of the Danube River in Serbia with special attention to quantitative and qualitative composition, dominance, frequency, elements of the α-biodiversity and a number of environmental variables (Simić and Simić, 1999). The study was carried out in 65 rivers eight geographic regions from 1989-1996. As the result of the study, these rivers were classified into 5 categories based on the similarities of water quality and macroinvertebrates habitats. Following the river categories, five scores of BNBI incorporating the water quality and diversity of the macrozoobenthos were determined. The concept and mode of use of this index are very similar to Biotic Score (BS) of Chandler (1970), but with significant consideration was given to specific taxa of the territory of investigations. In comparison to other biotic indices such Trent Biotic Index (TBI), Extended Biotic Index (EBI), Biological Monitoring Working Party (BMWP) and River Invertebrate Prediction and Classification System (RIVPACS), different approach was applied in BNBI for family Baetidae and genus *Gammarus* (Amphipoda) (Simić and Simić, 1999). In other indices, the presence of Baetidae indicate weakly to moderately polluted water and Gammarus is an indicator for moderate pollution. However, the

BNBI divided Baetidae species according to their variation in response to water quality. For instance, cleanest water is characterized by species of *Baetis alpinus* whereas *Baetis bicaudatus* indicates moderately polluted water. In BNBI, *Gammarus* is an indicator for weakly polluted water.

2.6.5 Species At Risk Pesticide (SPEAR$_{pesticides}$)

SPEAR$_{pesticides}$ focused on effect of pesticides on non-target freshwater organism, thus useful for monitoring the health of freshwater running streams. A study was carried out to investigate the effect of pesticides on the patterns of aquatic invertebrate community composition (Liess and Van Der Ohe, 2005). In the study, 20 first order streams around Braunschweig, Lower Saxony, Germany were investigated. The streams were selected to match the study requirements such as all-year water flow, no dredging in the years before and during the study, no pollution from other than agricultural nonpoint sources, various pesticide loads and with differences in the percentage of adjacent arable land.

In the study, macroinvertebrates species were classified and grouped according to their vulnerability to pesticides known as species at risk (SPEAR) and species not at risk (SPEnotAR), to reduce the site-specific variation of community descriptors due to factors other than pesticides. During the period of maximum pesticide application, these groups' sensitivity to toxicants, generation time, migration ability, and presence of aquatic stages were defined using the ecological data of macroinvertebrates.

This study found that the pesticide concentrations of 1:10 of the acute 48-h median lethal concentration (LC50) reduced the abundance of *Daphnia magna* (Cladocera) of SPEAR and increased the SPEnotAR in short- and long-term trial, respectively. Nevertheless, reducing the pesticide concentrations to 1:100 of the acute 48-h LC50 of *D. magna* correlated with a long-term change of macroinvertebrates community composition in the rivers. However, diversity and abundance of SPEAR at the disturbed streams increased greatly when a section of an undisturbed stream was present in upstream reaches. These results indicated that the ecological traits of the aquatic macroinvertebrates and recolonization processes on the landscape level for ecotoxicological risk assessment were important factors to consider in biological assessment of the rivers.

2.6.6 Singapore Biotic Index (The SingScore)

The Singscore is a macroinvertebrate biotic index that has been used for assessing the health of Singapore's streams and canals (Blakely and Harding, 2010). Singapore has a diverse array of freshwater rivers ranging from small streams to larger rivers and canals. Rapid urbanization of Singapore since the last decades left behind the so-called modernization remnants in their rivers. Due to Singapore's limited water resources, it is critical that water pollution and quality are carefully monitored and regulated. Traditionally, quality of the rivers health was monitored using water chemical parameters. However, this can be very costly and time consuming. As a result, a new tool has been proposed, the SingScore, developed for measuring Singaporean rivers' health using stream macroinvertebrates.

In 2008, the Public Utilities Board (PUB) of Singapore noticed the need for development of biotic index specific to Singapore's rivers. Therefore, they funded a research project, undertaken by Freshwater Ecologists at the University of Canterbury, New Zealand to develop a macroinvertebrates biotic index for Singaporean rivers' health assessment (Blakely and Harding, 2010). This new tool was not only useful for long-term monitoring of Singaporean streams and canals, but also for assessing the response of ecosystem recovery of canals post-restoration.

Forty-seven streams were investigated for their macroinvertebrates communities and physico-chemical condition. Thirty-three of these study streams were concretized canals and 14 sites were natural forested streams. From the streams and concretized canals, 59 116 macroinvertebrates respectively, belonging to 68 families and six higher taxonomic groups (Ostracoda, Copepoda, Isopoda, Amphipoda, Acari and Collembola) were collected. The development of SingScore was started with the assignment of new tolerance value (TV) for Singaporean aquatic macroinvertebrate. Using Weighted Average (WA) analysis. The TV ranged from 1 to 10, with the tolerance value of 10 represented intolerance to environmental variables, while a value of 1 represented tolerance. The SingScore was calculated for each of the 47 sites as follows,

$$\text{SingScore} = \frac{\sum_{i=1}^{i=S} ai}{S} \times 20$$

where,

ai = the tolerance value for the ith taxon

S = the total number of taxa in the sample

This site value was then multiplied by an arbitrary constant of 20 to give SingScore values between 0 and 200. The biotic index was then divided into four categories based on SingScore tolerance values for macroinvertebrates in Singapore rivers (Table 2.4).

Table 2.4: Categories of the SingScore.

SingScore	Likely water quality
0 – 79	Poor
80 – 99	Fair
100 – 119	Good
120 – 200	Excellent

2.7 Factor Influencing Water Quality and Their Relation to Living Aquatic Organism

2.7.1 Total Organic Carbon (TOC)

Determination of total organic carbon (TOC) content in water is useful as a measure of pollution. TOC is the sum of organically bound carbon present in water, bonded with dissolved or suspended matter such as cyanate and elemental carbon (Doleža and Tomic, 2003). Measurement of TOC will determine a number of carbon containing compounds in a source and an indicator of the level pollution of the water. Polluted water is not suitable for some macroinvertebrates and will influence their colonization of the freshwater streams (Morse *et al*., 2007).

2.7.2 Total Suspended Solid (TSS)

Suspended Solid (SS) is ubiquitous components of freshwater streams. Suspended solid is among the highest priority contaminants for the management of freshwater biodiversity and ecosystems in tropical streams (Dunlop *et al*., 2008). TSS requires laboratory measurement and is not able to be provided in real time. The measurement of TSS is represented by the dry weight per volume of particulate matter. Increase of TSS will influence the macroinvertebrates communities in the streams such as smothering of the macroinvertebrates or their habitat (Wood *et al*., 2005), reducing streams depth and limiting aquatic plant growth (Parkhill and

Gulliver 2002), interfering with predator-prey interactions (Granqvist and Matilla 2004), and increased drift of macroinvertebrates (Bond and Downes 2003). TDS is an important parameters to measure river pollution in the Water Quality Index (WQI) of Malaysian rivers (DID, 2012).

2.7.3 Ammonia-nitrogen, nitrate and nitrite

Ammonia-nitrogen is the waste product of animals including aquatic insects through their metabolic process. Ammonia-nitrogen is directly excreted into water as one of the important sources of nitrogen for aquatic plant. In rivers, ammonium undergoes two steps process before being transformed into nitrate compounds, that produces nitrite as the intermediate product (Beketov, 2004). The ammonia-nitrogen, nitrate and nitrite are toxic to living organisms. High amount of these three components in the water reduces river water quality, the river becomes polluted and the abundance of macroinvertebrates decreases. Although the amount of ammonia-nitrogen influenced the colonization of macroinvertebrates in the rivers, different species response to the concentrations of ammonia-nitrogen in the water differently (USEPA, 1999).

2.7.4 Total Dissolved Solid (TDS) and salinity

Total Dissolved Solid (TDS) is a measurement of inorganic salts, organic matter and other dissolved materials in water. TDS cause toxicity through increases in salinity and changes in the ionic composition of the water (Weber-Scannell and Duffy, 2007). The abundance of aquatic species especially macroinvertebrates declines as osmotic pressure exceeds their tolerances when salinity increases (Derry *et al*., 2003).