THE POTENTIAL USE OF LOCAL INDEX OF BIOLOGICAL INTEGRITY FOR TROPICAL RIVER ASSESSMENT

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To my beloved family and friends

In thankful appreciation for your endless love, support and encouragement

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ABSTRACT

Economic and industrial growth in this country has led to environmental problems which in turn affect the quality of human life and nature. Particularly, the management plans for river rehabilitation are less effective in addressing issues related to rivers in Malaysia. To date, most of the efforts undertaken focused on evaluating physicochemical properties of water whereas biological evaluation in determining the health of a river ecosystem is given less attention. Therefore, this study aims to integrate assessment tools of physical, chemical and biological approaches by highlighting benthic macroinvertebrates as key indicator. This study was conducted at four rivers in the state of Johor, which represents different gradients of land use, namely Sungai Ayer Hitam Besar, Sungai Berasau, Sungai Mengkibol and Sungai Melana. *In-situ* and *ex-situ* monitoring were carried out with ten (10) sampling frequencies for each river, starting from 2010 to 2013. Benthic macroinvertebrates were sampled using rectangular dip-net with frame dimension 0.5 m x 0.3 m based on the United States Environmental Protection Agency Rapid Bioassessment Protocol whilst water samples were analysed according to Standard Methods for the Examination of Water and Wastewater. River habitat assessments were also conducted concurrently with the sampling of benthic macroinvertebrates and water quality whereas, secondary data such as rainfall, land use plans and maps of catchment area were obtained from various agencies. Assessment results varied among study sites. Non-parametric statistical analysis, Spearman correlation coefficients was also conducted to measure the correlation between biological and environmental endpoints, hence the selection of most suitable and effective indices for the development of macroinvertebrate-based multimetrics of Index Biotic Integrity (IBI) and the preliminary establishment of the biocriteria. Integration of six potential metrics within three categories (taxonomic richness, taxonomic composition and tolerance and intolerance index) had produced four-level discriminatory biocriteria for river health assessment. The re-scored result showed that water quality of Sungai Ayer Hitam Besar was in non-impaired condition with excellent water quality. Both Sungai Berasau and Sungai Mengkibol showed slightly impaired water quality, whereas Sungai Melana was moderately impaired with fair to poor water quality. The validation of IBI was conducted using different data thus demonstrated that the establishment of IBI and biological criteria could provide indispensable information in managing river ecosystem more effectively.

ABSTRAK

Pertumbuhan sektor ekonomi dan perindustrian di negara ini telah membawa kepada masalah alam sekitar seterusnya menjejaskan kualiti kehidupan manusia dan alam semulajadi. Pelan pengurusan bagi pemuliharaan sungai khususnya dilihat masih kurang berkesan dalam menangani isu berkaitan sungai di Malaysia. Sehingga kini kebanyakan usaha yang dijalankan lebih tertumpu kepada menilai ciri fisikokimia air, manakala penilaian secara biologi kurang diberi perhatian dalam menentukan status kesihatan sesebuah ekosistem sungai. Oleh itu, kajian ini bertujuan untuk mengintegrasikan kaedah penilaian secara fizikal, kimia dan biologi dengan menggunakan makroinvertebrata sebagai organisma petunjuk. Kajian ini telah dijalankan di empat batang sungai di negeri Johor yang mewakili guna tanah yang berbeza, iaitu Sungai Ayer Hitam Besar, Sungai Berasau, Sungai Mengkibol dan Sungai Melana. Pemantauan dijalankan secara *in-situ* dan *ex-situ* dengan kekerapan sepuluh (10) kali persampelan di setiap sungai, bermula dari 2010 sehingga 2013. Sampel makroinvertebrata diambil menggunakan jaring sauk berbentuk segi empat tepat bersaiz 0.5 m x 0.3 m berdasarkan *United States Environmental Protection Agency Rapid Bioassessment Protocol* sementara sampel air diuji mengikut kaedah piawai pengukuran kualiti air *APHA Standard Method.* Penilaian habitat dijalankan serentak dengan persampelan makroinvertebrata dan kualiti air, sementara data sekunder seperti taburan hujan, pelan guna tanah dan peta kawasan tadahan diperolehi daripada pelbagai agensi. Hasil penilaian adalah berbeza di antara kawasan kajian. Analisis statistik bukan parametrik, pekali korelasi Spearman turut diukur untuk melihat hubungan antara parameter biologi dan alam sekitar, seterusnya memilih indeks yang paling sesuai dan berkesan untuk pembangunan multimetrik berdasarkan makroinvertebrata bagi Indeks Biotik Integriti (IBI) dan penubuhan awal kriteria biologi. Integrasi enam metrik berpotensi yang mewakili tiga kategori (kekayaan taksonomi, komposisi taksonomi dan indeks toleransi dan intoleransi) telah menghasilkan empat peringkat diskriminasi kriteria biologi bagi penilaian kesihatan sungai. Hasil pengiraan semula menunjukkan bahawa kualiti air Sungai Ayer Hitam Besar adalah tidak terjejas dengan keadaan kualiti air yang cemerlang. Kedua-dua Sungai Berasau dan Sungai Mengkibol menunjukkan kualiti air sedikit terjejas, manakala Sungai Melana adalah sederhana terjejas dengan kualiti air yang sederhana. Pengesahan IBI turut dijalankan dengan menggunakan data yang berbeza, sekali gus menunjukkan bahawa penubuhan IBI dan kriteria biologi boleh memberikan maklumat yang berguna dalam menguruskan ekosistem sungai dengan lebih berkesan.

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LIST OF ABBREVIATIONS

4WD	-	Four Wheel Drive
Ag^{+}	-	Silver
ALUs	-	Aquatic Life Uses
APHA	-	American Public Health Association
ASPT	-	Average Score Per Taxon
BMWP	-	Biological Monitoring Working Party
BOD_5	-	Biochemical Oxygen Demand
CA	-	Correlation Analysis
Cc	-	Coefficient of Curvature
CCA	-	Canonical Correspondence Analysis
COD	-	Chemical Oxygen Demand
CPOM	-	Coarse Particulate Organic Matter
Cu	-	Coefficient of Uniformity
CWA	-	Clean Water Act
DID	-	Department of Irrigation and Drainage
DO	-	Dissolved Oxygen
DOE	-	Department of Environmental Malaysia
DOM	-	Dissolved Organic Matter
EIA	-	Environmental Impact Assessment
FBI	-	Family Biotic Index
FFG	-	Functional Feeding Groups
FPOM	-	Fine Particulate Organic Matter

H’	-	Shannon’s Diversity Index
H^+	-	Hydrogen Ions
H_2SO_4	-	Sulfuric Acid
IBI	-	Index of Biotic Integrity
INWQS	-	Interim National Water Quality Standards
IRBM	-	Integrated River Basin Management
IWRM	-	Integrated Water Resources Management
J	-	Pielou Evenness Index
JMG	-	Department of Minerals and Geosciences
$K_2Cr_2O_7$	-	Potassium Dichromate
LQI	-	Lincoln Quality Index
M	-	Margalef Richness Index
MetMalaysia	-	Malaysian Meteorological Department
MyGAP	-	Malaysian Good Agricultural Practice
NH_3N	-	Ammoniacal Nitrogen
NH_4^+	-	Ammonium
nMDS	-	Non-Multidimensional Scale
NRE	-	Natural Resources and Environment
OH^-	-	Hydroxyl Ions
OPP3	-	Third Outline Perspective Plan
OQR	-	Overall Quality Rating
RBP	-	Rapid Bioassessment Protocol
RCC	-	River Continuum Concept
RHS	-	River Habitat Survey
SI	-	Sub Index
SOM	-	Malaysian Organic Scheme
TAN	-	Total Ammonia Nitrogen
TSS	-	Total Suspended Solids
USA	-	United States of America
USEPA	-	United States Environmental Protection Agency
WQI	-	Water Quality Index

LIST OF SYMBOLS

>	-	more than
<	-	less than
mm	-	millimetre
µm	-	micrometer
%	-	percent
mg/l	-	milligram per litre
°C	-	degree Celsius
N	-	total number of individuals
Σ	-	sum of the calculations
ln	-	natural logarithm
ppm	-	parts per million
km^2	-	square kilometre
ha	-	hectare
g	-	gram
D_{10}	-	grain diameter at 10% passing
D_{30}	-	grain diameter at 30% passing
D_{60}	-	grain diameter at 60% passing
d	-	depth
Q	-	discharge rate
A	-	area
V	-	velocity
m/s	-	metre per second
r	-	coefficient of correlation
p	-	correlation of significant

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Since time immemorial, rivers play a major role in the development of human society, serving as transport routes, water supply for domestic and agricultural use and yielding an important source of protein for human consumption. Rivers have similarly played an important role in the growth of towns and cities in Malaysia, with early settlements springing up along river banks and estuaries (Chan *et al.*, 2003). The discovery of tin deposits in the flood plains and river valleys also encouraged settlements to mushroom in these areas, leading to a booming tin-mining industry in the 1800s till 1980s which made the country the largest producer of tin in the world.

Malaysia has grown rapidly over the last three decades, transforming from a rural economy based on agriculture and tin mining to an export-based, manufacturing economy. Unfortunately, rapid changes of land use, especially on forested land and food crops to plantations as well as urban development have triggered river erosion, surface runoff and sedimentation of rivers, resulting eventually in overstressed river systems. River basins are frequently facing problems arising from flooding. Many rivers are gradually losing their ability to supply fresh water and as a result, these rivers are now mainly used for transportation (Sulong *et al.*, 2005). Although raw water supply is not yet depleted, clean water that can be safely consumed by humans is becoming hard to come by.

The major causes of water pollution in Malaysia include effluent from sewage treatment plants, discharge from agro-based industries and livestock farming, land clearing activities and domestic sewage (Jabatan Perangkaan Malaysia, 2013). Rivers in both urban and rural areas are experiencing the same problems. Although environmental issues in Malaysia raise serious concerns, the measures taken to address the problem thus far have been fragmented and inadequate. In tandem with the growing global population and improvement of living standards, the increasing demand for fresh water has been said to overshadow the concerns of the warming effect of climate change (Nienhuis, 2006). This critical situation calls for water resource management to be addressed in order to meet growing consumer demand.

In earlier studies, the evaluation of river water quality relies merely on physicochemical characteristics. However, taking into consideration the physicochemical aspects alone are not sufficient to indicate a healthy ecosystem as a whole. Healthy water bodies exhibit ecological integrity, which consist of three components, namely chemical, physical and biological integrity. When one or more of these components are degraded, health of the water body is affected and in most cases aquatic life living in it will reflect the degradation. According to Gordon *et al.*, (2013), stream health measurement takes into consideration the water quality, habitat availability and suitability, energy sources, hydrology and the biota themselves.

In order to achieve a comprehensive evaluation of healthy water bodies, biological assessment tool should be carried out simultaneously with the standard physicochemical method. Biological assessment, the primary tool to evaluate the biological condition of a water body, comprise surveys and other direct measurements through biological communities such as plankton, periphyton, microphytobenthos, macrozoobenthos, aquatic macrophytes and fish. Among all, benthic macroinvertebrates are the most favored in freshwater monitoring and are widely used to evaluate the water body health and condition (Conti, 2008; Meng *et al.,* 2009). The advantages of using biological indicators, particularly macroinvertebrates are biological communities reflect the overall ecological quality and provides a broad measurement of fluctuating environmental conditions. In addition, the result of biological monitoring is reliable and relatively inexpensive compared to toxicity testing (Iliopoulou-Georgudaki *et al.*, 2003).

The history of biological monitoring methods for assessing water quality began more than a century ago by Kolenati (1848) and Cohn (1853) (both quoted by Liebmann, 1962). However, such studies in Malaysia is still very limited and started relatively late with the earliest documented was in the early 90's (Khan, 1990; Arsad *et al.*, 2012). After year 2000, interest on this topic is gaining attention and grows, and example of studies can be seen in (Al-Shami *et. al*, 2010; Al-Shami *et al.,* 2011; Zaiha *et al.*, 2015; Sharifah Aisyah *et al.*, 2015; Ghani *et al.*, 2016). More recently, in 2009, DID in collaboration with Universiti Sains Malaysia, has produced a Guideline for Using Macroinvertebrates for Estimation of Streams Water Quality. The guideline provides simple, inexpensive and easy approach to estimate water quality through the identification of freshwater macroinvertebrates. This government's effort is an initial step to the development of such studies in Malaysia and proving biological methods in the study of water quality began to be accepted.

1.2 Problem Statement

In recent years, there is a growing interest in protecting and managing rivers to be more sustainable, both ecologically and aesthetically. River management and technologies in Malaysia has experienced paradigm shift from the artificial and engineering-based to be more ecological friendly approaches. Although the method using the restoration concept managed to improve the water quality and amenity of rivers, its usefulness for the reinstatement of the river biota is rarely observed when biological aspect is given little consideration. Many river rehabilitation projects tend to focus on improving water quality and beautification of the riverbanks without taking into account the importance of habitat to aquatic life. The notion that the abiotic factors (particularly water quality) have greater influence on the structure of stream community led to many river rehabilitation activities focusing more on altering the instream habitat. Simplification of stream habitat not only affects the function of ecosystem, but also structural ecosystem features that include species composition and diversity. Furthermore, placement of physical materials such as large woody debris (LWD), boulders and other materials as an effort to improve fish and other aquatic organism for habitat enhancement still not enough to obtain suitable environment for species population. Such practices are impossible to achieve the river rehabilitation goal without initial assessment of what are the factors leading to habitat degradation, disturbance in the watershed and how to cope the issue, and disruption factors of a physical and biological production of a system. Besides, the use of single classification index such as Water Quality Index (WQI) is inappropriate, especially when only six parameters are taken into account. Though WQI is a useful tool for instantaneous water quality benchmarking, it's still not enough to represent the overall health of river ecosystem. Hence, for a better decision making tool, the National Water Quality Standards (NWQS) should be referred to achieve the desired target class. Unfortunately, these standards are still poorly understood among the authorities, making the preservation efforts in the country will continue to be hampered. Moreover, physicochemical assessment provides only a partial perspective of water degradation and regarded as one of the limitation factor of this method. Thus far, the integrated assessment of ecosystem health in the country is very limited and lack of quantity with no comprehensive assessment has been developed. On top of that, assessment practices in Malaysia is much dependent on the physical and chemical based techniques, with biological methods are often ignored.

1.3 Aims and Objectives

This study aims to evaluate the ecological health of river ecosystem by the integration of a comprehensive assessment method. Therefore, the objectives are:

i. To assess and describe the status of the river in the state of water quality and habitat quality, based on the integration of physicochemical, biological and habitat assessment approach.
ii. To establish the relationship between macroinvertebrates composition, water quality and habitat quality condition.
iii. To evaluate the ecological quality and describe biological communities through the development of multi-metric Index of Biological Integrity (IBI) using benthic macroinvertebrate.
iv. To propose a baseline data of biological criteria for river health assessment that can be applied as a measurement of water resource management.

1.4 Scope of Study

This study focused on the description of the existing ecological environment of four rivers with different environmental gradient ecosystem, *viz.* Sg Ayer Hitam Besar as reference site and Sg Berasau, Sungai Mengkibol and Sg Melana as impacted sites. Three main processes explored in this study were consisted of physical characteristic (general characteristics that are important in influencing the river's aquatic ecology such as channel forms, instream habitats, substrates, riverbank vegetation and structure. Additional habitat attributes such as anthropogenic alterations to the river were briefly described), biological characteristics (focusing on the composition and abundance of macroinvertebrates species) and chemical characteristics (documentation of existing conditions related to commonly observed water quality parameters). The study also investigated the correlation between the physicochemical attributes and variations in the macroinvertebrates assemblages. In addition, the main objective that needs to be achieved in the end of the study is to develop a benthic macroinvertebrate-based multimetrics for the bioassessment of stream water quality in Malaysia.

1.5 Significance of Study

Generally, the Water Quality Index (WQI) is used as a measurement of water quality status and classifying rivers in the country. The basic foundation of WQI is solely based on physicochemical parameters alone, comprises of biological oxygen demand, chemical oxygen demand, organics substance, suspended solids, alkalinity, temperature and dissolved oxygen, are then calculated and evaluated. Unfortunately, the physicochemical analysis cannot yield enough information on the overall health of the river ecosystem. Therefore, this approach is not strong enough as a main tool of evaluation status of aquatic ecosystems. This is because the index could not clearly define and justify the condition of aquatic life either may survive in the water body or vice versa. Therefore, integration of biological monitoring is necessary to complete the information. The integration between the physicochemical and biological assessment gives a broader perspective to describe the state of the environment.

There is still a lack of information regarding the integration of assessment tools to ascertain the health of the river ecosystem. Most biological monitoring studies conducted were involved simple qualitative system based on the absence or presence of indicator species according to the environmental gradient regardless of the causal factors of the environment. Thus, the development of biological assessment methods such as multimetric index is appropriate to reflect all kinds of degradation and cumulative effect at the ecosystem level. A multimetric index consisted of several metrics related to the biological properties (i.e. taxa richness, taxa composition and pollution tolerance) that changes in expected way with increasing anthropogenic interference. This method can be widely used in the valuation of the ecosystem because it involves multiple measurements and provides comprehensive information related to the pre-determined criteria derived from reference conditions. Furthermore, the methods developed will facilitate the monitoring work of river water quality status in the country, and easily understood by general users.

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