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

NOR ZAIHA BINTI ARMAN

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

NOR ZAIHA BINTI ARMAN

A thesis submitted in fulfilment of the requirements for the award of the degree of Doctor of Philosophy (Civil Engineering)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

MAY 2017
To my beloved family and friends

In thankful appreciation for your endless love, support and encouragement
ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful

Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this thesis. First and foremost I offer my sincerest gratitude to my supervisor, Assoc. Prof. Dr. Mohd. Ismid Mohd. Said, for thoughtful guidance, constructive comments and motivation throughout the completion of this research. Also a million thanks to my co-supervisor, Dr. Salmiati for her patience, encouragement, support and friendship. My acknowledgement also goes to all staffs and technicians, especially to the Environmental Engineering Laboratory, FKA UTM for their assistance and co-operations.

I greatly appreciate the Research University Grant Scheme (GUP) for the funding received with grant number Q.J130000.2522.00H99 and Ministry of Higher Education (MOHE) for scholarship assistance. Sincere thanks to my fellow postgraduate students, colleagues and others who have provided assistance at various occasions. Thank you for the great moments we have shared together.

Last but not least, heartfelt thanks to my beloved family for their continuous support and encouragement. To those who indirectly contributed in this research, your kindness means a lot to me. Thank you very much.
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

# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECLARATION</td>
<td></td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td></td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td></td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td></td>
<td>v</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td></td>
<td>vi</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td></td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLE</td>
<td></td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td></td>
<td>xiv</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td></td>
<td>xvii</td>
</tr>
<tr>
<td>LIST OF SYMBOLS</td>
<td></td>
<td>xix</td>
</tr>
<tr>
<td>LIST OF APPENDICES</td>
<td></td>
<td>xx</td>
</tr>
</tbody>
</table>

1 INTRODUCTION
1.1 Research Background 1
1.2 Problem Statement 3
1.3 Aims and Objectives 5
1.4 Scope of Study 5
1.5 Significance of Study 6

2 LITERATURE REVIEW
2.1 Overview 8
2.2 River Ecosystem Concept 9
2.3 Overview

2.4 River Ecosystem Concept

2.5 Thread to Stream Biodiversity and Conservation Approaches

2.6 Biological Assessment

2.7 Biological Criteria

2.8 Macoinvertibrate as Bioindicator

2.9 Development of Benthic Macroinvertebrate

2.10 Benthic Macroinvertebrate Functional Feeding Groups

2.11 Factors Affecting Benthic Macroinvertebrate Distribution

2.12 Assessment Approaches Based on Macroinvertebrate

2.13 Water Quality

2.14 Conclusion
## METHODOLOGY

### 3.1 Introduction

### 3.2 Material

### 3.3 Analytical Method
- **3.3.1 Water Quality Analysis**
- **3.3.2 Benthic Macroinvertebrate Analysis**
- **3.3.3 Particle Size Distribution**
- **3.3.4 Data Analysis Technique**

### 3.4 Study Area

### 3.5 Experimental Procedure
- **3.5.1 Water Quality Sampling**
- **3.5.2 Benthic Macroinvertebrate Sampling**
- **3.5.3 River Habitat Assessment**
- **3.5.4 Sediment Sampling**
- **3.5.5 River Discharge**

## RESULTS AND DISCUSSION

### 4.1 Overview of the Study Area
- **4.1.1 Sg Ayer Hitam Besar, Gunung Pulai Forest Reserve**
- **4.1.2 Sg Berasau, Ulu Sedili Plantation Forest**
- **4.1.3 Sg Mengkibol, Kluang**
- **4.1.4 Sg Melana, Skudai**

### 4.2 Benthic Macroinvertebrates Composition

### 4.3 Ecological Indices

### 4.4 Physicochemical Characteristics for Water Quality

### 4.5 Comparison of Water Quality Classification Based on Different Indices

### 4.6 River Habitat Survey

### 4.7 River Discharge

### 4.8 Particle Size Distribution
4.9 The Influence of Hydrological, Physicochemical and Habitat Characteristics on the Aquatic Macroinvertebrates 117
4.10 Establishment of Biological Criteria 123

5 CONCLUSIONS AND RECOMMENDATIONS 131
5.1 Conclusions 131
5.2 Recommendations 132

REFERENCES 134
Appendices A - E 162 - 202
# LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Summary of the River Continuum Concept (RCC)</td>
<td>11</td>
</tr>
<tr>
<td>2.2</td>
<td>Summary of river concept characteristics</td>
<td>14</td>
</tr>
<tr>
<td>2.3</td>
<td>Biological assessment studies using different type of bioindicators</td>
<td>23</td>
</tr>
<tr>
<td>2.4</td>
<td>Advantages and disadvantages of using fish, macrophytes, macroinvertebrate, plankton and periphyton as bioindicator in biological assessment (Abbasi and Abbasi, 2012)</td>
<td>24</td>
</tr>
<tr>
<td>2.5</td>
<td>Advantages and disadvantages of narrative or numeric criteria (Bauder and Pearson, 2002)</td>
<td>27</td>
</tr>
<tr>
<td>2.6</td>
<td>Traditional Saprobic System Classes and typical biological oxygen demand (BOD) and dissolved oxygen (DO) levels (Gordon <em>et al.</em>, 2004)</td>
<td>42</td>
</tr>
<tr>
<td>2.7</td>
<td>Comparison of BMWP and FBI</td>
<td>45</td>
</tr>
<tr>
<td>3.1</td>
<td>List of equipments used in this study</td>
<td>52</td>
</tr>
<tr>
<td>3.2</td>
<td>Basic soil type groups based on BS5390:1981 (Craig, 2013)</td>
<td>60</td>
</tr>
<tr>
<td>3.3</td>
<td>Coordinate of sampling sites</td>
<td>61</td>
</tr>
<tr>
<td>3.4</td>
<td>Physical and chemical observations measured alongside the RBP habitat assessment</td>
<td>66</td>
</tr>
<tr>
<td>4.1</td>
<td>Benthic macroinvertebrates composition in Sg Ayer Hitam Besar</td>
<td>76</td>
</tr>
<tr>
<td>4.2</td>
<td>Benthic macroinvertebrates composition in Sg Berasau</td>
<td>79</td>
</tr>
<tr>
<td>4.3</td>
<td>Benthic macroinvertebrates composition in Sg Mengkibol</td>
<td>81</td>
</tr>
</tbody>
</table>
4.4 Benthic macroinvertebrates composition in Sg Melana  84
4.5 Diversity, richness and evenness indices of Sg Ayer Hitam Besar  88
4.6 Diversity, richness and evenness indices of Sg Berasau  89
4.7 Diversity, richness and evenness indices of Sg Mengkibol  91
4.8 Diversity, richness and evenness indices of Sg Melana  93
4.9 Assessment of water quality according to applied indices  102
4.10 Assessment of Spearman correlation between physicochemical parameters and applied indices  105
4.11 Mean ± standard deviation values for instream features and habitat quality for Sg Ayer Hitam Besar  109
4.12 Mean ± standard deviation values for instream features and habitat quality for Sg Berasau  110
4.13 Mean ± standard deviation values for instream features and habitat quality for Sg Mengkibol  111
4.14 Mean ± standard deviation values for instream features and habitat quality for Sg Melana  112
4.15 River discharge data (m³/s) between 2010 and 2013 from all studied rivers  114
4.16 Value of D₆₀, D₃₀ and D₁₀, Cu and Cc for Sg Ayer Hitam Besar  116
4.17 Value of D₆₀, D₃₀ and D₁₀, Cu and Cc for Sg Berasau  116
4.18 Value of D₆₀, D₃₀ and D₁₀, Cu and Cc for Sg Mengkibol  116
4.19 Value of D₆₀, D₃₀ and D₁₀, Cu and Cc for Sg Melana  117
4.20 Summary statistic for the canonical correspondence analysis (CCA) relating aquatic macroinvertebrates-environmental variables (11 variables) of four investigated rivers in Johor, Malaysia  118
4.21 Candidate metric of IBI development  125
4.22 Metric values of both, the reference and test sites according to analysis  125
4.23 Percent similarity of the study site metrics to the reference site metrics  126
4.24 Percent ranges and corresponding point values  126
4.25 Scoring point for each sampling site  127
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.26</td>
<td>Results of comparison to reference stream points</td>
<td>127</td>
</tr>
<tr>
<td>4.27</td>
<td>Recommended biocriteria for river health assessment</td>
<td>128</td>
</tr>
<tr>
<td>4.28</td>
<td>Step 1: Metric values</td>
<td>128</td>
</tr>
<tr>
<td>4.29</td>
<td>Step 2: Percent similarity</td>
<td>129</td>
</tr>
<tr>
<td>4.30</td>
<td>Step 3: Scoring point</td>
<td>129</td>
</tr>
<tr>
<td>4.31</td>
<td>Step 4: Comparison to reference stream points</td>
<td>129</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>A generalized depiction of the relationship between stream size (order), energy inputs, and ecosystem function as predicted by the river continuum concept (Vannote <em>et al.</em>, 1980)</td>
<td>10</td>
</tr>
<tr>
<td>2.2</td>
<td>A typical stream food web (Avril and Barten, 2007)</td>
<td>29</td>
</tr>
<tr>
<td>2.3</td>
<td>Metamorphosis (a) Complete metamorphosis, midge (b) Incomplete metamorphosis, damselfly (McCafferty, 1998)</td>
<td>31</td>
</tr>
<tr>
<td>2.4</td>
<td>Major morphological features of all aquatic insects (Whitlock, 2010)</td>
<td>32</td>
</tr>
<tr>
<td>3.1</td>
<td>Flowchart of study</td>
<td>53</td>
</tr>
<tr>
<td>3.2</td>
<td>Example of physical characteristics of channel unit</td>
<td>66</td>
</tr>
<tr>
<td>3.3</td>
<td>Diagram of channel cross-section using the mechanical current-meter method (source: US Geological Survey)</td>
<td>67</td>
</tr>
<tr>
<td>4.1</td>
<td>The Sg Ayer Hitam Besar and its location in Sg Pontian Besar river basin</td>
<td>69</td>
</tr>
<tr>
<td>4.2</td>
<td>The Sg Berasau and its location in Sungai Ulu Sedili Besar river basin</td>
<td>71</td>
</tr>
<tr>
<td>4.3</td>
<td>The Sg Mengkibol and its location in Sungai Endau river basin</td>
<td>72</td>
</tr>
<tr>
<td>4.4</td>
<td>The Sg Melana and its location in Sungai Skudai river basin</td>
<td>74</td>
</tr>
<tr>
<td>4.5</td>
<td>Benthic macroinvertebrate assemblages sampled from Sg Ayer Hitam Besar</td>
<td>76</td>
</tr>
<tr>
<td>4.6</td>
<td>Distribution pattern of benthic macroinvertebrate assemblages in Sg Ayer Hitam Besar</td>
<td>77</td>
</tr>
<tr>
<td>4.7</td>
<td>Macrobenthic assemblages sampled from Sg Berasau</td>
<td>78</td>
</tr>
<tr>
<td>4.8</td>
<td>Distribution pattern of macrobenthic assemblages in Sg Berasau</td>
<td>80</td>
</tr>
<tr>
<td>4.9</td>
<td>Macrobenthic assemblages sampled from Sg Mengkibol</td>
<td>81</td>
</tr>
<tr>
<td>4.10</td>
<td>Distribution pattern of macrobenthic assemblages in Sg Mengkibol</td>
<td>83</td>
</tr>
<tr>
<td>4.11</td>
<td>Macrobenthic assemblages sampled from Sg Melana</td>
<td>83</td>
</tr>
<tr>
<td>4.12</td>
<td>Distribution pattern of macrobenthic assemblages in Sg Melana</td>
<td>85</td>
</tr>
<tr>
<td>4.13</td>
<td>Biotic indices for Sg Ayer Hitam Besar</td>
<td>87</td>
</tr>
<tr>
<td>4.14</td>
<td>Biotic indices for Sg Berasau</td>
<td>89</td>
</tr>
<tr>
<td>4.15</td>
<td>Biotic indices for Sg Mengkibol</td>
<td>90</td>
</tr>
<tr>
<td>4.16</td>
<td>Biotic indices for Sg Melana</td>
<td>92</td>
</tr>
<tr>
<td>4.17</td>
<td>pH values from all sampling rivers and events</td>
<td>94</td>
</tr>
<tr>
<td>4.18</td>
<td>DO values from all sampling rivers and events</td>
<td>96</td>
</tr>
<tr>
<td>4.19</td>
<td>BOD$_5$ values from all sampling rivers and events</td>
<td>97</td>
</tr>
<tr>
<td>4.20</td>
<td>COD values from all sampling rivers and events</td>
<td>98</td>
</tr>
<tr>
<td>4.21</td>
<td>TSS values from all sampling rivers and events</td>
<td>99</td>
</tr>
<tr>
<td>4.22</td>
<td>NH$_3$N values from all sampling rivers and events</td>
<td>100</td>
</tr>
<tr>
<td>4.23</td>
<td>WQI values from all sampling rivers and events</td>
<td>102</td>
</tr>
<tr>
<td>4.24</td>
<td>Riparian vegetation from second sampling station of Sg Ayer Hitam Besar</td>
<td>107</td>
</tr>
<tr>
<td>4.25</td>
<td>Riparian vegetation from second sampling station of Sg Berasau</td>
<td>107</td>
</tr>
<tr>
<td>4.26</td>
<td>Post-harvested land area in Sg Berasau</td>
<td>108</td>
</tr>
<tr>
<td>4.27</td>
<td>Channel stabilization of man-made structures for flood prevention (a) gabion at Sg Mengkibol (b) concrete wall at Sg Melana</td>
<td>108</td>
</tr>
<tr>
<td>Section</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------------------------------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>4.28</td>
<td>Riverbank erosion resulting in soil deposition in (a) Sg Mengkibol, and (b) Sg Melana</td>
<td>112</td>
</tr>
<tr>
<td>4.29</td>
<td>Before and after channel alteration and riverbank strengthening works in Sg Melana</td>
<td>113</td>
</tr>
<tr>
<td>4.30</td>
<td>The nMDS Euclidean distance plot of the studied rivers based on their hydrological and physicochemical variables</td>
<td>119</td>
</tr>
<tr>
<td>4.31</td>
<td>The canonical correspondence analysis (CCA) biplot of the aquatic macroinvertebrates in relation to the hydrological and physicochemical parameters in four investigated rivers in Johor, Malaysia</td>
<td>120</td>
</tr>
<tr>
<td>4.32</td>
<td>Illustrative schematic of the potential interactions between the threats, impact, and the response to the stream macroinvertebrate assemblage</td>
<td>122</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>4WD</td>
<td>Four Wheel Drive</td>
<td></td>
</tr>
<tr>
<td>Ag&lt;sup&gt;+&lt;/sup&gt;</td>
<td>Silver</td>
<td></td>
</tr>
<tr>
<td>ALUs</td>
<td>Aquatic Life Uses</td>
<td></td>
</tr>
<tr>
<td>APHA</td>
<td>American Public Health Association</td>
<td></td>
</tr>
<tr>
<td>ASPT</td>
<td>Average Score Per Taxon</td>
<td></td>
</tr>
<tr>
<td>BMWP</td>
<td>Biological Monitoring Working Party</td>
<td></td>
</tr>
<tr>
<td>BOD&lt;sub&gt;5&lt;/sub&gt;</td>
<td>Biochemical Oxygen Demand</td>
<td></td>
</tr>
<tr>
<td>CA</td>
<td>Correlation Analysis</td>
<td></td>
</tr>
<tr>
<td>Cc</td>
<td>Coefficient of Curvature</td>
<td></td>
</tr>
<tr>
<td>CCA</td>
<td>Canonical Correspondence Analysis</td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>Chemical Oxygen Demand</td>
<td></td>
</tr>
<tr>
<td>CPOM</td>
<td>Coarse Particulate Organic Matter</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>Coefficient of Uniformity</td>
<td></td>
</tr>
<tr>
<td>CWA</td>
<td>Clean Water Act</td>
<td></td>
</tr>
<tr>
<td>DID</td>
<td>Department of Irrigation and Drainage</td>
<td></td>
</tr>
<tr>
<td>DO</td>
<td>Dissolved Oxygen</td>
<td></td>
</tr>
<tr>
<td>DOE</td>
<td>Department of Environmental Malaysia</td>
<td></td>
</tr>
<tr>
<td>DOM</td>
<td>Dissolved Organic Matter</td>
<td></td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
<td></td>
</tr>
<tr>
<td>FBI</td>
<td>Family Biotic Index</td>
<td></td>
</tr>
<tr>
<td>FFG</td>
<td>Functional Feeding Groups</td>
<td></td>
</tr>
<tr>
<td>FPOM</td>
<td>Fine Particulate Organic Matter</td>
<td></td>
</tr>
<tr>
<td>Chemical Symbol</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>H’</td>
<td>Shannon’s Diversity Index</td>
<td></td>
</tr>
<tr>
<td>H⁺</td>
<td>Hydrogen Ions</td>
<td></td>
</tr>
<tr>
<td>H₂SO₄</td>
<td>Sulfuric Acid</td>
<td></td>
</tr>
<tr>
<td>IBI</td>
<td>Index of Biotic Integrity</td>
<td></td>
</tr>
<tr>
<td>INWQS</td>
<td>Interim National Water Quality Standards</td>
<td></td>
</tr>
<tr>
<td>IRBM</td>
<td>Integrated River Basin Management</td>
<td></td>
</tr>
<tr>
<td>IWRM</td>
<td>Integrated Water Resources Management</td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>Pielou Evenness Index</td>
<td></td>
</tr>
<tr>
<td>JMG</td>
<td>Department of Minerals and Geosciences</td>
<td></td>
</tr>
<tr>
<td>K₂Cr₂O₇</td>
<td>Potassium Dichromate</td>
<td></td>
</tr>
<tr>
<td>LQI</td>
<td>Lincoln Quality Index</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Margalef Richness Index</td>
<td></td>
</tr>
<tr>
<td>MetMalaysia</td>
<td>Malaysian Meteorological Department</td>
<td></td>
</tr>
<tr>
<td>MyGAP</td>
<td>Malaysian Good Agricultural Practice</td>
<td></td>
</tr>
<tr>
<td>NH₃N</td>
<td>Ammoniacal Nitrogen</td>
<td></td>
</tr>
<tr>
<td>NH₄⁺</td>
<td>Ammonium</td>
<td></td>
</tr>
<tr>
<td>nMDS</td>
<td>Non-Multidimensional Scale</td>
<td></td>
</tr>
<tr>
<td>NRE</td>
<td>Natural Resources and Environment</td>
<td></td>
</tr>
<tr>
<td>OH⁻</td>
<td>Hydroxyl Ions</td>
<td></td>
</tr>
<tr>
<td>OPP3</td>
<td>Third Outline Perspective Plan</td>
<td></td>
</tr>
<tr>
<td>OQR</td>
<td>Overall Quality Rating</td>
<td></td>
</tr>
<tr>
<td>RBP</td>
<td>Rapid Bioassessment Protocol</td>
<td></td>
</tr>
<tr>
<td>RCC</td>
<td>River Continuum Concept</td>
<td></td>
</tr>
<tr>
<td>RHS</td>
<td>River Habitat Survey</td>
<td></td>
</tr>
<tr>
<td>SI</td>
<td>Sub Index</td>
<td></td>
</tr>
<tr>
<td>SOM</td>
<td>Malaysian Organic Scheme</td>
<td></td>
</tr>
<tr>
<td>TAN</td>
<td>Total Ammonia Nitrogen</td>
<td></td>
</tr>
<tr>
<td>TSS</td>
<td>Total Suspended Solids</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
<td></td>
</tr>
<tr>
<td>USEPA</td>
<td>United States Environmental Protection Agency</td>
<td></td>
</tr>
<tr>
<td>WQI</td>
<td>Water Quality Index</td>
<td></td>
</tr>
</tbody>
</table>
# LIST OF SYMBOLS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;</td>
<td>more than</td>
</tr>
<tr>
<td>&lt;</td>
<td>less than</td>
</tr>
<tr>
<td>mm</td>
<td>millimetre</td>
</tr>
<tr>
<td>µm</td>
<td>micrometer</td>
</tr>
<tr>
<td>%</td>
<td>percent</td>
</tr>
<tr>
<td>mg/l</td>
<td>milligram per litre</td>
</tr>
<tr>
<td>°C</td>
<td>degree Celsius</td>
</tr>
<tr>
<td>N</td>
<td>total number of individuals</td>
</tr>
<tr>
<td>Σ</td>
<td>sum of the calculations</td>
</tr>
<tr>
<td>ln</td>
<td>natural logarithm</td>
</tr>
<tr>
<td>ppm</td>
<td>parts per million</td>
</tr>
<tr>
<td>km²</td>
<td>square kilomet</td>
</tr>
<tr>
<td>ha</td>
<td>hectare</td>
</tr>
<tr>
<td>g</td>
<td>gram</td>
</tr>
<tr>
<td>D&lt;sub&gt;10&lt;/sub&gt;</td>
<td>grain diameter at 10% passing</td>
</tr>
<tr>
<td>D&lt;sub&gt;30&lt;/sub&gt;</td>
<td>grain diameter at 30% passing</td>
</tr>
<tr>
<td>D&lt;sub&gt;60&lt;/sub&gt;</td>
<td>grain diameter at 60% passing</td>
</tr>
<tr>
<td>d</td>
<td>depth</td>
</tr>
<tr>
<td>Q</td>
<td>discharge rate</td>
</tr>
<tr>
<td>A</td>
<td>area</td>
</tr>
<tr>
<td>V</td>
<td>velocity</td>
</tr>
<tr>
<td>m/s</td>
<td>metre per second</td>
</tr>
<tr>
<td>r</td>
<td>coefficient of correlation</td>
</tr>
<tr>
<td>p</td>
<td>correlation of significant</td>
</tr>
</tbody>
</table>
# LIST OF APPENDICES

<table>
<thead>
<tr>
<th>APPENDIX</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Biotic Indices</td>
<td>162</td>
</tr>
<tr>
<td>B</td>
<td>Malaysia Water Quality Standard</td>
<td>169</td>
</tr>
<tr>
<td>C</td>
<td>Particle Size Distribution Curve</td>
<td>173</td>
</tr>
<tr>
<td>D</td>
<td>River Habitat Assessment</td>
<td>174</td>
</tr>
<tr>
<td>E</td>
<td>Photos of Major Taxa From Four Studied Rivers</td>
<td>180</td>
</tr>
<tr>
<td>F</td>
<td>Water Quality Analysis Result</td>
<td>182</td>
</tr>
<tr>
<td>G</td>
<td>Particle Size Distribution</td>
<td>187</td>
</tr>
<tr>
<td>H</td>
<td>List of Papers Published</td>
<td>200</td>
</tr>
</tbody>
</table>
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.
 REFERENCES


Bauder, J. W., & Pearson, K. E. (2002). Justification for numeric standards of salinity and sodicity of water to be considered for beneficial use for irrigation. *Departement of Land Resources and Environmental Sciences, Montana State University-Bozeman, MT*.


Nakamura, Sundari Ramakrishna & Taej Mundkur. Pulau Pinang, Malaysia: Penerbit Universiti Sains Malaysia.


