PRIORITY RANKING OF SKUDAI RIVER SUB-WATERSHEDS FOR POTENTIAL FLOOD DAMAGES AND WATER QUALITY PARAMETERS

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requirements for the award of the degree of
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To these important people in my life:

- ***Azizah binti Ali***
- ***Naubi bin Meean***
- ***Diana binti Naubi***
- ***Muhammad Nasir bin Naubi***
- ***Muhamad Shahril bin Mohd. Salleh***

What would I do without you? Thank you for EVERYTHING

To my supervisor,

Thank you for helping me in so many ways

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ABSTRACT

Sustainability of a watershed generally depends on climatic, hydrological, environmental, social, economical, ecological and many more other factors. The watersheds in Malaysia generally have two issues, which are water quality degradation and flash floods. Economic development activities have increased many folds in last few decades which have affected many watersheds including Skudai River watershed. In this study, Skudai River watershed was delineated into 25 sub-watersheds (SW) and a sustainability index for the watershed was developed by considering Potential Water Quality Deterioration (PWQD) and Potential Flood Damage (PFD) parameters. In order to get actual or at least close to actual classification of river water, the existing water quality index (WQI) developed by the Department of Environment (DOE) known as DOE-WQI formula was modified by adding six more important water quality parameters, which were total phosphorus, nitrate, total dissolved solids, electrical conductivity, turbidity and temperature. The weights to the water quality parameters in the modified WQI were elicited from 32 water experts in face-to-face survey. The modified WQI produced river water classifications, which were Class II for Skudai River- Natural (SKN) and Skudai River- Head (SKH) sampling points and Class III for Senai River (SEN), Skudai River- Middle (SKM), Skudai River- Tail (SKT), Danga River (DAN), Melana River (MEL) and Kempas River (KEM) sampling points. The weights of watershed sustainability indicators in the Skudai River watershed sustainability index (WSI) were obtained from 30 stakeholders consisted of engineers from various departments. Combining modified WQI and PFD parameters using pressure-state-response (PSR) model resulted in a framework of WSI for the Skudai River watershed. The WSI score for every sub-watershed was calculated by incorporating watershed sustainability indicators data and weights. The final ranking of sub-watersheds was SW2> SW7> SW6> SW1> SW4> SW3> SW5> SW8> SW12> SW18> SW25> SW10 >SW9 > SW14> SW16> SW24> SW17> SW11> SW22> SW19> SW13> SW15> SW21> SW23> SW20.

ABSTRAK

Kelestarian sesebuah kawasan tadahan air secara umumnya bergantung kepada iklim, hidrologi, alam sekitar, sosial, ekonomi, ekologi dan banyak lagi faktor lain. Kawasan tadahan air umumnya mempunyai dua isu iaitu kemerosotan kualiti air dan banjir kilat. Aktiviti pembangunan ekonomi telah meningkat berlipat kali ganda dalam beberapa dekad yang lalu dan menjejaskan banyak kawasan tadahan air termasuk kawasan tadahan air Sungai Skudai. Dalam kajian ini, kawasan tadahan Sungai Skudai telah dibahagikan kepada 25 sub-kawasan tadahan air (SW) dan indeks kelestarian untuk kawasan tadahan ini telah dibangunkan dengan mengambil kira parameter Potensi Kemerosotan Kualiti Air dan Potensi Kerosakan Akibat Banjir. Dalam usaha untuk mendapatkan klasifikasi air sungai yang sebenar atau sekurang-kurangnya menghampiri klasifikasi sebenar, indeks kualiti air sedia ada yang dibangunkan oleh Jabatan Alam Sekitar dikenali sebagai formula DOE-WQI telah diubahsuai dengan menambah sebanyak enam parameter kualiti air iaitu jumlah fosforus, nitrat, jumlah pepejal terlarut, kekonduksian, kekeruhan dan suhu. Nilai pemberat untuk parameter kualiti air dalam formula kualiti air yang telah diubahsuai didapati daripada 32 orang pakar dalam bidang sumber air melalui kajian secara bersua muka. Indeks kualiti air yang diubahsuai telah menghasilkan klasifikasi air sungai iaitu Kelas II untuk kawasan pensampelan Sungai Skudai- Semula jadi (SKN) dan Sungai Skudai- Hulu sungai (SKH) dan Kelas III untuk kawasan pensampelan Sungai Senai (SEN), Sungai Skudai- Tengah sungai (SKM), Sungai Skudai- Hilir sungai (SKT), Sungai Danga (DAN), Sungai Melana (MEL) dan Sungai Kempas (KEM). Nilai pemberat bagi indikator kelestarian kawasan tadahan air didapatkan daripada 30 orang pihak berkepentingan yang terdiri daripada jurutera di pelbagai jabatan. Gabungan parameter formula kualiti air yang telah diubahsuai dan parameter potensi kerosakan akibat banjir dengan menggunakan modal tekanan-keadaan-respons menghasilkan rangka untuk indeks kelestarian kawasan tadahan air Sungai Skudai. Skor untuk indeks kelestarian kawasan tadahan air Sungai Skudai dikira dengan menggabungkan data dan nilai pemberat bagi indikator kawasan tadahan air tersebut. Kedudukan bagi sub-kawasan tadahan air Sungai Skudai adalah SW2> SW7> SW6> SW1> SW4> SW3> SW5> SW8> SW12> SW18> SW25> SW10> SW9> SW14> SW16> SW24> SW17> SW11> SW22> SW19> SW13> SW15> SW21> SW23> SW20.

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LIST OF ABBREVIATIONS

AEI	Alternative Evaluation Index
APHA	American Public Health Association
AN	Ammoniacal-nitrogen
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DAN	Danga River
DEM	Digital Elevation Model
DO	Dissolved Oxygen
DOA	Department of Agriculture
DOE	Department of Environment
DID	Department of Irrigation and Drainage
EC	Electrical Conductivity
GIS	Geographical Information System
KEM	Kempas River
MCDA	Multi-criteria Decision Analysis
MCDM	Multi-criteria Decision Making
MEL	Melana River
NTU	Nephelometric Turbidity Units
OECD	Organisation for Economic Co-operation and Development
PFD	Potential Flood Damage
PROMETHEE	Preference Ranking Organization Method
PSD	Potential Streamflow Depletion
PWQD	Potential Water Quality Deterioration
SEN	Senai River
SKH	Skudai River (Head)
SKM	Skudai River (Middle)
SKN	Skudai River (Natural)

SKT	Skudai River (Tail)
SW	Sub-watershed
SWAT	Soil and Water Assessment Tool
TDS	Total Dissolved Solids
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TP	Total Phosphorus
UNESCO	United Nations Educational, Scientific and Cultural Organization
WQI	Water Quality Index
WSI	Watershed Sustainability Index

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The health of a watershed is important for guaranteed water supply with good quality and usefulness to all water uses such as domestic, industry and agriculture. For the best evaluation of watershed health, we must understand quantitative and qualitative indicators that determine the sustainability level of a watershed. Watershed sustainability index (WSI) is a quantitative output of various sustainability indicators in a watershed. The index provides a simplified and multidimensional view of a system (Mayer, 2008). In order to maintain sustainability of a watershed, decision-makers require timely information on the health of the watershed. Sustainability indicators and aggregation of these indicators into a single quantitative unit (i.e. WSI) is increasingly being used by the decision-makers (Chaves and Alipaz, 2007; Chung and Lee, 2009a; Firdaus *et al.*, 2014; Kim and Chung, 2014). It is important to emphasize that the WSI is not adequate for sustainable management of a watershed as additional information unique to each watershed which is not included in the index is also needed (Hezri and Dovers, 2006; Ness *et al.*, 2007). Although WSI cannot cover all aspects of the watershed especially the intangible qualities which are difficult to present in monetary units, it is useful in providing an initial assessment of the watershed's health and guides decision-makers to make better and timely decisions for preventing watersheds from degradation.

A framework can be used to organize indicators. One example of framework is the pressure-state-response (PSR) which shows relationships between indicators. Majority of information that determines the sustainability index scores is selected based on their quantifiable nature, but there are many indicators that are qualitative (e.g. social values attached to river waters) and are based on the subjectivity factor (Catano *et al.*, 2009). The qualitative indicators may need to be converted to a numerical value for determining WSI.

1.2 Background of the Study

Watershed is the area that captures water from various forms and drains it into common water body such as stream, lake and ocean (DeBarry, 2004). Among the main functions of watershed are collecting water from sources like rainfall and snowmelt, storing the water and then discharge it. Most of our activities depend on watershed thus it is vital to keep our watersheds healthy and sustainable. Sustainability has been an important concept in watershed managements. The concept was introduced in Brundtland report that defines sustainability as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). Due to rapid developments and mismanagement, many watersheds all around the world (e.g., Chittagong Hill Tracts in Bangladesh (Biswas *et al.*, 2012), Yangtze River Basin in China (Cui *et al.*, 2012) and Bernam Watershed in Malaysia (Alansi *et al.*, 2009)) are undergoing degradation and this causes problems such as the reduction of the quantity as well as the quality of water resources and deterioration of natural resources. Noticing the watershed problems that bring so much loss to human and the environment, many studies have been done to devise effective watershed managements that can prevent and mitigate the problems related to watersheds (Agostinho *et al.*, 2010; Curtis *et al.*, 2002; Strager *et al.*, 2010; Richardson *et al.*, 2011; Qi and Altinakar, 2011).

Proper management of a watershed needs a complete understanding of the current watershed conditions. A prominent way in evaluating the condition of watersheds is by developing WSI. It can help to communicate and organize the information of the watershed in a simplified manner besides assessing the watershed sustainability. There are many frameworks that can be applied to develop and organize the indicators for watersheds and one of them is the Pressure-State-Response (PSR) framework. This framework lays out basic relationships between the human activities, resulting condition of environment and human response to improve the pressure (Figure 1.1). The PSR model brings an advantage by highlighting the links between pressure, state and response thus helping the decision makers to see environment issues as interconnected (OECD, 2003). This framework assists the process of determining the suitable watershed sustainability indicators which consists of many important aspects or criteria such as social, economic and environmental.

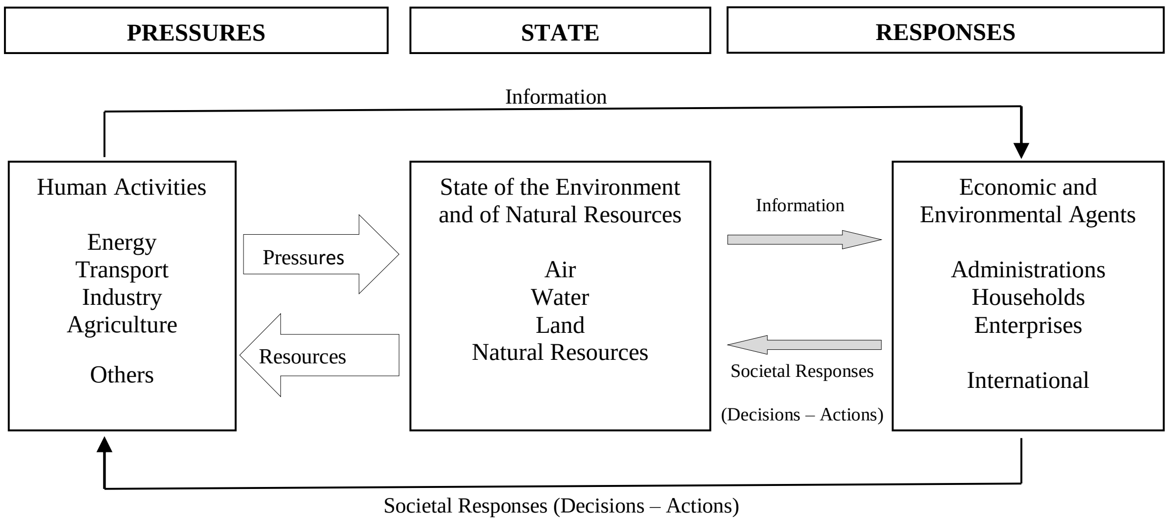

Figure 1.1 PSR Framework (Source: OECD, 1994)

Since watersheds are complex systems that integrate several components and factors such as forest, land, people and animals thus to manage watersheds, a holistic approach is more appropriate compared to dealing with the problems in fragmented manner. Other than that, management of watersheds requires the collaborative effort and input by various stakeholders and organizations with different priorities and objectives (Arnette *et al.*, 2010; Perkins, 2011; Bosch *et al.*, 2013). Therefore, in watersheds management that involves not only multiple criteria and indicators but also multiple parties, Multi-Criteria Decision Making (MCDM) approach should be employed rather than using the single-criterion approach (e.g., benefit-cost analysis)

(Chang *et al.*, 2008; Trenholm *et al.*, 2013). MCDM approach consists of several methods (e.g., ELECTRE, PROMETHEE and Evamix Method) where each has different procedures (Corrente *et al.*, 2014; Darji and Rao, 2013; Rogers, 1999). The interest of decision-makers and researchers in solving watersheds problems by using MCDM approach has grown rapidly over the years (Biswas *et al.*, 2012; Chung and Lee, 2009a; Hermans *et al.*, 2007). It is widely used because it can consider different alternatives on various criteria for selecting the best or the suitable alternative management strategy.

1.3 Problem Statement

Malaysia is rich in water resources with the annual rainfall ranges from 1800 mm to 2600 millimetres, which is above the global average of annual rainfall of 1123 millimetres (Adnan *et al.*, 2002; Legates and Willmott, 1990). However, the richness in water resource does not guarantee that watersheds in Malaysia are healthy and safe from deterioration. Watersheds in Malaysia are affected by increasing rates of urbanization and industrialization. Many environmental problems (e. g. river water pollution, flooding, river sedimentation and water shortage) have already been witnessed in some regions of the country. From the assessment of the river water quality by the Department of Environment (DOE), it was found that 18 river basins were polluted, 46 were slightly polluted and 79 were clean (DOE, 2007). Actions should be taken to improve quality of the polluted and slightly polluted rivers as well as maintaining the quality of clean rivers in Malaysia. Another major problem that should be addressed is flooding. Having tropical and humid climate with heavy rain, some of the areas in Malaysia are prone to flooding and this causes enormous loss (e.g. humans' lives, economy, health and environment) and the problem is worsen by having flash floods due to rapid developments in most cities in the country. The 2007 floods in Johor caused 18 deaths and USD 489 million in damage and the floods in 2008 killed 28 people and caused damage estimated at USD 21.19 million (Chan, 2012).

Skudai River watershed is in danger as it faces rapid development activities in areas such as Kulai, Senai, Tampoi and Johor Bahru City. The major problems identified in Skudai River watershed are polluted rivers and flooding (Chin and Goh, 1981; DOE, 2007; Salarpour, 2010). Two rivers in the Skudai River watershed (i.e. Skudai and Melana rivers) were classified as slightly polluted by the DOE. Without immediate action, the rivers might be more polluted as the population and urbanization levels increase. Besides that, some areas in Skudai River watershed are prone to flooding. These problems should not be left without any actions to solve them. Skudai River watershed needs some drastic measures of rehabilitation. Rehabilitating a watershed costs hundreds of millions Ringgit Malaysia and the cost will increase if the problems in the watersheds are more critical. However, rehabilitation without proper watershed management may cause the watershed problems to arise again in future.

In this study, Skudai River watershed was delineated into 25 sub-watersheds based on topography characteristics for better investigation and identification of more vulnerable areas by using ArcGIS 10. The development of watershed sustainability index for the Skudai River watershed is proposed by using PSR framework. Employing PSR framework is useful to determine the suitable watershed indicators for gaining the information about the watershed. Realizing the importance of integration approach, the sustainability indicators are developed based on several aspects that can be linked to the problems in the Skudai River watershed such as hydrology and environmental. The watershed sustainability indicators were categorized into two main components which were PFD and PWQD. From the indicators that were selected in this study, data for the indicators were acquired from respective departments and authorities.

Since there were many watershed sustainability indicators involved, short-listing of the indicators was performed from literature review and the Malaysian watershed conditions and environment. As all the indicators were not of equal importance for determining sustainability level of the watershed, an expert opinion survey of 30 experts was conducted to get relative importance weights of the sustainability indicators. Obtaining the relative importance weights of the sustainability indicators involved many steps including the selection of suitable weighting method, the mode of survey, the survey participants, the survey sample size and the suitable survey data analysis tool. Besides that, from previous studies, it was found that one of the ways to effectively manage a watershed was prioritizing sub-watersheds so that more vulnerable sub-watersheds could be easily identified and immediate actions can be initiated. The identification of more vulnerable areas within a watershed could save resources and fast rehabilitation measures could be adopted. Thus, in this study, all the sub-watersheds were ranked by using the PROMETHEE through the D-Sight software (Yu *et al.*, 2013).

1.4 Objectives

The purpose of this study is to develop a priority ranking of Skudai River sub-watershed based on PFD and PWQD by considering suitable watershed indicators and stakeholders' preferences on those sustainability indicators. The specific objectives of the study are as follows:

i. To modify DOE-WQI for the Skudai River and tributaries for assessing accurate water quality status in the river.
ii. To identify the problematic areas affected by land use patterns in Skudai River sub-watersheds for priority rehabilitation measures in the watershed.
iii. To know experts' preferences on flood damages and water quality parameters in a pairwise comparison method.
iv. To assess the sustainability level of the Skudai River sub-watersheds from flood damage and water quality parameters.

1.5 Scope of the Study

This study is limited to Skudai River watershed. The watershed sustainability indicators developed were filtered by several criteria as suggested in literature to avoid unmanageable number of indicators. Since the duration for this study was limited to maximum three years, one criterion was more important compared to the others was the availability of data. Therefore, the sustainability indicators that either were not available with respective departments or require more time and resources (human as well as financial resources) to collect were not incorporated in the WSI. The WSI was also limited to hydrology and environment aspects only. PROMETHEE was selected for developing priority ranking of sub-watersheds in the Skudai River watershed. D-Sight software was employed to analyse watershed problems more efficiently. The expert opinion survey was completed from 30 respondents but the selection of the respondents was not done blindly as the respondents who are experts in watershed management would provide a fair and quality response. Despite all the limitations, the study can still have extensive supporting material for high reliability in the results and the study conclusions.

1.6 Significant of the Study

This study is significant because the results produced can bring contributions to watershed management and hydrological field in Malaysia. Development of WSI is seen as an effective method to manage a watershed. It can assist us in finding the factors that are contributing to watershed problems before taking appropriate actions to lessen the effects. The WSI can also be developed for other watersheds but we must be aware that different watersheds may require different sets of watershed indicators to comprehensively understand the watershed. Sustainability indicators developed in this study can provide a reference to other researchers where they can refer to the Skudai River WSI before developing the suitable watershed indicators for the watershed that they want to investigate.

Priority ranking of Skudai River sub-watersheds according to PWQD and PFD would help the watershed management authority and watershed managers to know the problematic sub-watersheds thus management strategies can be focused on them on priority basis. It can definitely contribute to an effective watershed management. Other than that, this study can be an example of integrated watershed management (as required by the government) because all the possible indicators that can contribute to the watershed problems were taken into account. It also includes many departments and local authority for obtaining watershed related data for the Skudai River watershed.

1.7 Thesis Outline

Chapter 1 gives the general overview of the study by briefly introducing the concept of watershed management, WSI, PSR framework and MCDM approach. The study objectives and scope are also provided in this chapter. Chapter 2 discusses the literature review which comprises sub-topics such WSI, WQI, PWQD, PFD and MCDM methods. Chapter 3 describes the methodology of the study. Steps in achieving study objectives including delineation of the Skudai River watershed by using ArcGIS 10, river water sample collection, questionnaire design and survey administration in field are discussed in this chapter. Chapter 4 discusses the data analysis of river water quality and the WSI. The weights on water quality parameters and watershed sustainability indicators are shown in this chapter. Chapter 5 provides in-depth discussion on the study findings. It comprises the results and discussion of water quality and WQI of Skudai River and its tributaries. The results of WSI score and sub-watersheds ranking generated from the D-Sight software application are also discussed in chapter 5. The study conclusion and recommendations are given in Chapter 6.

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