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DEVELOPMENT OF A HYDROLOGICAL INDEX FOR MANGROVE IN MATANG MANGROVE FOREST RESERVE, PENINSULAR MALAYSIA

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By

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DEVELOPMENT OF A HYDROLOGICAL INDEX IN MATANG MANGROVE FOREST, PENINSULAR MALAYSIA

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Faculty : Forestry

Mangrove hydrology is threatened by the massive degradation resulted from anthropogenic impacts such as rapid development and other land uses over the years. This study was implemented to characterize the climate and hydrological conditions with the seasonal and tidal variations and further developed an index to assess the mangrove hydrological conditions using Principal Component Analysis (PCA). Climate data were acquired from the Malaysian Meteorological Department (MetMalaysia) from 1989 to 2014 and the Department of Irrigation and Drainage (DID) from 1995 to 2014. Water samples from 24 sampling stations were collected from four rivers (Sg Tiram Laut, Sg. Jarum Mas, Sg. Tinggi, and Sg. Sepetang) representing three areas of Matang Mangrove (i.e. Kuala Trong, Sungai Kerang, and Kuala Sepetang) during the dry period (June and July) and the wet period (November and December) of 2015. *In-situ* data collection (DO, pH, EC, turbidity, TDS, salinity, temperature, river width, depth, and velocity) and laboratory analysis of TSS were conducted according to Standard Methods (APHA, 2012). Results from the climatic data analysis showed that the period 1999 to 2000 recorded the highest total rainfall for all sampled stations. Bukit Larut recorded the highest average annual rainfall (4,008.3 mm in 1999), and highest total rainfall (5,244 mm in 1999). Range for parameters in all sampled rivers were as follows: DO (0.16–12.36 mgL^{-1}), temperature (26.70–32.90 °C), pH (6.21–9.81), EC (0.50–468.10 μScm^{-1}), TDS (0.06–57.30 gL^{-1}), salinity (0.10–32.33 ppt), turbidity (2.29–819.00 NTU), and TSS (0.10–41.70 mgL^{-1}). Based on the PCA analysis, two of the parameters came out as important metrics for Mangrove Hydrology Index (MHI) which were TDS (score = 0.50) and salinity (score = 0.50). Findings from this study exhibited that the activities adjacent to the Matang Mangrove rivers, such as aquaculture, agriculture, and tourism contributed to the water quality dynamics, particularly TDS and salinity. Thus, the Mangrove Hydrological Index formulated might be able to benchmark the hydrology conditions and acts as a guideline for future land uses in mangrove.

Abstrak tesis yang telah dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

PEMBANGUNAN INDEKS HIDROLOGI DI HUTAN BAKAU MATANG, SEMENANJUNG MALAYSIA

Oleh

NIK HARUN AL-RASHID BIN NIK ZAIDIN

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Hidrologi hutan bakau terancam dengan kemerosotan yang teruk daripada impak antropogenik seperti pembangunan pesat dan guna tanah yang lain sejak bertahun-tahun. Kajian ini dijalankan untuk mencirikan iklim, hidrologi dan membangunkan indeks hidrologi bagi hutan bakau menggunakan 'Principal Component Analysis' (PCA). Data iklim diperoleh dari Jabatan Meteorologi Malaysia (MetMalaysia) dari 1989-2014 dan Jabatan Pengairan dan Saliran (JPS) dari 1995-2014. Sampel air dari 24 buah titik pensampelan dikutip dari empat sungai utama (Sungai Tiram Laut, Sungai Jarum Mas, Sungai Tinggi dan Sungai Sepetang) di dalam tiga kawasan utama Matang (iaitu Kuala Trong, Sungai Kerang dan Kuala Sepetang) semasa musim kering (Jun dan Julai) dan musim basah (November dan Disember) tahun 2015. Pengumpulan data *in-situ* (Oksigen Terlarut, pH, Konduktiviti Elektrik, Kekeruhan, Jumlah Pepejal Terlarut, Kemasinan, dan Suhu) serta analisis makmal (Jumlah Pepejal Terampai) mengikut Kaedah Piawai (APHA, 2012). Hasil analisis iklim menunjukkan tahun 1999 hingga 2000 merekodkan jumlah hujan tertinggi antara stesen-stesen yang diambil. Bukit Larut merekodkan purata hujan tahunan tertinggi (4008.3mm) pada 1999 dan jumlah hujan tertinggi (5244mm). Julat bagi semua parameter di semua sungai yang disampel adalah seperti berikut; oksigen terlarut (0.16-12.36 mgL^{-1}), suhu (26.70-32.90°C), pH (6.21-9.81), konduktiviti elektrik (0.50-468.10 μScm^{-1}), jumlah pepejal terlarut (0.06-57.30 gL^{-1}), kemasinan (0.10-32.33 ppt), kekeruhan (2.29-819.00 NTU) and jumlah pepejal terampai (0.10-41.70 mgL^{-1}). Hasil analisis PCA, dua parameter yang mempunyai metrik penting untuk MHI iaitu jumlah pepejal terlarut (skor = 0.50), kemasinan (skor = 0.50). Penemuan kajian ini menunjukkan aktiviti berdekatan sungai-sungai hutan paya bakau Matang seperti akuakultur, pertanian dan pelancongan menyumbang kepada dinamik parameter kualiti air terutamanya jumlah pepejal terlarut dan kemasinan. Maka, Indeks Hidrologi yang dibina berupaya untuk menanda-aras keadaan hidrologi yang berperanan sebagai satu garis panduan untuk aktiviti manusia pada masa hadapan di hutan paya bakau.

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I certify that a Thesis Examination Committee has met on date month 2017 to conduct the final examination of Nik Harun Al-Rashid b. Nik Zaidin on his thesis entitled "Development of Hydrological Index For Mangrove in Matang Mangrove Forest, Perak Peninsular Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1988. The Committee recommends that the student be awarded the Master of Science.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

°C	Degree Celsius
$(HI)_C$	Hydrological Index
μScm^{-1}	Micro Siemen per centimetre
ANOVA	Analysis of Variance
APHA	American Public Health Association
AWS	Automatic Weather Station
Ca	Calcium
CCD	Coast Conservation Department
CO^2	Carbon Dioxide
DID	Department of Irrigation and Drainage
DO	Dissolved Oxygen
DOE	Department of Environment
DRMT	Duncan Multiple Range Test
E	East
EC	Electric Conductivity
ENSO	El-Niño Southern Oscillation
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FTU	Formazin Turbidity Unit
gL^{-1}	Gram per litre
GFC	Guyana Forest Commission
GGWS	Golden Gate Weather Service
H	High tide
ha	Hectares
hPa	High Power Amplifier
i.e.	In other words
ID	Identification
IPCC	Intergovernmental Panel on Climate Change
ITTO	The International Tropical Timber Organization
L	Low tide
m	Metre
ms^{-1}	Metre per second
MCE	Multicriteria Evaluation
MetMalaysia	Malaysian Meteorological Department
Mg	Magnesium
mgL^{-1}	Milligram per litre
MHI	Mangrove Hydrological Index
MMD	Malaysia Meteorological Department
MQI	Mangrove Quality Index
MSL	Mean Sea Level
MSLP	Mean Sea Level Pressure
MWQCS	Malaysia Marine Water Quality Criteria and Standards
N	North
NA	Not available
NEC	Nature Education Centre
NS	Not significant
NTU	Nephelometric Turbidity Units
NWQS	National Water Quality Standards for Malaysia

PC	Principal Component
PCA	Principal Component Analysis
ppt	Part per thousand
PSU	Practical Salinity Unit
PT.	Point
RH	Relative humidity
s	Second
S	Significant
SFD	Sabah Forestry Department
Sg.	Sungai
SJM	Sungai Jarum Mas
SPSS	Statistical Package for Social Science
SSP	Sungai Sepetang
Std. Dev.	Standard deviation
Std. Error	Standard Error
STG	Sungai Tinggi
STR	Sungai Tiram Laut
TDS	Total Dissolved Solids
TEEB	The Economics of Ecosystems and Biodiversity
TSS	Total Suspended Solids
WQI	Water Quality Index
WWF	World Wildlife Fund

Forests of the Tide

At the intersection of land and sea, mangrove forests support a wealth of life, from starfish to people, and may be more important to the health of the planet than we ever realized…

National Geographic

CHAPTER 1

INTRODUCTION

1.1 General Background

Mangrove is an ecological assemblage of trees, shrubs, palms, and ferns adapted to grow above mean sea level in the inter-tidal region of coastal and estuarine environments (Duke, 1998; Feller *et al.*, 2010). They have been recognized as the only forests situated at the confluence of land and sea in the world's subtropics and tropics area. Mangrove is commonly found in sheltered coastlines and estuaries of tropical and subtropical regions (Giri *et al.*, 2011). The unique characteristics of mangroves are that they are inundated regularly with seawater and exposed to harsh environmental settings such as high salinity, high temperatures, extreme tides and currents, high rates of accretion (sedimentation), and often acidic anaerobic soil (Chong, 2006).

Mangroves possess characteristics that, in total, make them structurally and functionally unique (Arumugam & Kumar, 2014). Morphological and ecophysiological characteristics and adaptations of mangrove trees include aerial roots, viviparous embryos, tidal dispersal of propagules, rapid rates of canopy production, frequent absence of an understorey, absence of growth rings, wood with densely distributed narrow vessels, highly efficient nutrient retention mechanisms, and the ability to cope with salt and to maintain water and carbon balance (Alongi, 2002). Over the decades, mangroves have been acknowledged for the provision of numerous types of ecosystem services which directly or indirectly contribute to human well-being (TEEB, 2010). This includes timber for commercial charcoal production (Chun *et al.*, 2011), food for subsistence (Mumby *et al.*, 2004), coastline barrier against natural disasters (Alongi, 2002) as well as breeding and nursing grounds for fish (Jusoff, 2008).

In recent years, mangroves play a significant role in the global carbon cycle as a major coastal carbon sink (Laffoley and Grimsditch, 2009). According to Donato *et al.* (2011), mangroves are among the most carbon-rich forests in the tropics. The burial of carbon in sediments, soil organic carbon, and the aboveground and belowground living biomass are the carbon pools that are critical to the role of mangroves as efficient and intense carbon sinks (Laffoley and Grimsditch, 2009; Murray *et al.*, 2011). In fact, the amount of carbon sequestered in non-wetland forest is significantly lower than in mangroves and it has been estimated that the destruction of a hectare of mangrove forest can potentially release as much carbon as a destruction of 3 to 5 ha of tropical forest (Ong, 1993; Murray *et al.*, 2011). The carbon captured and stored by coastal marine and wetland ecosystems such as mangroves is known as blue carbon (Nellemann *et al.*, 2009; Murray *et al.*, 2011).

Basically, mangrove systems differ greatly with respect to hydrological and hydro-geochemical parameters which principally vary because of some factors such as tidal processes, rainfall events, evapotranspiration, and differences in topography (Kjerfve *et al.*, 1999). Hydrological conditions in mangrove systems control structures such as the vegetation and production. These regularly cause changes in the hydrogeochemical properties of waters and suspended material in mangrove.

Mangrove forests are threatened by two factors which are natural processes and human activities (Hassan and Rahmat, 2016). These two factors are the primary causes of coastline changes in mangrove. This ecosystem is extremely sensitive to current rising sea levels caused by global warming and climate change (Erkki, 2010). For example, climate change is one of causes of coastline changes. Climate change will bring various negative effects including: greater frequency of heat waves; increased intensity of storms, floods and droughts; rising sea levels; a more rapid spread of disease; and loss of biodiversity (Dasgupta *et al.*, 2009). Recent evidences suggested that the increased water level caused by climate change is one of the many threats to mangrove forest survival worldwide (Alongi, 2002; Gilman *et al.*, 2008; Briceño *et al.*, 2014). Climate change components that affect mangroves include changes in sea-level, high water events, storminess, precipitation, temperature, atmospheric CO_2 concentration, ocean circulation patterns, and health of functionally-linked neighboring ecosystems as well as human responses to climate change (Gilman *et al.*, 2008) .

Nevertheless, continuous development will affect the stability of the mangrove coastline (Winterwerp *et al.*, 2013). It is reported that the areal extent of mangrove forests has declined by 30-50% over the past half century because of coastal development, aquaculture expansion, and overharvesting of mangrove timbers (Duke *et al.*, 2007). World Resources Institute (2015) estimated that the total mangrove loss in Malaysia and the insular region of Southeast Asia is 25,810 ha (Figure 1.1). Due to the increasing rate of human population, the exploration of mangrove forest through human activities such as logging, deforestation, agricultural land, and waste from industry gives negative impact to the environment and to water quality of mangrove forest (Lugo and Snedaker, 1974; Smith, 1992; Hauff *et al.*, 2006).

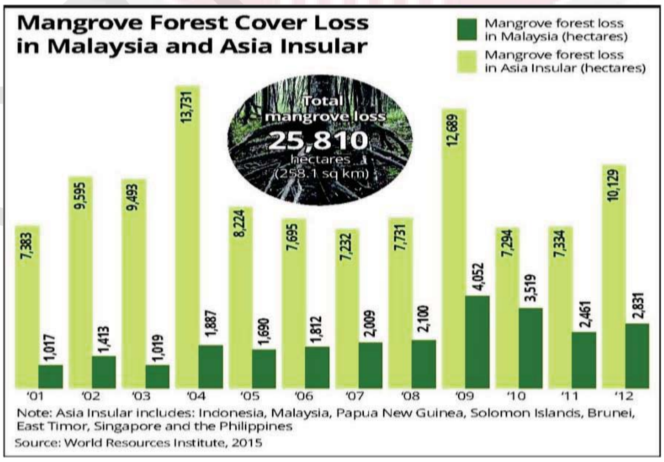

Figure 1.1: The extend of mangrove cover loss in Malaysia and Asia Insular (includes Indonesia, Papua New Guinea, Solomon Islands, Brunei, East Timor, Singapore and the Philippines from 2001 to 2012 (Source: Richard and Friess, 2015)

1.2 Problem Statement

Mangroves have been heavily used traditionally and commercially worldwide. Local communities have always used mangroves as a source of wood for daily use such as cooking, heating, and building houses. Besides, mangroves are important sites for small scale cultivation of shellfish, fish, and crustaceans. Fisherman, farmers, and other rural populations depend on mangroves as a source of wood (e.g. timber, poles, posts, fuelwood, charcoal) and non-wood forest products (food, thatch, fodder, sugar, medicine, and honey) which contributed to high economic returns to the country. Mangroves were also often used for production of tannin suitable for leather work and for curing and dyeing of fishing net (FAO, 1994).

Besides that, felling of trees is one of the oldest forms of commercial exploitation including in mangrove. In particular, mangroves should be treated carefully without underestimating their role for local livelihoods, and determine their long-term benefits reach future generations via appropriate conservation and management practices (Goessens *et al.*, 2014). There is an increasing need to monitor and assess mangrove forest structure and dynamics to increase a better understanding of their basic biology and foster help for guidance in conservation, restoration, and management efforts of the ecosystem. Another concern of mangroves is their function for aquaculture, both as open water estuarine mariculture (e.g. oyster and mussels) and as pond culture (mainly for shrimps), with the areas extending gradually year to year.

Recent evidences also suggested that mangrove conversion to other land uses such as agriculture showed an increasing trend (Giri *et al.*, 2014). Lately, tropical mangrove has been facing tremendous challenges from urban development and human exploitation. Many forested areas in particularly mangrove areas have been extensively cleared for agriculture, plantation, and other development purposes resulting in pollution to the mangrove water. Human activities and land uses impacted the mangrove ecosystem particularly on hydrology. Mangrove water often deteriorates because of the plantation, intensive aquaculture, deforestation, industrial factory, and urban development which discharge wastes and runoffs into water bodies (Ardebili *et al.*, 2006).

In contrast to tropical rainforests, mangroves lack the prominent level of research and conservation efforts which resulted in the limited understanding of these ecosystems. Until today, there is no standard guideline for policy maker to regulate the human activities that have impacted mangrove hydrology (Ibharim *et al.*, 2010) except for Marine Water Quality Criteria and Standards (MWQCS) introduced by Department of Environment of Malaysia (DOE). Therefore, this study is conducted to provide a guideline for human activities in mangrove forests.

The assessment of hydrology in mangrove rivers demonstrates the hydrological conditions in Matang Mangrove. To understand the dynamics of mangrove hydrology, the basic knowledge of hydrology and mangrove characteristics itself need to be mastered. Thus, seasonal and tidal variations are the crucial elements that are considered for hydrological assessment. In addition, with the contributed pollution from adjacent land uses, the mangrove water is likely being affected with impacts such as degradation and sedimentation. Therefore, the development of a hydrological index is projected to benchmark the extent of the influence from land uses in Matang Mangrove.

To date, minimal studies which is less than another kind of mangrove studies were carried out focusing on the mangrove hydrology which have been impacted by adjacent land use,. All the major human activities in Matang Mangrove (i.e. forest production, agriculture, aquaculture, and ecotourism) is believed to affect the mangrove biotic and abiotic components such as its vegetation, aquatic life, and most importantly, the water. It is crucial to assess the pollutant contribution of human activities towards the hydrology of mangrove. So, the development of hydrological index from Matang Mangrove can act as a baseline and should be reliable to be used in other mangrove areas.

If there is no index specifically for mangrove hydrology, there will be an adverse impacts on the mangrove ecosystem itself such as the function of mangrove will be disturbed and eventually will threaten the mangrove ecosystem. Besides, without regulation such as hydrology index, the hydrology in mangrove will be altered and this will affect the mangrove structure and system.

1.3 Aim and Objectives

The aim of this research is to assess the hydrological conditions in Matang Mangrove in Perak, Peninsular Malaysia. Four objectives were designed to achieve this aim, which are:

1. To characterize long-term rainfall (1989–2014) and climate data (1995–2014) from Matang Mangrove in relation to global changes.
2. To characterize the physicochemical parameters in mangrove rivers in relation to climatic seasonal variations.
3. To analyze the physicochemical parameters in mangrove rivers in relation to tidal variations.
4. To develop a Mangrove Hydrological Index for mangrove forest in Peninsular Malaysia.

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