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TROPICAL RAINFOREST TYPOLOGY AND CONVERSION EFFECTS ON RIVER WATER QUALITY SARAWAK, MALAYSIA

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**TROPICAL RAINFOREST TYPOLOGY AND CONVERSION EFFECTS
ON RIVER WATER QUALITY SARAWAK, MALAYSIA**

By

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**Thesis Submitted to the School of Graduate Studies, Universiti Putra
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TROPICAL RAINFOREST TYPOLOGY AND CONVERSION EFFECTS ON RIVER WATER QUALITY SARAWAK, MALAYSIA
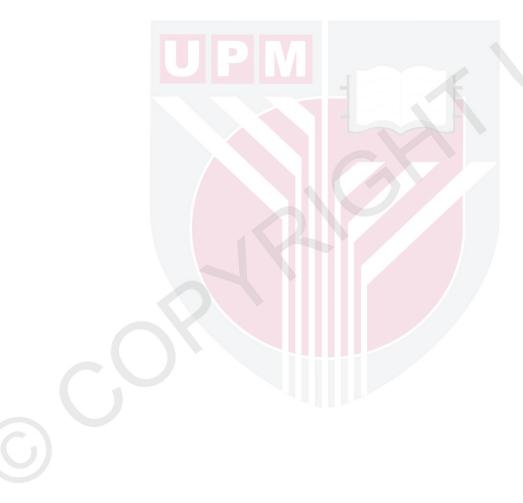
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Despite various efforts taken by Malaysia Government, water quality degradation in Malaysian rivers remains unsolved. There is an urgent need to conduct detail studies on water quality condition from various land use of Malaysia. This study was conducted in response to environmental problems of Malaysia and its conversions effect on river water quality. Thus, the objectives of this study were to: (i) determine the impacts of converted forest on water quality; (ii) determine water quality status of several tropical forest types and forest conversion; (iii) derive pollutant concentration of the river water; and (iv) identify the most influence variables cause deteriorating of water quality of forest land uses. A total of 756 water samples were collected from upstream, middle stream and downstream of river at each study area. Water quality was interpreted using National Water Quality Standard and Water Quality Index developed by Department of Environment Malaysia and analysis implemented according to Standard Methods for the Examination of Water and Wastewater by APHA was followed. The physico-chemical variables of river water of dam (Bakun), oil palm plantations (Lawas II) and agricultural area (Lawas III) were found under Class III (moderate water quality) status; while river waters at logging area (Mukah) found under Class IV (slightly polluted). The most influence variables that cause the deteriorating of water quality is moderately low dissolved oxygen; high concentration of ammonia nitrogen; biochemical oxygen demand; chemical oxygen demand; major ion and trace metals; and nearly acidic pH. This study also revealed that due to conversion of tropical forest into various land use; water quality had deteriorated significantly as was evident from variation of water quality variables. Independent samples test (t-test) showed that the selected physico-chemical variables varied significantly from disturbed and undisturbed forest ($P<0.05$). Whereas one-way ANOVA showed that the selected physico-chemical variables varied significantly from locations ($P<0.05$); and both found high at disturbed forest. The ANOVA illustrated that the water quality progressively deteriorated from upstream to downstream areas. Pearson correlation revealed the

facts that all the physicochemical variables of river water are correlated to some or the other ways. Any deterioration to one variables; will cause deterioration to other variables. The PCA results revealed that 87.30% of the total variance was explained by five factors, that is, organic and inorganic (42.96%), salinity factors (22.11%), organic pollution (dissolved and suspended material) (8.61%), waste water pollution from agricultural and organic load (7.07%) and erosion factor (6.56%) that represents total variance of waters quality in the disturbed forest. Overall these results highlight the sensitivity of river water towards quality changes respectively, which may be altered as a result of both, extensive land management and natural ecosystem disturbances. Conversion of natural tropical forest to other land uses to generate negative impacts and severely affects the forest waters quality. Balancing the needs of growth and protecting forest usually has a large effect on water quality and should be a priority.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

TIPOLOGI HUTAN HUJAN TROPIKA DAN KESAN PENUKARAN KE ATAS KUALITI AIR SUNGAI SARAWAK, MALAYSIA

Oleh

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Pengerusi : Profesor Madya Seca Gandaseca, PhD
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Walaupun pelbagai usaha telah diambil oleh Kerajaan Malaysia, kemerosotan kualiti air di sungai-sungai Malaysia masih belum dapat diselesaikan. Terdapat keperluan mendesak untuk menjalankan kajian terperinci mengenai keadaan kualiti air dari pelbagai guna tanah di Malaysia. Kajian ini dijalankan sebagai tindak balas kepada masalah alam sekitar di Malaysia dan kesan penukaran tanah terhadap kualiti air sungai. Oleh itu, objektif kajian ini adalah untuk: (i) menentukan impak penukaran hutan terhadap kualiti air; (ii) menentukan status kualiti air daripada beberapa jenis hutan tropika dan hutan yang ditukar (iii) memperoleh kepekatan bahan pencemar air sungai; dan (iv) mengenal pasti pembolehubah yang paling mempengaruhi serta menyebabkan kemerosotan kualiti air melalui penggunaan tanah hutan. Sebanyak 756 sampel air telah diambil dari hulu, aliran tengah dan hilir sungai di setiap kawasan kajian. Kualiti air telah ditafsirkan menggunakan Standard Kualiti Air Negara dan Indeks Kualiti Air yang dibangunkan oleh Jabatan Alam Sekitar Malaysia dan analisis dilaksanakan mengikut Kaedah Standard bagi Peperiksaan Air dan Air Sisa oleh APHA diikuti. Pembolehubah fiziko-kimia air sungai empangan (Bakun), ladang kelapa sawit (Lawas II) dan kawasan pertanian (Lawas III) didapati berada di bawah status Kelas III (kualiti air sederhana); manakala air sungai di kawasan pembalakan (Mukah) didapati di bawah Kelas IV (sedikit tercemar). Pembolehubah yang paling mempengaruhi menyebabkan kemerosotan kualiti air adalah kandungan oksigen terlarut yang sederhana rendah; kepekatan ammonia nitrogen; permintaan oksigen biokimia; permintaan oksigen kimia ion utama dan logam surih yang tinggi dan pH yang hampir berasid. Kajian ini juga menunjukkan bahawa disebabkan oleh penukaran hutan tropika ke dalam pelbagai kegunaan tanah; kualiti air telah merosot dengan ketara seperti yang terbukti daripada perubahan pembolehubah kualiti air. Ujian sampel bebas (t-test) menunjukkan bahawa pembolehubah fizikokimia yang dipilih adalah berbeza dengan ketara antara hutan terganggu dan tidak terganggu $(P<0.05)$. Manakala ANOVA satu hala menunjukkan bahawa pembolehubah fiziko-kimia adalah berbeza dengan ketara antara lokasi

(P<0.05); dan kedua-dua didapati tinggi di hutan terganggu. ANOVA menggambarkan bahawa kualiti air semakin merosot dari kawasan hulu ke hilir. Manakala, korelasi Pearson mendedahkan fakta yang semua pembolehubah fizikokimia air sungai sentiasa berhubungan antara satu sama lain. Sebarang kemerosotan kepada satu pembolehubah kualiti air akan menyebabkan kemerosotan kepada pembolehubah yang lain. Keputusan PCA mendedahkan bahawa 87.30% daripada jumlah varians yang dijelaskan oleh lima faktor, iaitu, pencemaran organik dan bukan organik (42.96%), faktor-faktor kemasinan (22.11%), pencemaran organik (terlarut dan terampai) (8.61%), pencemaran air buangan dari beban pertanian organik (7.07%) dan faktor hakisan (6.56%) yang mewakili jumlah varians kualiti air di dalam hutan terganggu. Secara keseluruhannya, keputusan ini menyerlahkan sensitiviti air sungai ke arah perubahan kualiti masing-masing, yang mana boleh berubah akibat daripada kedua-duanya, iaitu penggunaan tanah secara meluas dan akibat gangguan ekosistem semula jadi. Penukaran hutan tropika semula jadi untuk kegunaan tanah yang lain menjana impak negatif dan menjejaskan kualiti air hutan dengan teruk. Mengimbangi keperluan pertumbuhan dan melindungi hutan biasanya mempunyai kesan yang besar kepada kualiti air dan harus menjadi keutamaan.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:
- the research conducted and the writing of this thesis was under our supervision;
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LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AAS	Atomic Absorption Spectrophotometry
APHA	American Public Health Association
DOE	Department of Environment
EPA	Environment Protection Agency
FAO	Food and Agriculture Organization of the United Nations
GPS	Geographical Positioning System
Min	minimum
Max	maximum
mg/L	milligrams per liter
mm	Millimeter
MW	Megawatt
NWQS	National Water Quality Standards
NTU	Nephelometric Turbidity Unit
PCA	Principal Component Analysis
SPSS	Statistical Package for Social Science
Std.	Standard Deviation
T-test	t-test
UNESCO	The United Nations Educational, Scientific and Cultural Organization
UPM	Universiti Putra Malaysia
USEPA	United States Environmental Protection Agency
SD	Standard Deviation

WHO   World Health Association

WQI   Water Quality Index

°C   degree Celsius

INTRODUCTION

1.1   Background

Tropical rainforests are the oldest ecosystems in the world and the oldest tropical rainforest in Malaysia is estimated at 130 million years old. The classifications of forests are categorized according to the characteristics of flora composition, habitat, climate, soil, biotic and altitude. Forest typology in Malaysia consists of lowland dipterocarp forest, hill dipterocarp forest, upper hill dipterocarp forest, oak-laurel forest, montane ericaceous forest, peat swamp and mangrove forest (KPKKT, 2008; WWF, 2017; USGS, 2016).

Montane ericaceous forest is located at an altitude of over 1,500 meters; oak-laurel forest (1.200 to 1.500 meters); hill dipterocarp forest (300-750 meters) and lowland dipterocarp forest (300 meters). Peat swamp located behind the mangroves towards the land with peat and the water is less salty. Mangrove forest is salt tolerate plant that can be defined as woody trees and shrubs, which grow in the intertidal vegetation in estuaries system, lagoons and seashores that had convergent evolved physiological and morphological adaptations to low tidal shorelines (Figure 3). Forest is a water catchment area and plays a vital role as a sponge, absorbing rainwater and diverts it back into the river or water bodies where the cycle continues. Forest also acts as a filter to ensure the cleanliness and clarity of the water. Hydrological cycles in forest ecosystem have a positive impact on the quantity and quality of river water (Walter *et al.,* 2004; Strauch *et al.,* 2012; WWF, 2017; USGS, 2016).

Over the past few decades, tropical forests have been destroyed at a very fast rate where logging and burning is a major cause of forest destruction (Leng *et al.,* 2009; Berry *et al.,* 2010; Carlson *et al.,* 2012; Abram *et al.,* 2013; Bryan *et al.,* 2013; Gaveau *et al.,* 2014). The Malaysian Borneo is global hotspot of tropical deforestation which facing destruction to all types of forest typology due to logging, industrial, and land development for various purposes such as agricultural, plantation and crops (UNEP, 2008; FAO, 2010; Arthur, 2013; Jason and Shozo, 2013). The degradation rate of forests in Malaysia is accelerating faster compared to other tropical countries in the world (FAO, 2010). Most of the primary forest still remains in Sabah and Sarawak; but majority has been logged (Shannon, 2012).

Approximately 872, 263 (10%) of Sarawak's forests have been destroyed in the last five-year period in which it is four times faster than any other country in Asia (Arthur, 2013). Various development projects and economic activities carried out in Malaysia in pursuit of modernization and rapid increases in living standards in Malaysia have caused various environmental problems. Currently, the primary forests are decreasing, while clearing land for plantations is increasing.

About 8% of forests have been assigned for reserves and protected areas; but still threatened by illegal logging. Urbanization and industrial development directly gave a major impact on natural ecosystems. Excessive exploitation of forests for logging and land development has led to soil erosion, landslides and the destruction of biodiversity in Malaysia.

Uncontrolled deforestation in the catchment area has a negative effect on water supply and water resources in terms of quantity and quality (Ariffin *et al.,* 2008; FAO, 2010). Water pollution occurs because of natural process and most of the contamination is the result of human activities. The process of globalization to pursue development has led to greater pollution problems.

Rivers in developing countries are vulnerable to contamination due to pollution increase, climate and also on various socio-economic purpose (Mustapha *et al.,* 2013). Most of the rivers suffered serious pollution in the rivers that flowing through urban areas with many residents, biodiversity destruction, global warming, and improper waste management in big cities and industrial areas compared to rivers located in rural and remote areas.

According to the Department of Environment Malaysia, the rivers in Malaysia are either slightly contaminated or polluted due to urban waste or agricultural activities (DOE, 2016). The development and rapid urbanization has led to changes in land use in order to meet the needs of economic development, social facilities and other related infrastructure. Whereas, due to economic development and human activities in the catchment area of river have been putting pressure on water bodies. Toxic material that is released into rivers affect the food cycle by influencing and poisoning the life-forms in rivers and lakes such as algae, birds, fish and other wildlife (FAO, 1996; Van der Perk, 2006).

A natural process affects the water quality through rainfall, corrosion, erosion and sediment transport. Various human activities contaminate river water by changing the quality of the river to a level that causes subsequent use was limited. Excessive amount of sediment, nutrients, temperature and chemicals affects water chemistry and cause aquatic habitats degradation. An increasing number of different types of pollutants resulting from residential, industrial and agricultural areas and natural changes over time have led to a decline in water quality. Deforestation, logging and uncontrolled land development had a negative impact on forest ecosystems. Land development and land use changes have exposed the river to various pressures that are not incurred by the river, which indirectly led to changes and instability in the river system not only in quality but also quantity.

Tropical forests of Sarawak Malaysia have experienced various anthropogenic effects that eventually led to the deterioration of water quality, loss of biodiversity and degradation of ecosystems. Thus, the rapid destruction to forest may cause

serious threat to the environment. Most of the tropical forests have been cleared and converted to agriculture and farming for economic return. Most tropical forests have been cleared and converted to agriculture and farming for economic return. Conversion of forests to various land uses causes the destruction to natural ecosystems and biodiversity, soil loss due to erosion and cause serious damage to the watershed in forest area. If the land uses of pristine forests continue without control, all natural forests will be destroyed.

The increased demand for water and degradation of water quality are two major issues at this time. River pollution requires immediate and continuous efforts of various parties to solution. Water resources as a source of fresh water has diminished or even vanished if poorly managed. Although there is still water source; water can be used safely by humans is diminish. The environmental impact assessment is essential for preservation of the ecosystem and its water resources. Without proper management, constant and uncontrolled exploitation of forests may cause long-term adverse effects on environment. This study was conducted in response to environmental problems of Malaysia in some tropical rain forest typology consisting of several types of forest such as natural forest, peat swamp forest and mangrove forests that converted into agriculture, plantation and land development as well as its conversion effect on water quality.

1.2   Problem Statement

To date, the previous studies have some gaps between knowledge on the land conversion effect on river water quality. The present studies are conducted to fill in such information gaps by providing more comprehensive understanding on the river pollution status of tropical waters in different forest typologies. This work uses environmental research approach by combining analytical and statistical analyses to trace and interpreted the collected data. The findings highlight the importance of considering multiple spatial scales of understanding the impacts on human activities on watershed ecosystem services. This study is expected to provide a better perspective on the complex underlying factors that control the river water pollution in the river.

River water quality has become a global concern due to its effect on human life and natural ecosystem, particularly in tropical forest of Sarawak which is under pressure on intensive agricultural and land development. Protecting river water quality is one of the serious issues in water management, which are highly depending on accurate view of river waters quality conditions. The study concerns on water quality deterioration in rivers arising from development. Various development activities have led to changes in the characteristics and function of river ecosystems services. As the country is undergoing a rapid pace of development in the world, most of the rivers in urban areas in Malaysia are slightly polluted. Several anthropogenic activities have continued to degrade the natural environment. Some of the rivers in the area being developed by the industry are heavily contaminated and have lost their natural ecosystem due to rapid urbanization and development activities around the

3

area. Water pollution caused by various types of pollutants such as solid, liquid, organic and inorganic factor. Waste produced in large quantities put pressure on the natural environment and cause severe environmental conditions. This leads to destabilization of natural ecosystems and cause environmental degradation as well as water resources. Human activities pollute and degrade water quality which caused the subsequent use was limited. The availability and quality of water in the state is threatened by pollution, and overall affected by forest condition. In the middle of the new initiative and to meet some other demands, the quality of the environment, particularly water resources is deteriorating. Though, there is a clear general lack of quantification of the effect of deforestation and land conversion to the water quality of the forest. Although efforts to save the tropical forests have received widespread attention, another type of forest is perhaps even more threatened.

Forest supplies a high proportion of the water for domestic, agricultural, industrial and ecological needs in both upstream and downstream areas. There is no denying the fact that the conversion to virgin forests to any commercial venture included oil palm plantations would in one way or another has impact on the environment. The relationship between forests and water is a critical issue that must be accorded high priority. Although some of these occur naturally, with or without the presence of plantations, many adverse impacts are clearly due to poor forest management practices. Furthermore, few studies have considered effects on a river water conditions simultaneously and the effect of forest conversion and research into the impacts on oil palm on freshwaters is very limited.

Therefore, study was conducted in response to environmental problems of Malaysia in selected tropical rain forest typology as well as its conversion effects on water quality. The findings of this study could provide information on the source, and cause of the pollution on its water quality and represent as a baseline data in order to achieve sustainable development as well as environmental concern.

1.3   Research questions

Many studies recognized that land use affect water quality (Osterkamp *et al.,* 1998; Ruhl, 2000; Juahir *et al*., 2011; Juan Huang *et al.,* 2013; Rasul *et al.* 2015; Teck-Yee Ling *et al.* 2016; Narany *et al.,* 2017; Zhang *et al.,* 2017). Potential pollutants include excessive concentrations of organic matter, agricultural or industrial chemicals. As a response to the above challenges, water conservation and efficiency have been increasingly sought as solutions to address deficiencies and to achieve sustainable development. Research efforts identify problems and areas problem, and the probable cause of the problems particularly in different to forest typology that converted into various land uses. There are many types of forest conversion; is there any different effect on water quality of each type of forest conversion? Therefore, in this study it is searched for a better understanding of the interactions between different forest typologies to known the water chemistry trend impacts by forest conversion. A sufficient data onto multiple sites of forest typology can be used to investigate water quality and risk factors statistically. Once sufficient data have been

4

gathered, it is possible to describe the conditions. A significant amount of information and data on tropical forests river has been generated by the study and will be consolidated in permanent databases, monitoring and management procedures.

1.4   Research Framework

STAGE 1: BACKGROUND AND THEORITICAL STUDIES	→	The research design developed to meet the research objectives. Factors that must be considered at this stage of the process include the environmental setting, location of sampling sites, frequency of sample collection, the constituents to be measured, and the methods to be used in the field and the laboratory. Argument, evidence and support, categories below developed as needed. History, background, context, research studies, gaps in research, content as needed, theory, philosophy. Research questions based on issues/concerns in discipline, field *Problem statement *Aim of the study *Significance of study *Objectives determination

↓

STAGE 2: STUDY PLAN	→	The principal elements of a study plan are: a) A clear statement of aims and objectives b) a description of study area concerned c) a description of study sites d) listing of water quality variables that measured e) frequency and timing of sampling f) resources required to implementation.

↓

STAGE 3: ANALYSIS OF DATA	→	Methods of data collection and data analysis (APHA and WHO methods), Quality assurance (QA) and Quality control (QC). Getting background information, ensure adequate monitoring and instrument calibration. Measurements taken in the field and laboratory translate the water's properties into quantitative data that provide information about the condition of water quality. Accurate and complete documentation of procedures is essential at this stage of the process. Statistical analysis/Data management *STATA version 14 *IBM SPSS software version 22 *Descriptive Statistics, ANOVA, T-test, Cluster, PCA, HACA, DA, FA

↓

STAGE 4: Findings, Discussion, and Interpretation/Water quality condition	→	1) Type 1: Natural forest: WQ = ↑ 2) Type 2: Secondary forest: WQ = < Type I 3) Type 3: Conversion forest WQ = < Type I and type 2

STAGE 5: Conclusion	→	Conclusions and suggestion for further research

Figure 1 : Flowchart of the framework of research methodology

1.5 Objectives

The objectives of this study were to determine the impacts of converted forest on water quality. Hence this research has been undertaken with the following objectives summarized as follows:

1. To determine water quality status of several tropical forests types and land conversion.
2. To derive pollutant concentration of river waters.
3. To identify the most influence variables causes deteriorating of water quality of forest land uses.

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184

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