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EVALUATION OF WATER QUALITY USING PATTERN RECOGNITION TECHNIQUE IN MELAKA RIVER BASIN, MALAYSIA

ANG KEAN HUA

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EVALUATION OF WATER QUALITY USING PATTERN RECOGNITION TECHNIQUE IN MELAKA RIVER BASIN, MALAYSIA

By

ANG KEAN HUA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

EVALUATION OF WATER QUALITY USING PATTERN RECOGNITION TECHNIQUE IN MELAKA RIVER BASIN, MALAYSIA

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May 2018

Chair : Faradiella Mohd Kusin, PhD
Faculty : Environmental Studies

The unorganised expansion and uncontrolled urbanisation development had led to environmental issues involved with river water pollution that occurred within the Melaka River basin. There are three objectives study to solve the water quality of the Melaka River basin through (1) to identify the potential sources of Melaka River pollution in correlation with the temporal land use classification, (2) to determine the land use land cover changes in 2015 and predict the future land use land cover for 2022, and (3) to verify pattern recognition based on the land use classification between 2015 and 2022 in the determination of pollutant sources within the Melaka River. The results indicated HCA have two cluster areas (C1 and C2). The DA indicated 12 variables were found to be the most significant parameters with a high variation in the spatial distribution. The PCA found that the C1 was attributed to contamination from the agricultural and residential activities; while the C2 included the pollution sources from the agricultural, residential, industrial, animal husbandry, and sewage treatment activities. In the Pearson correlation analysis and ANOVA analysis shown Vegetation Area (VA), Non-Industrial Area (NIA), Industrial Area (IA), Open Space Area (OSA), and Farming Area (FA) were correlated with majority of the physico-chemical and biological variables. LULC incorporated with CA-Markov chain model analysis showed NIA (67.50%), IA (29.15%) and FA (3.35%) were increased from 2001 to 2015 and 2022; while the VA (89.59%), OSA (3.32%) and WB (7.08%) continued to decrease. In GIS, the LISA analysis indicates 2015 showed the clustered area of C1 with S1 as the main contributor; while C2 of S5 as the main contributor. The Moran I analysis from high-to-low pollutant sources are NIA (0.80) > VA (0.59) > IA (0.42) > OSA (0.40). In 2022, the contamination from high-to-low are VA (0.59) > NIA (0.58) > IA (0.50) > OSA (0.41) in the Melaka River. The hotspot analysis for year 2015 indicated C1 of S1 as the main contributor; while C2 of S5 as main contributor. General G-statistic analysis from high-to-low are IA (1.099×10^{-3}) > NIA (5.39×10^{-4}) > VA (6.9×10^{-5}). In 2022, the hotspot

analysis in C1 indicated S7 as the main contributor; while C2 remains the same as S5 which is the main contributor to have pollutant sources from high-to-low are IA (3.012×10^{-3}) > NIA (5.95×10^{-4}) > VA (7.6×10^{-5}). In conclusion, Moran I and general G-statistic had gained support especially in benefiting from the PCA in recognising the pattern of pollutant sources (e.g. land use classes) with precise details. Simultaneously, LISA and hotspot analysis have an advantage over HCA by recognising the clustered area more specifically, which was based on the pattern of pollutant sources.

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

PENILAIAN KUALITI AIR MENGGUNAKAN TEKNIK CORAK PENGIKTIRAFAN DI LEMBANGAN SUNGAI MELAKA, MALAYSIA

Oleh

ANG KEAN HUA

Mei 2018

Pengerusi : Faradiella Mohd Kusin, PhD
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Pembangunan perbandaran yang tidak teratur dan tidak terkawal telah membawa kepada isu-isu alam sekitar yang melibatkan pencemaran air sungai yang berlaku di dalam lembangan Sungai Melaka. Oleh itu, penyelesaian terhadap kualiti air sungai di lembangan Sungai Melaka melalui kajian objektif seperti (1) untuk mengenal pasti potensi sumber pencemar Sungai Melaka dalam korelasi dengan klasifikasi penggunaan tanah sementara, (2) untuk menentukan perubahan guna tanah 2015 dan meramalkan masa depan guna tanah pada 2022, dan (3) untuk mengesahkan pengiktirafan corak berdasarkan klasifikasi guna tanah antara 2015 dan 2022 dalam menentukan sumber pencemar di Sungai Melaka. Dapatan kajian menunjukkan HCA mempunyai dua kawasan cluster (C1 dan C2). DA menunjukkan 12 pembolehubah didapati merupakan parameter yang paling ketara dengan variasi yang tinggi dalam taburan spatial. PCA menunjukkan C1 dikaitkan dengan pencemaran dari aktiviti pertanian dan kediaman; manakala C2 termasuk sumber pencemaran dari aktiviti pertanian, kediaman, perindustrian, penternakan, dan rawatan kumbahan. Dalam analisis korelasi Pearson dan analisis varians (ANOVA) menunjukkan Vegetation Area (VA), Non-Industrial Area (NIA), Industrial Area (IA), Open Space Area (OSA), and Farming Area (FA) mempunyai perhubungan signifikan dengan majoriti pembolehubah fiziko-kimia dan biologi. Seterusnya, LULC menggabungkan analisis model rantaian CA-Markov menunjukkan NIA (67.50%), IA (29.15%), dan FA (3.35%) telah meningkat dalam tempoh 15 tahun (2001 hingga 2015) dan juga luas guna tanah masa depan (2022); manakala VA (89.59%), OSA (3.32%), dan WB (7.08%) pula terus berkurangan. Dalam GIS, analisis LISA tahun 2015 menunjukkan kawasan kluster C1 dengan S1 adalah penyumbang utama; manakala C2 adalah S5 sebagai penyumbang utama. Analisis Moran I dari sumber-sumber pencemar dari tinggi-ke-rendah adalah NIA (0.80) > VA (0.59) > IA (0.42) > OSA (0.40). Pada 2022, pencemaran dari tinggi-ke-rendah adalah VA (0.59) > NIA (0.58) > IA (0.50) > OSA (0.41) di Sungai Melaka. Analisis hotspot tahun

2015 menunjukkan C1 dari S1 adalah sebagai penyumbang utama; manakala C2 ialah S5 sebagai penyumbang utama. Analisis G-statistik umum dari tinggi-ke-rendah adalah IA (1.099 x 10^{-3}) > NIA (5.39 x 10^{-4}) > VA (6.9 x 10^{-5}). Pada tahun 2022, analisis hotspot di C1 menunjukkan S7 sebagai penyumbang utama; manakala C2 tetap sama dengan S5 sebagai penyumbang utama untuk mempunyai sumber pencemar dari tinggi-ke-rendah ialah IA (3.012 x 10^{-3}) > NIA (5.95 x 10^{-4}) > VA (7.6 x 10^{-5}). Kesimpulannya, Moran I dan G-statistik banyak menyokong terutama dalam memberi manfaat kepada PCA dalam mengiktiraf corak sumber pencemar (contohnya kelas luas guna tanah) dengan tepat dan terperinci. Pada masa yang sama, analisis LISA dan hotspot mempunyai kelebihan terhadap HCA dengan mengenali kawasan kluster dengan lebih spesifik dan khusus, yang berdasarkan corak sumber pencemar.

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I certify that a Thesis Examination Committee has met on 4 May 2018 to conduct the final examination of Ang Kean Hua on his thesis entitled "Evaluation of Water Quality Using Pattern Recognition Technique in Melaka River Basin, 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 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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I hereby confirm that:

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Name of Member of Supervisory Committee: SARVA MANGALA PRAVEENA

Signature: ______________________
Name of Member of Supervisory Committee: NISFARIZA MOHD NOOR

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LIST OF ABBREVATIONS

AOI	Area of Interest
APHA	American Public Health Association
CA-Markov	Cellular Automata-Markov
DA	Discriminant Analysis
DF	Discriminant Function
DOE	Department of Environment
GIS	Geographical Information System
Ha	Hectare
HCA	Hierarchical Cluster Analysis
HPS	High-Pollution Sources
ICP-MS	Inductive Coupled Plasma-Mass Spectrometry
LISA	Local Indicators of Spatial Association
LULC	Land Use Land Cover
MLD	Millions of Litres per Day
MPS	Moderate-Pollution Sources
MRSA	Malaysian Remote Sensing Agency
NWQS	National Water Quality Standard
PCA	Principal Component Analysis
QC/QA	Quality Control and Quality Assurance
ROI	Region of Interest
RS	Remote Sensing
SD	Standard Deviation
Sis	Sub-Indexes
SS	Sampling Station
UNESCO	United Nationals Educational, Scientific and Cultural Organization
USGS	United States Geological Survey
VFs	Varimax Factor
WQI	Water Quality Index

CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysia achieved the best performance in the Environmental Performance Index (EPI) which was recognised as the best in the Asia-Pacific region and ranked 25th out of a total of 132 countries worldwide (MRPE Official Portal, 2012). New Zealand took the top position followed by Japan and Malaysia in the Asia-Pacific region. The EPI for Malaysia is equivalent to the EPI for the best-performing group of countries such as Germany, Iceland, Finland, Denmark, Belgium, and Japan. Among the various aspects that were evaluated ranged from climate change, agriculture, fisheries, forestry, air and water pollution (MRPE Official Portal, 2012). Inevitably, water pollution is considered an important aspect that requires attention which would affect the EPI performance.

Generally, Malaysia is made up of thirteen states, in which Melaka is the smallest state after Perlis and Penang. The Melaka state is located in the southern region of the Peninsular Malaysia and is bordered by Negeri Sembilan to the north and Johor to the south. The Melaka state also known as a state of traditions and was listed as a UNESCO World Heritage Site since 7th July, 2008 (UNESCO Official Portal, 2016). This has provided immense economic development and job opportunities through various sectors such as tourism, commercial and industrial activities. However, the rapid development and urbanisation have indirectly affected the political, cultural, and environmental aspects in the Melaka state.

Inadvertently, unorganised expansion and uncontrolled urbanisation development have led to several water pollution issues within the Melaka River (Rosli *et al.*, 2015). As highlighted earlier, the rapid development and urbanisation that took place in the Melaka state have indirectly resulted in drastic and extreme land use changes within a few years back. In other words, forest land are being victimised for deforestation to transform into agriculture, urban, industrial, as well as farmland, which are important to enhance the quality of human life. This circumstance is taking place especially in Kampung Batu Berendam sub-basin in the urban area after it was recognised as the world tourism centre, where majority of the land resources was in the process of conversion into other classes of land use for human activity purposes (Figure 1.0). Due to the increasing demand for land resources within a period of 5 years after 2007 (Daneshmand *et al.*, 2011), the development for urbanisation has also increased and is suspected to extend northwards into Kampung Cheng, Kampung Tualang and Kampung Harmoni Belimbing Dalam sub-basin area. Since various activities are carried out along the Melaka River and within the Melaka River basin, this has indirectly caused river water pollution (Hamid *et al.*, 2016; Rosli *et al.*, 2015; Baharuddin *et al.*, 2014; Mustpha *et al.*, 2013; Lim *et al.*, 2012; Juahir *et al.*, 2011) and has impacted the riverine ecosystem (Govorov *et al.*, 2016; Sun, 2015; Zhai *et al.*, 2014). This was supported by previous studies of Bu *et al.* (2014), Fucik *et al.* (2014) and Kibena *et al.* (2014), who emphasised that any changes in land use will affect the environmental ecosystem, especially the quality of river water.

Until today, the development of Melaka State is still in line with its mission to be a developed country by 2020. In line with the vision, the state government had planned to reconstruct the Melaka State into three phases, namely (i) the urban areas with residential and commercial activities, (ii) sub-urban areas with industrial activities, as well as (iii) rural areas with agriculture and farming activities. Continuous development could cause pollution in the Melaka River to increase, as the circumstances are connected with the illegal vegetation and farming activities, rapid and uncontrolled development of residential and commercial activities, failure to maintain and manage sewage treatment plant, as well as focusing less on industrial activities. This would probably lead to the inability to control the unceasing pollution due to the ignorance of the danger of pollution on waste dumping, legal law and regulation. These are unavoidable in order to prevent direct discharge of wastewater, as 40% of household, 30% of industrial, and 30% of agriculture are connected with sewage network in the Melaka River basin (Figure 1.0).

In this case, the river water will experience high level of organic and inorganic pollution. This condition would increase when wastewater from factories and household are discharged directly into the river without undergoing any treatment. Similarly, there are also issues where wastewater treated in plants does not meet the environmental standards. In other words, the river water quality can be deteriorated due to majorly by anthropogenic activities and a minor contribution from natural activities (Al-badaii *et al.*, 2016; Hamid *et al.*, 2016; Herojeet *et al.*, 2016). This means that any changes of land resources from the natural into constructed environment (El-Zeiny and El-Kafrawy, 2016; Mishra and Rai, 2016; Yildiz and Doker, 2016) will directly or/and indirectly affect the good and healthy quality of water condition.

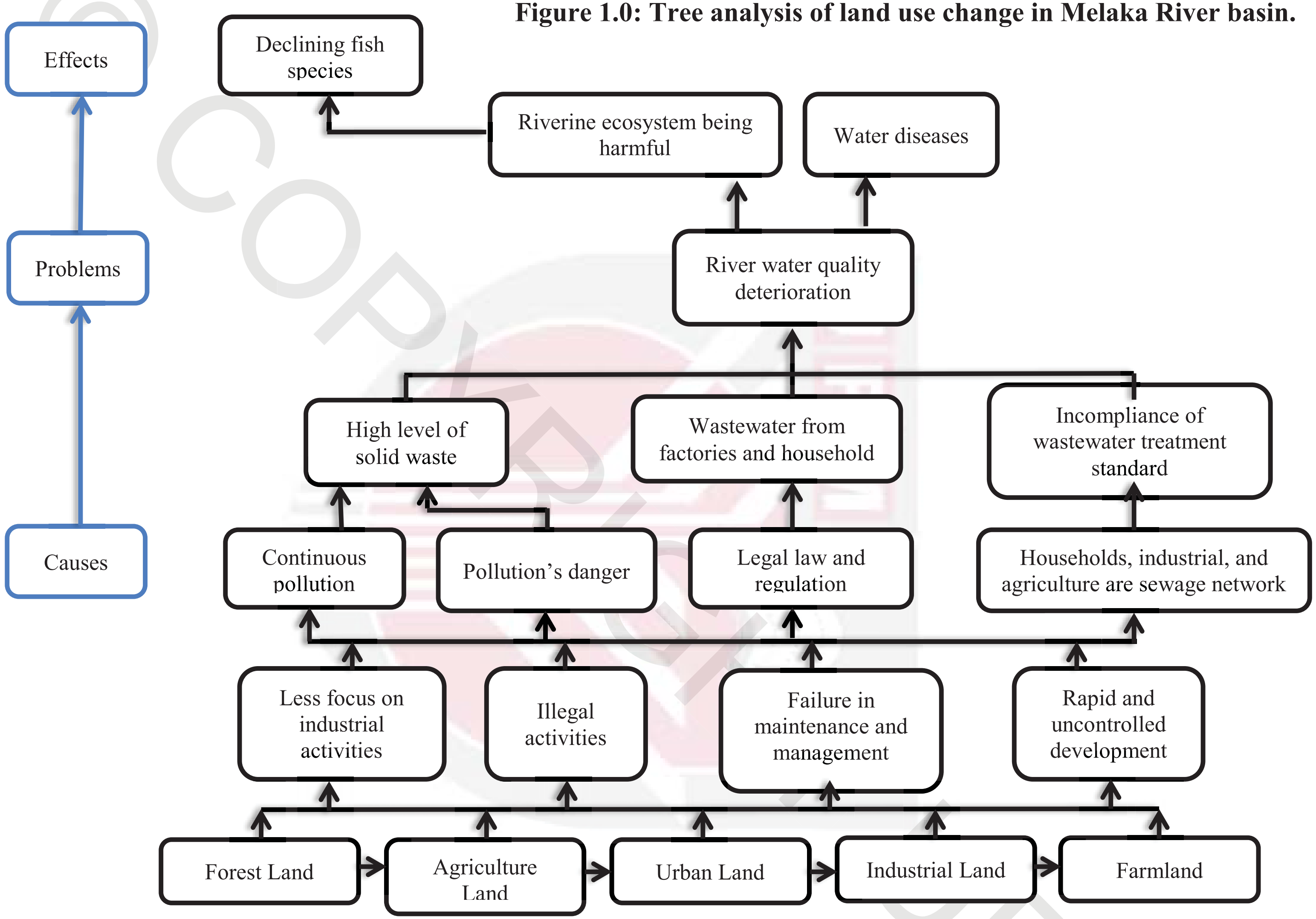
Apart from reducing the water quality level, the riverine ecosystem will be harmful as some organic pollution will lead to the spread of disease resulting to the death of fishes. For instance, several issues on the pollution of the Melaka River had been reported for the death of aquatic fisheries due to lack of oxygen and disease spreading within the river water (PPPP Official Portal, 2015; Sinar Official Portal, 2012; Nasbah, 2010; Jabar, 2010), where such circumstances would cause a decline in the fish species and families resulting to extinction. Simultaneously, the water diseases in the river would be harmful to the aquatic species, which are considered as food supply in the food chain. This will directly or indirectly transfer the disease to the human community upon consumption of the food. Therefore, drastic land use changes could lead to the destruction and impairment of the river water quality as well as to animal and human which are fully dependent on the environment for survival.

In view of this, the present study intends to investigate the extent to which the Melaka River had been contaminated. By taking into account the potential sources of water pollution in relation to the changes in previous and current land uses, future prediction of the affected areas would be possible. This is especially important for future development planning and decision making in order to avoid any overexploitation of the existing land use.

1.2 Overview of River Water Pollution

Every day, 2 million tons of industrial and agricultural discharges were released into the world water, of which the estimated amount of wastewater produced annually is about 1,500 millions of litres per day (MLD) (UNWWAP, 2009). The National Geographic Portal (2016) reported that developing countries produced 70% of industrial wastes that were dumped untreated into waters. The deterioration in the quality of the river water was due to growing population, rapid urban development, anthropogenic inputs (e.g. municipal and industrial wastewater discharges, agricultural runoff) and natural processes (e.g. chemical weathering and soil erosion) (Figure 1.0) (Holloway *et al.*, 1998; Singh *et al.*, 2011; Shin *et al.*, 2013) that have threatened human and ecological health, availability of drinking water, and further economic development (Houser and Richardson, 2010; Li and Zhang, 2010; Morse and Wolheim, 2014).

Figure 1.0: Tree analysis of land use change in Melaka River basin.



The contamination of river water is no exception for a developing country like Malaysia. According to the Department of Environment (2012), among the 473 rivers monitored, only 278 (59%) were found to be clean, 161 (34%) were slightly polluted and 34 (7%) were already polluted (Figure 1.1). Apparently, within 8 years from 2005 to 2012, the total number of rivers that have a clean condition had decreased by about 60 rivers. The trend indicates that the quality of clean river water is decreasing, whereas a higher percentage of the rivers had changed into slightly polluted or polluted river. Notwithstanding, generally the status of the river water pollution can be associated with the level of water quality indicators such as biochemical oxygen demand (BOD), ammoniacal nitrogen (NH_3N), and suspended solids (SS). For instance, a high BOD can be attributed to inadequate treatment of sewage or effluent from agro-based and manufacturing industries. NH_3N mainly comes from livestock farming and domestic sewage; while SS is mainly due to improper earthworks and land clearing activities. Apparently, most of the factors that have led to river water pollution are caused by human activities as shown in Table 1.1.

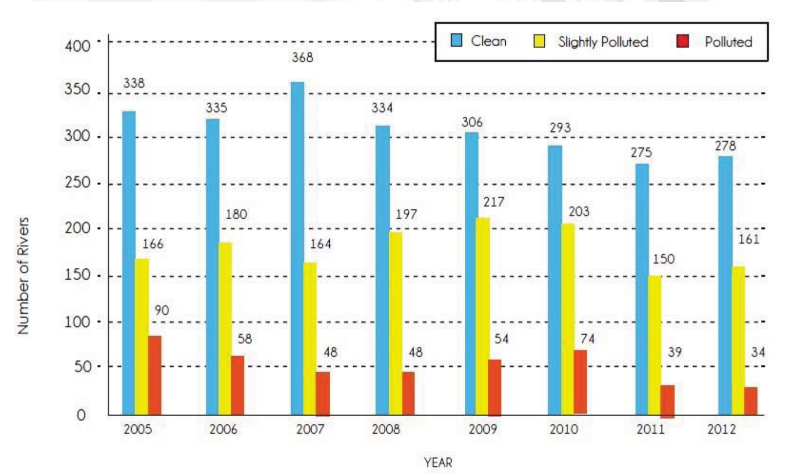


Figure 1.1: River water quality status in Malaysia (2005-2012)
(*Source*: DOE Malaysia Report, 2012)

Table 1.1: Water Pollution Source by Sector in 2012 (Malaysia)

Type of Sources	**No. of Sources**	**Percentage**
Manufacturing Industries	4,595	0.276
Agro-based Industries		
(a) Rubber Mill	72	0.004
(b) Palm Oil Mill	436	0.026
Animal Farm (Pig Farming)	754	0.045
Sewage Treatment Plant		
(a) Public	5,800	0.349
(b) Private	4,083	0.246

(c) Individual Septic Tank	1,449,383	87.190
(d) Communal Septic Tank	3,631	0.218
Food Services Establishment	192,710	11.593
Wet Market	865	0.053

Source: DOE, 2012

1.3 Overview of the Effect of Land Use Change on Water Quality

Melaka state is experiencing rapid economic growth with various kinds of transformation through industrialisation and urbanisation. This has somehow resulted to an overexploitation of natural resources and massive increase in the discharge of pollutants into the waterways. This is especially pronounced in areas of dense population with rapid population growth and rapid changes in land use land cover (LULC). Among the most affected areas in the state of Melaka are within the Melaka River basin; potentially due to increased industrial and residential expansion. Many researchers agreed that uncontrolled and unmanageable land use development would seriously pollute the river water quality (Bu *et al.*, 2014; Fucik *et al.*, 2014; Gyawali *et al.*, 2013). Generally, both industrial and domestic wastewater discharged by human activities may cause serious water quality degradation such as water eutrophication, algal blooms, loss of ecological function and other problems (Zhao *et al.*, 2012). Since industrial wastewater has complex chemical components, and is difficult to treat, degrade and purify, it could be more harmful than the domestic wastewater. Apparently, the impact of industrialisation and urbanisation on water quality is inevitable. However, careful management of current and future land use may negate the impact and lessen the extent of contamination on our waterways.

1.4 Problem Statement

Rapid population growth, unorganised expansion, and uncontrolled urbanisation development has led to various environmental issues in the Melaka state (Rosli *et al.*, 2015). Among the apparent environmental issues which was reported to the public and the state authorities are cases of water pollution in the river. In recent years, several cases involving river water pollution have been reported on Melaka River (Nasbah, 2010; Jabar, 2010). Various efforts have been carried out to reduce and prevent continuous pollution in the river, e.g. through the beautification of the Melaka River which is a synchronised effort with the state tourism sector (Sinar Official Portal, 2012). Even with multiple beautification and rehabilitation programmes in place, the Melaka River continues to be polluted. For instance, numerous cases have been reported on aquatics death and the situation is still worrying (PPPP Official Portal, 2015; Zakinan, 2015). Therefore, it is important that extensive monitoring and assessment of the river water quality be carried out to identify potential sources of pollution across the river basin (Hamid *et al.*, 2016; Al-badaii *et al.*, 2016; Rosli *et al.*, 2015; Baharuddin *et al.*, 2014).

In most previous studies, the water quality was analysed using statistical data analysis. The analysis confirmed that the water quality was affected due to the temporal and spatial variations that have possibly caused the contamination (Hamid *et al.*, 2016; Al-badaii *et al.*, 2016; Aris *et al.*, 2013; Juahir *et al.*, 2011). According to a report by DOE in 2012, the river water pollution as indicated by the values of Biochemical Oxygen demand (BOD), Suspended Solid (SS), and Ammoniacial-NitrogenBOD, (NH_3N), was suspected to have come from industrial, residential, agriculture, as well as farming activities (Mishra and Rai, 2016; Parsa *et al.*, 2016;Yulianto *et al.*, 2016; Wilson, 2015; Fucik *et al.*, 2014; Gyawali *et al.*, 2013). These are being continuously investigated to find an appropriate solution towards water quality destruction of the Melaka River basin (Rosli *et al.*, 2015; Daneshmend *et al.*, 2011). In other words, land use classes are anticipated to have a relationship with the water quality in order to sustain the level of ecological health (Govorov *et al.*, 2016; Shi *et al.*, 2016; Fucik *et al.*, 2014; Kibena *et al.*, 2014). Therefore, if the land use changes in the future, the level of contamination will also be subjected to changes. However, there are uncertainties on what the impact would be. Hence, several studies have suggested that land uses are assumed to influence the river water quality and are appropriate to be included as part of the analysis (El-Zeiny and El-Kafrawy, 2016; Kibena *et al.*, 2014), rather than be dependent on the water quality data when determining the source of the pollutants (Hamid *et al.*, 2016; Al-badaii *et al.*, 2016; Rosli *et al.*, 2015; Baharuddin *et al.*, 2014). Therefore, by suggesting land use as a variable, this study is conducted to determine with the relation between land use and water quality in the Melaka River basin using Geographical Information System (GIS) and remote sensing techniques.

1.5 Objectives of Study

This study aims to identify the pollutant sources in the Melaka River using the LULC change model and pattern analysis. The specific objectives can be described as follows;

(a) To identify the potential sources of Melaka River pollution in relation with temporal land use classification;
(b) To determine the land use land cover changes in 2015 and predict the land use land cover for 2022;
(c) To verify the pattern recognition based on land use classification between 2015 and 2022 in the determination of the pollutant source within the Melaka River.

1.6 Research Questions

This study will attempt to identify the sources of pollution within a catchment scale based on the changes in river water quality and corresponding land uses. The underlying research questions are:

- What is the extent of river pollution occurrence in the Melaka River? Is there any relation between land use classification and water quality variables?

- What are the changes from previous, current and future land use in relation to water quality in a particular area?
- What is the pattern of pollutant source in conjunction with the land use that may impact the river water quality in the Melaka River?

1.7 Scope of Work

River pollution is reported yearly worldwide (Al-badaii *et al.*, 2016; Baharuddin *et al.*, 2014; Mustapha *et al.*, 2013; Gazza *et al.*, 2012; Juahir *et al.*, 2011). According to DOE (2012), Melaka River was listed in the report as having pollution in the country. This condition was supported by Daneshmand *et al.* (2011) and the river water quality is expected to continue decreasing (Rosli *et al.*, 2015). As has been proven, daily news had reported that some aquatic species were found dead (PPPP Official Portal, 2015; Zakinan, 2015) in the Melaka River. Apparently, the quality of the riverine ecosystem has been greatly affected. This condition reflects that contamination might have occurred in the Melaka River basin.

Applied environmetric techniques using HCA, DA and PCA were popularly used by researchers to investigate and identify the source of pollution (Hamid *et al.*, 2016; Al-badaii *et al.*, 2016; Aris *et al.*, 2013; Juahir *et al.*, 2011) in the Melaka River basin (Rosli *et al.*, 2015; Daneshmand *et al.*, 2011). In general, the river water was investigated of its pollution level based on the physicochemical parameters (i.e. pH, temperature, electrical conductivity (EC), salinity, turbidity, total suspended solid (TSS), dissolved solids (DS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD) and ammoniacal-nitrogen (NH_3N), biological indicators (i.e. total coliform and *Escherichia* coliform) as well as trace elements (i.e. mercury, cadmium, chromium, arsenic, zinc, lead, and iron). Pollution can be anticipated from anthropogenic activities (such as industrial, municipal and domestic waste, agricultural runoff, animal farm, land clearing) and/or natural processes (e.g. erosion and runoff) (Al-badaii *et al.*, 2016; Hamid *et al.*, 2016; Mustapha *et al.*, 2013; Juahir *et al.*, 2011). Therefore, environmetric techniques are suitable for application in the Melaka River basin as these techniques are important for collating information regarding the pollutant sources.

In general, the water pollution in the Melaka River basin continues to occur until today. Therefore, suggestion to incorporate land use and water quality data has become the main subject in this study. In particular, the pollutant sources are suspected to be linked with land use classes. The land use classes are able to change temporarily over a period of time (Mishra and Rai, 2016; Parsa *et al.*, 2016; Yulianto *et al.*, 2016; Wilson, 2015). In other words, land use classes possess connectivity with human activities, where this condition requires particular focus on the land use change (El-Zeiny and El-Kafrawy, 2016; Kibena *et al.*, 2014) especially when involving extensive development. For example, the activities that is associated with industrial, residential, commercial, transportation, and sewage treatment plant (Wilson, 2015; Fucik *et al.*, 2014; Gyawali *et al.*, 2013). Therefore, the techniques in GIS (e.g. Moran I and LISA, as well as general G-statistic and Hotspot analysis) have become the major tools to pattern the pollutant source in a river basin. Accordingly, this study uses the land use classes and water quality data to determine the pollutant source based on the monitored station along the Melaka River. Apparently, the application of GIS in the river water quality analysis had been widely used in the discovery of the contamination (Sun, 2015; Alqadi *et al.*, 2014; Lezzaik and Milewski, 2014), and additional input from the land use data (El-Zeiny and El-Kafrawy, 2016; Kibena *et al.*, 2014; Chang, 2008) will extensively support the findings that is produced from the environmetric technique approach.

1.8 Significance of Study

Environmetric techniques analysing the spatial variability of large and complex river water quality data provide meaningful information by identifying, delineating, and differentiating contaminants resulting from various sources (Hamid *et al.*, 2016; Al-badaii *et al.*, 2016; Aris *et al.*, 2013; Juahir *et al.*, 2011). Considering the methods applied such as HCA, DA, and PCA in the techniques, the findings offer reliable classification and serve as an excellent tool for water resources control and management (Hamid *et al.*, 2016; Al-badaii *et al.*, 2016; Rosli *et al.*, 2015; Baharuddin *et al.*, 2014). These techniques allow the optimisation of a monitoring programme by decreasing the number of sampling stations, number of parameters monitored, as well as serving as a cost-effective method in the water quality assessment (Papaioannou *et al.*, 2010a). Therefore, this study applies environmetric techniques into water quality data analysis to visualise the condition of the pollutant source in the Melaka River basin.

Further discussion on the river pollution has become the main point of study for majority of the researchers. The pollutant source is typically related with river water quality and the land use change (Mishra and Rai, 2016; Parsa *et al.*, 2016;Yulianto *et al.*, 2016; Wilson, 2015; Fucik *et al.*, 2014; Gyawali *et al.*, 2013). The land use in LULC analysis is anticipated to be linked with water quality in the river (Wilson, 2015; Fucik *et al.*, 2014; Gyawali *et al.*, 2013). This condition may continue to affect the river in the future, -if it has connection with the land use (Mishra and Rai, 2016; Parsa *et al.*, 2016; Yulianto *et al.*, 2016). Additional evidence from El-Zeiny and El-Kafrawy (2016), as well as Kibena *et al.* (2014) indicated that the land use may be considered as a variable (e.g. independent) in the analysis, whenever land use has relation with the water quality data. Hence, this study is carried out to evaluate the land use classes that potentially impact the water quality in the river. Therefore, this study is focused on the previous and current land use changes while predicting the future trend in relation to the water quality in the Melaka River basin. On the other hand, GIS was typically included for assessment of the water quality data (Sun, 2015; Alqadi *et al.*, 2014; Lezzaik and Milewski, 2014). Previous studies suggested that pattern analysis of GIS (Moran I and LISA, general G-statistic and Hotspot) are favourable for inclusion into the river water quality study to interpret the pollutant source in a particular area (Shi *et al.*, 2016; Govorov *et al.*, 2016; Zhai *et al.*, 2014; Zhao *et al.*, 2012). Therefore, this study is carried out to incorporate the land use classes and water quality analysis to recognise the pattern of pollutant source in the Melaka River basin. This study applies land use classes as independent variable and water quality data as dependent variable.

1.9 Structure of Thesis

The content of this thesis is presented in five chapters as follows;

(i) Chapter One: Introduction

In this chapter, an overview of the river water pollution in Malaysia is presented. This chapter also highlights the problem statement of the contamination that has occurred in the Melaka River. This will be further explained through the objectives of the study, thus strengthening the significance of this study. Literature reviews and research findings are presented in the following chapters.

(ii) Chapter Two: Literature Review

The literature review explains the previous studies on river water quality including the fundamentals of water quality characteristics (i.e. physico-chemical and biological parameters), as well as the impact of water pollution. The conceptual and fundamental methods and techniques applied in the methodologies will also be described, which include the environmetric technique, LULC change models, and pattern analysis models.

(iii) Chapter Three: Methodology

The methodology section describes the research methodology that includes primary and secondary data collection. The collection and analysis of data for river water quality is presented alongside the land use data acquisition. In addition, the concepts of environmetric models, LULC change models, and pattern analysis models are also explained in this chapter.

(iv) Chapter Four: Results and Discussion

This chapter reports on the major findings of the study. This begins with a discussion and interpretation of the river water quality assessment of the Melaka River. It is followed by the results of the land use and land cover changes across the study area. This includes the discussion on previous and current land uses and future prediction changes, as well as the pattern analysis based on the land use classification.

(v) Chapter Five: Conclusion and Recommendation

Chapter Five summarises the overall research findings and the conclusion drawn from the study. This section also provides some recommendations for further improvement for future research.

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