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WATER QUALITY PATTERN RECOGNITION OF THE MUDA RIVER BASIN, MALAYSIA

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June 2017

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Faculty : Environmental Studies

Muda River Basin (MRB) in the state of Kedah, Malaysia with the range values of Water Quality Index (WQI) were between 55.8 and 91.0 during the period 1998-2013. The wide variations in water quality (WQ) indicate that the MRB is affected by various sources. Agricultural-related cover approximately 55% of the total area of the MRB. Meanwhile, about 35% of the catchment area is still covered by forests. Therefore, agriculture, logging activities, and agro-based industries are the main human activities in the area which contributes to water pollution. While, the presence of point sources such as factories may cause river water quality at the same level degraded differently in the same catchment. Therefore, there is a growing interest to determine the sources of pollution and land use classes responsible for this deteriorated WQ and determining how the desired WQ can be secured on a sustainable basis.

The overall aim of this study is to recognise the pattern of water quality across different land classes within the Muda River system The objectives of this study were to (i) elucidate the water quality pattern that best represent the water quality variation of the Muda River Basin; (ii) determine the impacts of various land use on the water quality of Muda River Basin; (iii) develop the artificial neural network model for the prediction of spatial clusters and water quality status among the nine monitoring stations of the Muda River Basin; and (iv) forecast the status of water quality for the year 2020 for each monitoring station in Muda River Basin.

The study employed secondary water quality and land use data. The land use data were put into four land use categories; agricultural, forestry, urban areas, and others. Investigation of the impacts of various land use on the WQ were carried out at four buffer zones(500 m, 1000 m, 1500 m, and 2000 m) as well as the whole river basin.

The data was processed using multivariate analysis, artificial neural network (ANN) technique, and geographic information system (GIS).

The study results elucidated that four sources of contamination in the MRB were organic pollution (contaminants that can be biodegraded by microorganisms), turbidity factor (include high flow rates, soil erosion, urban runoff), agricultural runoff (the portion of rainfall that runs over agricultural land) and natural factor (include geology, soil types, topography, precipitation intensity). Station MD02, which was adjacent to the rubber factory, should be the focus of remediation efforts. The monitoring stations that best represent the water quality variation of the MRB were MD02, MD03, MD05, and MD09.Hence, there is potential in improving the efficiency of the monitoring network in MRB. Subsequently, the study found that the land use types only had a minor effect on WQ in MRB.

The ANN models developed to predict the spatial clusters, the WQI, and the water quality class (WQC). The results suggest that the ANN models can be used by environmental planners and decision makers for WQ management purposes. Moreover, ANN models were utilised to forecast the status of WQ for the year 2020. The predicted WQ remained in class II except for stations on the Jerung River (MD02 and MD03), which was in class III. The predicted value of WQI for the year 2020 assumed that no other land use types will take place in the river basin from 2007 to 2020.

The findings of this study provide information to authorities responsible for river basin management to address the issue of WQ deterioration. These efforts can help to make plans in advance to guarantee the continuity of good water quality for generations to come.

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

PENGECAMAN CORAK KUALITI AIR DI LEMBANGAN SUNGAI MUDA, MALAYSIA

Oleh

SHAH CHRISTIRANI BINTI AZHAR

Jun 2017

Pengerusi : Profesor Ahmad Zaharin Aris, PhD
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Lembangan Sungai Muda (MRB) di negeri Kedah, Malaysia mempunyai nilai julat Indeks Kualiti Air (WQI) antara 55.89 dan 91.0 dalam tempoh 1998-2013. Variasi yang besar dalam kualiti air (WQ) menunjukkan bahawa MRB dipengaruhi oleh pelbagai sumber pencemaran Kawasan berkaitan pertanian kira-kira 55% daripada jumlah kawasan MRB. Sementara itu, kira-kira 35% kawasan tadahan masih dilindungi oleh hutan. Oleh itu, pertanian, aktiviti pembalakan, dan industri berasaskan pertanian adalah aktiviti ekonomi utama di kawasan ini yang menyumbang kepada pencemaran air. Manakala, kehadiran sumber titik seperti kilang-kilang boleh menyebabkan kualiti air sungai pada tahap yang sama tergradiasi secara berbeza dalam kawasan tadahan yang sama. Oleh itu, terdapat minat yang semakin meningkat untuk menentukan sumber-sumber pencemaran dan kelas penggunaan tanah yang bertanggungjawab untuk WQ yang merosot ini dan menentukan bagaimana WQ yang dikehendaki dapat dijamin secara mampan.

Matlamat keseluruhan kajian ini adalah untuk mengenali corak kualiti air di pelbagai kelas tanah di dalam sistem Sungai Muda. Objektif kajian ini adalah untuk (i) menjelaskan corak kualiti air yang terbaik mewakili perubahan kualiti air di Lembangan Sungai Muda; (ii) menentukan kesan pelbagai guna tanah terhadap kualiti air di Lembangan Sungai Muda; (iii) membangunkan model rangkaian neural tiruan untuk meramalkan kluster ruang dan status kualiti air di antara sembilan stesen pemantauan di Lembangan Sungai Muda; dan (iv) meramalkan status kualiti air untuk tahun 2020 bagi setiap stesen pemantauan di Lembangan Sungai Muda.

Kajian ini menggunakan data sekunder kualiti air dan data guna tanah. Data guna tanah telah dibahagikan kepada empat kategori guna tanah; pertanian, perhutanan,

kawasan bandar, dan lain-lain. Penyiasatan kesan pelbagai penggunaan tanah ke atas WQ telah dijalankan di empat zon penampan (500 m, 1000 m, 1500 m, dan 2000 m) serta keseluruhan lembangan sungai. Data-data telah diproses dengan menggunakan multivariat analisis, teknik rangkaian neural tiruan (ANN), dan sistem maklumat geografi (GIS).

Dapatan kajian menjelaskan bahawa empat punca pencemaran di MRB adalah pencemaran organik(bahan pencemar yang boleh dibiodegradasi oleh mikroorganisma), faktor kekeruhan (termasuk kadar aliran yang tinggi, hakisan tanah, air larian bandar), air larian pertanian (sebahagian air hujan yang mengalir di atas tanah pertanian) dan faktor semulajadi (termasuk geologi, jenis tanah, topografi, intensiti hujan). Stesen MD02, yang terletak bersebelahan dengan kilang getah, harus menjadi tumpuan kepada usaha pemulihan. Stesen pemantauan yang terbaik mewakili perubahan kualiti air di MRB adalah MD02, MD03, MD05 dan MD09.Oleh itu, terdapat potensi dalam meningkatkan kecekapan rangkaian pemantauan di MRB. Seterusnya, kajian ini menunjukkan jenis guna tanah hanya memberi kesan yang sedikit ke atas WQ .

Model ANN telah dibangunkan untuk meramalkan kluster ruang, WQI, dan kelas kualiti air (WQC). Keputusan menunjukkan bahawa model ANN boleh digunakan oleh perancang yang terlibat dengan alam sekitar dan pembuat keputusan bagi tujuan pengurusan WQ. Selain itu, model ANN telah digunakan untuk meramal status kualiti air bagi tahun 2020. WQ yang diramalkan kekal di dalam kelas II kecuali untuk stesen–stesen di Sungai Jerung (MD02 dan MD03), berada di kelas III. Nilai WQI yang diramalkan bagi tahun 2020 mengandaikan tiada jenis guna tanah lain akan mengambil tempat di lembangan sungai ini dari 2007 hingga 2020.

Hasil kajian ini memberi maklumat kepada pihak yang bertanggungjawab dalam hal pengurusan lembangan sungai untuk menangani isu kemerosotan WQ. Usaha-usaha ini boleh membantu membuat perancangan awal untuk menjamin kesinambungan kualiti air yang baik untuk generasi akan datang.

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I certify that a Thesis Examination Committee has met on 15 June 2017 to conduct the final examination of Shah Christirani binti Azhar on her thesis entitled "Water Quality Pattern Recognition of the Muda 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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LIST OF ABBREVIATIONS

Ag	Silver
AIC	Akaike's Information Criterion
ANN	Artificial Neural Network
ANOVA	One-Way Analysis of Variance
APCS	Absolute principle components scores
As	Arsenic
Ba	Barium
BIC	Bayesian Information Criterion
BOD	Biochemical oxygen demand
BP ANN	Back-propagation artificial neural network
BZ	Buffer zone
Ca	Calcium
CA	Cluster analysis
Ca-Hard	Calcium hardness
CCE	Correct classification efficiency
Cd	Cadmium
CE	Coefficient of efficiency
CEE	Cross entropy error
Cl	Chlorine

CN	Cyanide
Co	Cobalt
COD	Chemical oxygen demand
Coli	Coliform
Cr	Chromium
Cu	Copper
CV	Coefficient of variation
DA	Discriminant analysis
DEM	Digital elevation model
DF	Discriminant function
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DoE	Department of Environment (Malaysia)
DV	Dependent variable
EC	Electric conductivity
E. coli	*Escherichia coli*
ESRI	Economic Social Research Institute
FA	Factor Analysis
Fe	Iron
GIS	Geographic Information Systems

HCO_3^-	Bicarbonate
Hg	Mercury
IV	Independent variable
K	Potassium
LU	Land Use
KMO	Kaisere-Meyere-Olkin
MAE	Mean absolute error
Mg	Magnesium
MLP NN	Multi-layer perceptron neural network
MLR	Multiple linear regression
MLR-APCSs	Multiple linear regression analysis of absolute principal
Mn	Manganese
MRB	Muda River Basin
MSRE	Mean-squared relative error
MSE	Mean square error
Na	Sodium
NH_3-N	Ammonia-nitrogen
Ni	Nickel
NO_3^-	Nitrate ion
NO_2–N	Nitrite nitrogen

NO_3-N	Nitrate nitrogen
OLS	Ordinary least square
Pb	Lead
PIP	Percent incorrect prediction
PC	Principal components
PCA	Principal Component Analysis
$PO_4^{3-}P$	Phosphate phosphorous
PRFs	Permanent-Reserved Forests
QP	Quick propagation
R^2	Coefficient of determination
r	Correlation coefficient
RBF NN	Radial basis function neural network
RE	Relative error
RMSE	Root mean-squared error
RWQ	River water quality
Sal	Salinity
SD	Standard deviation
Se	Selenium
SO_4^{2-}	Sulphate
SS	Suspended solids

SSE	Sum-squared error
SOFM	Self-organizing future map
T-Alk	Total alkalinity
Temp	Temperature
TDS	Total dissolved solids
T-Hard	Total hardness
TKN	Total Kjeldhal nitrogen
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
Turb	Turbidity
USA	United State of America
VF	Varifactor
WQ	Water Quality
WQC	Water Quality Class
WQI	Water Quality Index
WQV	Water Quality Variables
WRB	Whole river basin
Zn	Zinc

CHAPTER 1

INTRODUCTION

1.1 Introduction

Rivers have always been an essential fresh water resource for human consumption (Wang et al., 2012), and historically, many civilisations have relied on the ample supplies of fresh water found in major river catchments (Taylor, 2003). The main river and its branches carry dissolved particles and suspended solids in bulk from a variety of sources to form the river system (Shrestha et al., 2008). The river system is also responsible for the transportation of municipal waste, industrial waste and runoff of surface water, particularly from agricultural areas (Singh et al., 2004). Therefore, river water quality (RWQ) is at a balance with the pollutant discharge, dilution, and decontamination (Chen et al., 2006). However, an over-discharge of pollutants will result in water quality (WQ) deterioration (Chen et al., 2006). An inadequate quantity and a poor quality of water have serious impacts on any sustainable development (Taiwo et al., 2010). Given the fact that the functions of rivers are crucial to life, serious efforts are needed to prevent any deterioration of RWQ.

The impairment of RWQ is a grave threat to water safety and is a crucial issue in handling river basins worldwide. Any degradation of RWQ seriously threatens human health. It has also resulted in devastating effects on the environment, substantial consequences on aquatic life, and the shortage of clean water resources within river basins. Water pollution and inefficient management of water resources is a key factor in the decline in WQ as well the reduction of water resources (Prasanna et al., 2012). Therefore, any WQ assessment, which is mostly based hydro chemical analysis, is extremely important (Zhang et al., 2012).

WQ in many rivers worldwide has degraded due to natural and anthropogenic factors that have led to point pollution and non-point pollution. In order to assess WQ, regular monitoring programmes are needed for estimates of trusted RWQ (Singh et al., 2005). As a result, an assessment of the levels of contaminants in river water and the amelioration of their effects requires a continuous monitoring of a wide range of physical, chemical, and biological parameters. The assessment produced a large data amount with a variety of parameters. Therefore, the complex data is hard to interpret to give meaningful conclusions for WQ assessed (Dixon and Chiswell, 1996). Next, water management authorities need to determine the causes of WQ deterioration and their quantitative contribution for controlling sources of pollution for efficient water management.

The quality of surface water in a region depends largely on anthropogenic activities and nature, along with the areas, and distribution of land use in catchments

(Gazzaz et al., 2012a). Besides natural and anthropogenic activities, the characteristics of the catchment area of a river have the potential to contribute to WQ deterioration. These features include the land use type, geological, land features, climate, topography, and population density and urbanization patterns (Carle et al., 2005; Xian et al., 2007; Zampella et al., 2007; Amiri and Nakane, 2008; Chang, 2008; Coats et al., 2008). Furthermore, the percentages of individual land uses (e.g., urban, agricultural, and mining) are quite significant, since they differ in their individual contributions to river water pollution. In this context, the impacts of land use on the WQ were studied (Hascic and Wu, 2006; Langpap et al., 2008; Gamble and Babbar-Sebens, 2012).

The results have shown that widespread land use activities may affect the aquatic systems (Thompson and Towsend, 2004). There have been previous studies that researched the relationship between the type of land use and water quality variables (WQV) (Oliveira and Cortes, 2005; Schoonover et al., 2005; Stutter et al., 2007). Moreover, the spatial variations of features in water catchment areas and the source of contamination have also been investigated. Understanding the relationships between WQV and the features of a river's catchment can help to assess the WQ conditions and identify human activities and risk areas that account significantly. However, the presence of point sources such as factories may cause river water quality at the same level degraded differently in the same catchment. Several studies reported that in Malaysia point-source pollution was due to a daily discharge of untreated latex effluent to river system (Hutagalung, 2003; Tekasakul and Tekasakul, 2006; Rungruang and Babel, 2008).In most developing countries, industrial waste is discarded without treatment triggering pollution in the nearby rivers (Ma et al, 2009). The area closest to the point source will be the worst polluted. Accordingly, the study also examined the effect of point sources of water pollution despite the degradation of water quality along a river (upper, middle and down streams) already established.

It is natural that upper streams have better WQ than downstream due to pollutant loading. Despite that the effects of various types of LUs on RWQ have yet to be quantified and confirmed. This research attempts studied the relationship between LUs and RWQ at a local scale using a comprehensive approach that incorporates two distance coverage approaches, the whole river basin, and buffer zone approaches corresponding to four spatial scales. The goal of this study is to analyse and interpret the patterns of water quality across different land classes within the Muda River system using multivariate analysis, Geographic Information System (GIS) and artificial neural network (ANN) applications. In addition, ANN technique is also used for model the impacts of number variables on the WQ of MRB. As such, this study was multi-scale, exploratory, inferential, and interpretative in nature.

1.2 Problem Statement

The deterioration of WQ is an important issue around the world as it is linked to population growth, urbanization, agricultural, logging activities and industrial development. With regards to Muda River Basin (MRB), the range values of Water Quality Index (WQI) for its nine WQ monitoring stations in during the period 1998-2013 were between 55.8 and 91.0. The wide variations in WQ indicate that the MRB is affected by various sources of contamination either from point or non-point source pollution. Agricultural-related operations, such as animal and crop farming, cover approximately 55% of the total area of the MRB. Meanwhile, about 35% of the catchment area is still covered by forests. Therefore, agriculture, logging activities, and agro-based industries, like rubber and palm oil processing factories, is the main economic activities in the area.

The agricultural activity in MRB is the largest agricultural sector in Malaysia. Farmers apply nutrients, such as nitrogen and phosphorous as fertilizers to enhance production. Consequently, agricultural land use has strong influence on the levels of phosphorus and nitrogen (Ishaku et al., 2011; Somura et al. 2012); sediments (Allan et al., 1997; Johnson et al., 1997; Ishaku et al., 2011); pathogens, pesticides, metals, and salts (Ma et al. 2009; Ishaku et al., 2011) in the river water. An intensive agricultural activities and extensive concomitant application of fertilizers and pesticides have deteriorated surface WQ (Schroder et al., 2004; Malhat and Nasr, 2012). Therefore, agricultural is a primary non-point source of water pollution through discharge of pollutants and sediments to the river water

The vast forest area at MRB caused deforestation is another serious issue in which local communities lose valuable system that provides a constant flow of clean water. As a result, the role of a vast number of watersheds has deteriorated leading to high concentrations of sediment in the river. Forest clearing results in hydrochemical changes in surface water which increase the export of solids and solutes (Ballester et al., 2003), raised water temperature and lowered DO levels(Thomas et al., 2004), and translation of Hg (Mainville et al., 2006). A case in point is the Ulu Muda Forest Reserve, which acts as a water catchment for Kedah, Penang and Perlis (Friends of Ulu Muda II, 2008). Logging activities have resulted in increased turbidity and sedimentation (Harris et al., 2007; Neary et al., 2010, Klien et al. 2011). Uncontrolled logging also will influence the WQ of surface water systems (Marryana et al., 2007).

Rapid industrial development in developing countries over the last decade has raised serious concerns about its environmental impacts (Reza and Singh, 2010). Agricultural-based industries, such as rubber and oil palm processing factories, are the major industrial sectors in the MRB. Effluent from rubber and oil palm processing plants release various pollutants to the environment. In the majority of the developing countries, urban and industrial waste is disposed of off without adequate treatment, hence exacerbating foreseeable pollution of fresh water resources (Ma et al., 2009). Several studies reported that in Malaysia point-source pollution was due to a daily discharge of of untreated latex effluent to river system (Hutagalung, 2003; Tekasakul and Tekasakul, 2006; Rungruang and Babel, 2008). The rubber effluent negatively impacts the WQ through BOD, NH_3-N, COD, phosphate phosphorous (PO_4^{3-}P), and EC (Rungruang and Babel, 2008; Arimoro, 2009). Therefore, the declining of WQ cause of industrial effluent needs to be more seriously observed.

Since the early 1980s, urbanization has increased in all cities (Chan, 2005). including the cities of MRB. However, uncontrolled or uncoordinated rapid urbanization can also lead to rapid degradation of WQ (Carle et al., 2005; Duha et al., 2008; Masamba and Mazvimavi, 2008). Even at a low-level scale urban development will lead to a significant deterioration in the surface water systems (Mustapha, 2013). The sources of pollutants in the urban areas are very diverse. Evidence suggests that organic pollution and heavy metal input and nutrients to the water surface are associated with urban land use (Li et al., 2009; Kang et al., 2010 Suthar et al., 2010). However, road traffic and construction have been found to be the most important contributors (Davis et al., 2001; Mahbub et al. 2010; Armas et al., 2012).

On the other hand, river contamination is related to the increase of population. The population of Kedah was 1,649,756 in 2000 had grown to 1,966,900 by 2010 and it is projected to reach 4,223,600 in 2020 (Department of Statistics of Malaysia, 2010). Population growth, which is an unavoidable process worldwide, is accompanied by urban growth, industrialization, and economic development (Walker, 2001). The increase in population have adverse impacts on the environment as it leads to increase the nutrients, sediment, microbes and organic matter in the surface water system through various human activities. Therefore, it is important to determine the sources of pollution and its contribution to the amount of contamination in the region (Tobiszewski et al., 2010).

A challenge to the environmental managers is to identify the origin of pollutants from the various possible sources. Factors and apportionment of water contamination sources can be ascertained if WQ was clearly understood (Singh et al., 2005; Wu et al., 2009; Fataei et al., 2011). Thus, it is essential to establish a set of reliable WQ data to define, manage, and control the adverse effects. Regular monitoring by the Department of Environment yield complex data and make interpretation more complex. For an efficient evaluation of the WQ, environmental managers need to overcome the difficulty of converting complex and diverse WQ monitoring data into meaningful information in order to better define the sources of the pollution. In the Malaysian context, WQI is used to determine the WQ status. Although the WQI can be used to predict changes in WQ, it does not provide evidence on the sources of contamination (Sanchez et al., 2007; Gazzaz et al. 2012a). Thus, large data sets with a variety of variables should be monitored to assess the WQ.

The work can begin by shifting focus to a relevant and sustained environmental monitoring system. The sampling frequency, number of samples, and number of monitoring stations are critical factors in the assessment of WQ. Monitoring starts with the measurement of water samples at identified locations. WQ status across networks is ideal if the river has many monitoring stations that provide continuous spatial data on WQ. However, a concerted effort to optimise the monitoring locations, by minimising the number of stations, is required in the event of budget constraints (Chilundo et al., 2008; Strobl and Robillard, 2008). Despite the fact that a monitoring system is needed to determine the optimum WQ status, the issues such as land use factors should be scrutinised.

Many studies have reported that WQ in many countries have declined significantly due to improper land use practices (Liu et al.,2000; Turner and Rabalais, 2003; Ahearn et al., 2005; Li et al.,2008; Bu et al.,2014). However, very few studies have examined the effects of land use through hydrology by combining statistical analysis and modelling approach (Tong and Chen, 2002). Most early studies have focused on the relationship between land uses and WQ in the catchment area (Jarvie et al., 2002; Li et al., 2008) or buffer zones (Jung et al., 2008; Maillard and Santos, 2008). Consequently, the variability and the complexity of the spatial patterns have on the impact of land uses on RWQ have not been fully explored (Guo et al., 2010). Additionally, many of the studies have only been presented in a short period of time, either one year (Kotti et al., 2005), or a limited number of years (Schoonover et al. 2005; Atosoy et al. 2006; Marryanna et al., 2007). In only very few cases, have the RWQ been examined over longer periods of time, like ten years (Brett et al., 2005; Juahir, 2009; Gazzaz, 2012).

To the researcher's best knowledge, no preliminary investigations of RWQ and land use patterns or their associations at the MRB have been published in English scientific literature. Therefore, there is a need to (i) determine the reasons behind the wide variations in WQ in MRB; (ii) decide on how this quality is affected by WQV and three land use (LU) classes (agriculture, forest and urban areas) within the basin; (iii) identify the main WQV and land use classes responsible for the degraded WQ of the Muda River; and (iv) determine how the historical data of LU and WQ status of Muda River Basin can be used to ensure safe WQ through forecasting. The outcomes of the forecasted results will assist the government in planning and making decisions that go towards achieving and sustaining a healthy WQ.

1.3 Research Questions

The research questions of this study are:

(1) What are the spatial patterns, factors that influent water quality and monitoring stations that best represents the water quality variation of the Muda River Basin?

(2) How do various lands use impacts the water quality of the Muda River Basin?
(3) How to predict spatial clusters and water quality status among the nine monitoring stations of the Muda River Basin; and
(4) How to ensure the safe water quality for each monitoring station in Muda River Basin for the year 2020?

1.4 Study Objectives

The overall aim of this study is to recognise the pattern of water quality across different land classes within the Muda River system using multivariate analysis, GIS and ANN applications. The objectives of this study are:

(1) To elucidate the water quality pattern that best represents the water quality variation of the Muda River Basin;
(2) To determine the impacts of various land use on the water quality of the Muda River Basin;
(3) To develop the artificial neural network model for the prediction of spatial clusters and water quality status among the nine monitoring stations of the Muda River Basin; and
(4) To forecast the status of water quality for the year 2020 for each monitoring station in Muda River Basin using the artificial neural network technique.

1.5 Scopes of study

This study has focused on the MRB in Kedah, Malaysia that is estimated as 203 km long and has a basin area of approximately 4,210 km^2. The scope of the research included an assessment of the WQ status of the Muda River, analysis of patterns in the RWQ and the land uses, and development of models that are predictive of the WQI and the Water Quality Class (WQC).The scopes of the study classified as follows:

i. Theoretic Scopes.

(1) A quantification of the land use changes within the MRB and an identification of the relationships between the land uses and the WQ of the Muda River;
(2) Pattern recognition of the WQ of the Muda River using linear and non-linear techniques;
(3) A modelling of the WQ-land use associations; and
(4) A modelling of the WQI-WQV and the WQC-WQV associations following a non-linear approach, (ANN). These tasks were implemented using a maximum of 22 WQVs and four major land use categories.

ii. Temporal Scopes. The WQ data involved limited temporally to the period 1998-2013. The first set was involving six WQV from year 1998-2013, while the second set was involving 22 WQV from year 1998-2007. On the other hand, the land use data involved limited temporally to the period 1998-2007.

iii. Geographic and Spatial Scopes. Geographically, the present study was restricted to the MRB in the Kedah, Malaysia. Five buffer areas were included in the present study: the whole river basin (WRB) and four buffer zones (BZ) (500 m, 1000 m, 1500 m, and 2000 m).

1.6 Significance of the Study

The effort to mitigate environmental pollution depends on an accurate identification of the temporal and the spatial characteristics of pollutants and pollution. An understanding of the causes of pollution and the effects of pollutants on WQ is necessary in order to devise the best strategy to improve it. In this regard, researchers and environmental managers have to quantify and understand how land use changes affect the quality of water, so that short and long term plans for RWQ management can be developed. The study of WQ and its relation to land use is essential in order to ensure the continuity of a clean water supply for domestic, industrial, and agricultural uses.

The MRB is an important agricultural area in Malaysia, it is known as the “Rice Bowl of Malaysia”. It is a source of water for the irrigation and the freshwater supplies for Kedah and adjacent states. However, the researcher maintains that there is no comprehensive study on the WQ of the Muda River. Most of the hydrological research in Malaysia has concentrated on severely polluted areas or industrial zones. To the researcher's best knowledge; there is no comprehensive study of the WQ in agricultural areas, such as the MRB, by using long-term data records. Specifically, research on land use changes and their impacts on WQ in the MRB have not been conducted. Furthermore, no ANN analysis of the patterns in land uses and/or WQ has been conducted for the MRB. A lack of such studies hinders sustainable management of the WQ of this river. Hence, recognition of the patterns in the land uses and the WQ in the MRB is expected to provide the scientific community, environmental managers, and professionals with new insights into the associations of surface WQ with land uses, space, and time.

The significance of this research lies in its strength as a multidisciplinary and integrated approach of using different techniques to solve an environmental problem. By incorporating concepts from chemometrics, land use change, and hydrology, with the GIS and ANN applications, a watershed analysis can reveal critical hidden information and associations that are not seen in the raw WQ or land use data. This approach can be used as a screening tool for the basin as a whole and at each sub-basin to understand the problems of deterioration in WQ. The analytical approach of this study can be used in inter-jurisdictional areas that need improvement, observation, and economic analysis, and for the treatment facilities that are necessary in order to ensure compliance with the regulations of the local WQ authorities. Moreover, this study is important for ensuring that the Muda River can meet the WQ level and the demands of the population, taking into account the intrinsic value of each ecosystem, human health, and safety, as well as for the safety of the environment. As a consequence, it is essential to ensure the continuity of its clean water for supplies of domestic, industrial, and agricultural uses.

The ability to predict changes in the WQI over time is believed to be helpful in improving, maintaining, or restoring RWQ sustainable and safe development. The ANN models provide forecasts for the WQI in 2020. The forecasting has the implication of revealing the monitoring stations which will have WQ conditions that are comparable to the WQ conditions from the year 1998. The forecasting helps stakeholders plan the management of WQ to ensure the best WQ in 2020 and beyond. Ultimately, the findings enable policy makers to make the decision to establish a balance between water use and healthy development. Finally, various modeling approaches presented in this study can be used for river basins in other urban areas, provided that the necessary data and expertise are available.

Ultimately, the study findings enable policy and decision makers to establish a balance between water use and extended development. And lastly, the various modelling approaches presented in the study can be applied to river basins in other urban settings provided that the necessary data and expertise are available.

1.7 Organisation of Thesis

This dissertation consists of five chapters, which are the Introduction, Literature Review, Methodology, Results and Discussion, and Conclusion, to provide information regarding WQ pattern recognition in the MRB. In Chapter One, a brief description is covered on the background of the study. The remainder of this dissertation is organised as follows:

Chapter Two introduces a review of the literature related to multivariate analysis, RWQ, land use effects on RWQ, and the theory and practice of ANN modelling.

Chapter Three describes the methods and the procedures followed to satisfy the goal and objectives of this research.

Chapter Four presents the research results and discusses them in view of the related reviewed literature and the study objectives.

Chapter Five refers to the whole thesis, binding the various theoretical and empirical data, to give a brief explanation and criticism of the findings and discuss the implications for further research in this field. It also suggests identifies and shows areas for further research.

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