PARTIAL LEAST SQUARES INTEGRATED NATIONAL WATER QUALITY STANDARDS (NWQS) FOR INDEXING OF WATER QUALITY FROM INDUSTRIAL EFFlUENT

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DECLARATION

I, FRED A EMANUEL hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

Date: _____________________  _____________________

(FRED A EMANUEL)
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I owe this achievement to many individuals in my life who believed in my abilities to pursue my studies, a goal I once let go due to other work and life commitments.

I will forever be grateful to my husband, my daughter and other family members who know that my priorities remained unchanged despite the many hours I invest in this study, and helped me find time to make this study an easy task to tackle.

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LIST OF ABBREVIATIONS

BOD  Biochemical Oxygen Demand

COD  Chemical Oxygen Demand

DID  Department of Irrigation & Drainage

DO   Dissolved Oxygen

DOE  Department of Environment

eNWQS Extended National Water Quality Standards

mg   miligram

l    liter

NWQS National Water Quality Standards

NH3-N Ammoniacal Nitrogen

P    Phosphorus

PLS  Partial Least Squares

SI   Sub-index

TSS  Total Suspended Solid

UNIMAS Universiti Malaysia Sarawak

WS   Water Sampling

WQI  Water Quality Index
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Partial Least Squares Integrated National Water Quality Standards (NWQS) for Indexing of Water Quality from Industrial Effluent

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ABSTRACT

This study attempts to provide a better classification of water quality that is of accurate representation of the actual health of river water and is achieved by applying existing water quality evaluation method used in our country, namely DOE-WQI and average NWQS as well as a newly developed model based on Partial Least Squares (PLS) regression and the guideline of NWQS, called PLS-WQI in the indexing process. Indexing with DOE-WQI equation method using six (6) pre-determined DOE-WQI parameters revealed that all stations falls under Class III with a slightly polluted status. PLS-WQI and average NWQS corresponds well with DOE-WQI method and it is also observed that average NWQS often provides better classification of water quality among all methods studied. Further indexing with PLS-WQI using the algorithm programmed in Matlab R2009b which allows for the consideration of only parameters that impart the greatest influence on water quality has resulted in a better presentation of the actual water quality at each station. PLS-WQI predicted Stations WS1 and WS2 to be of Class 3.66 with parameters pH, DO, BOD and COD at Station WS1 and pH, DO and COD at Station WS2. Meanwhile, Station WS3 is predicted to be of Class 4.45 when indexing was carried out with variables pH, DO, BOD, COD, TSS, AN, OG and Mn. Therefore, PLS-WQI is flexible and is thoroughly more sensitive compared to the other two (2) existing methods.

Keywords: water quality, water quality index, partial least squares regression, Sejingkat River.

Partial Least Squares Integrated National Water Quality Standards (NWQS) untuk Pengindeksan Kualiti Air dari Effluen Perindustrian

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ABSTRAK


Kata kunci: kualiti air, indeks kualiti air, partial least squares regression, Sungai Sejingkat.
1.0 INTRODUCTION

1.1 Research Background

Good quality water is essential for all living things and our dependency on this natural resource remain unaffected even as we develop into an era of modern technologies. However, our natural resources like river ecosystem suffer the consequences which stems from our actions to achieve higher level of urbanization and industrialization.

More areas are specified as industrial zone such as Sejingkat Industrial Zone, located approximately 20 km from Kuching town, comprises of various factories which manufactures different products such as glue resin, plywood and flour to meet market demand.

The establishment of industrial zone not only manufacture useful products to meet demand, but at the same time generates wastes that are complex in composition. When these wastes are discharged into the environment without prior treatment, it creates deleterious effect such as pollution and poses serious threat to human and the routine functioning of ecosystem.

The discharge of industrial effluents into the river became an important issue and received numerous attentions from environmentalist, policy makers and general public alike over the past few decades because of the declining health of the river water. Environmental Quality (Industrial Effluent) Regulations 2009 defines industrial effluent as “any waste in the form of liquid or wastewater generated from manufacturing process including the treatment of water for water supply or any activity occurring at any industrial premises”. The law further prohibits any spill, accidental discharge or leakage of industrial effluent
into soil and inland waters or Malaysian waters as the presence of toxic heavy metal can have an adverse impact on the environment.

Therefore, continuous monitoring of river water quality is vital as it forms the basis of water pollution control (Foran & Fink, 1993). In addition, periodic monitoring of water quality permits better understanding of the general condition of the river water thus allowing detection of any emerging pollutants in the river ecosystem.

Regular water quality monitoring programme has been carried out by Department of Environment (DOE) since 1978 in an effort to establish status and observe trends of water quality over time in addition to detecting water quality changes and identifying pollution sources (Country Report on Pollution, 2011). The tasks of evaluating river water quality status based on pollution load and designation of classes of beneficial uses were achieved through Water Quality Index (WQI) stipulated under the National Water Quality Standards (NWQS) for Malaysia (WEPA, 2006). The WQI was formulated by DOE hence the term DOE-WQI is also used interchangeably. While NWQS serves as a benchmark to provide recommended water quality criteria for respective parameters, WQI simplifies the complex water quality data into a single number ranging from 0 to 100 with larger value corresponding to better water quality.

By summarizing complex water quality data into a numerical score, people without background knowledge but are concerned about the health of the environment such as the general public and policy makers can be more informed in a consistent manner and in an easily understandable format (Bordalo, et.al, 2006) Furthermore, by classifying water into various beneficial uses, it provides hindsight of what the water can be used for and how. For example, a slightly polluted water body would require treatment prior to use for
drinking or domestic purposes and much polluted water would only be suitable for limited purposes.

Water quality indexing is a common method used by many countries to assess the overall status of the rivers. Although these indices differ from country to country, it is based on a few pre-determined physico-chemical parameters and compounded to numerical rating for evaluation of river water quality (Bhargava, 1983; Pesce & Wunderlin, 2000). In Malaysia, the parameters considered are pH, dissolved oxygen (DO), biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), ammoniacal nitrogen (NH₃-N) and total suspended solids (TSS).

Following the advancement in technology and the growing water quality database, researchers have directed their focus to implement advanced statistical approaches to manage high dimensional data such as water quality data (Abdullah, et al., 2008; Gazzaz et al., 2012). This study aims to employ the Partial Least Squares integrated National Water Quality Standards for prediction of river water quality affected by the industrial effluent. Conventionally, the National Water Quality Standards (NWQS) categorises water quality into 5 discreet classes according to parameters. No mathematical calculation is available to derive a numerical score to indicate the overall water quality. With the integration of PLS, a continuous variable is derived with an increasing number corresponds to more polluted water. This approach is an extension to the existing National Water Quality Standards with two distinct improvements:

- Instead of categorising the water quality into five classes according to parameters, an index of continuous variable can be computed to suggest the overall water quality offering better sensitivity. For example, two water samples with indices 2.05 and 2.95 indicate that the latter is more polluted.
The partial least squares integrated water quality index allows selection of indicators. Conventionally, parameters considered are pre-determined according to methods. For example, DOE-WQI uses 6 parameters for determination of water quality index; for PLS-WQI, users can determine the parameters and the number of parameters used for computation of WQI.

1.2 Statement of Problem

Our river ecosystem is never static. Indeed, it is subjected to constant change caused by physical forces and introduction of pollutants that threaten the quality of life. In addition, as population grows, a corresponding increase in wastes generated is observed as the Earth resources deplete at a worrying rate. This is a serious global issue as well as in our country, Malaysia as we advance into a developing nation through various development and industrialization projects that threatens the sustainability of water resources.

Department of Environment (DOE), Department of Irrigation & Drainage (DID) as well as other state level agencies have been conducting extensive water quality classification and monitoring of rivers throughout the states in Malaysia. According to Malaysia Environmental Quality Report (EQR, 2012), DOE alone has been monitoring 473 rivers at 832 manual stations and 10 continuous water quality monitoring stations throughout Malaysia using DOE-WQI evaluation method that summarizes complex water quality data into an index that reflects the quality of the river water.

However, despite the on-going evaluation and monitoring efforts, reports indicated a downward trend of water quality year by year. This could be attributed to the limitations of the evaluation method which are restricted to 6 pre-determined parameters which may fail to accurately communicate the water quality information (Zainudin, 2010).
Furthermore, the various inputs of pollutants along the stretch of a river alters the quality of the river and changes the dynamic of river water as it runs its course. A particular station may receive a good WQI and yet have its quality impaired by other constituents that are not accounted for in the index. An industrial zone area for instance would discharge industrial effluents consisting of new toxic pollutants thus making these heavy metals more polluting to the receiving water than other constituents. Therefore, the levels of heavy metal constituents should be monitored and accounted for in the water quality evaluation of the particular river.

However, the function of the index system of evaluation used in our country to provide precise information on water quality is incapacitated as it remained unchanged or undergoes very little change over the past few years. Such a loophole in the one-size-fits-all evaluation system could result in severe degradation of water quality if it continues to classify river water to respective beneficial classes which are not representative of the actual condition of the water.

Unless serious mitigation are applied to expel the negative impact contributed by pollutants, total water availability in our country will also decline in addition to degrading quality as a result of high cost of treating polluted waters for consumption.

Lastly, an efficient water quality monitoring index is even more essential now that there are more rivers to monitor throughout Malaysia. Malaysia Environmental Quality Report (EQR) has stated that in 2012, nine (9) rivers within the Klang River Basin were added to the national river water quality monitoring programme. As the water quality monitoring stations increase, more samples will be collected from the monitoring stations, thus causing the amount of data generated over time to swell and making the task of evaluating water quality data challenging (Gazzaz et al., 2012). The capability of the current evaluation
method needs to be improved so that it will be able to manage and evaluate large water quality database.

### 1.3 Objectives of Study

The general objective of this study is to assess the quality of river water at Sejingkat Industrial Zone with the aim of providing a better classification that is of accurate representation of the actual health of the river water. The specific objectives are as outlined below:

- To identify the key parameters responsible of significant change in river water quality
- To determine the water quality based on WQI, average NWQS and PLS-WQI using 6 pre-determined parameters and other additional parameters; and
- To ascertain the sensitivity of each water quality evaluation method
2.0 LITERATURE REVIEW

2.1 Introduction

Water is essential for the survival of plants, living organisms and especially human as most of us rely greatly on water resources in different aspects of life (Reeve, 2002). However, despite our reliance on clean water, we continue to severely degrade the quantity and quality of rivers and streams worldwide through our various activities. Agricultural production and industrial activities are some of the examples of human activities that impact water quality to an extent that weakens or destroy natural ecosystems. Furthermore, although both water quality and water quantity are important, the former has received far less investment, scientific support in recent decades compared to the latter (Palaniappan et al., 2010).

Besides, it is estimated that developing countries discharge more than 70 percent of untreated industrial wastes into the river water (UN Water Statistics, 2004). Such poor management of wastewater will result in poor quality of water hence the decreased availability of clean water for future use. Therefore, on-going monitoring and good data are vital in order to improve water quality.

2.2 Water Quality

Water quality refers to chemical, physical and biological characteristics of water and is often indicated by measuring the concentration of various water quality parameters. The set of parameters monitored are often chosen based on the objective of the monitoring and
is compared to a set of standards against which compliance can be assessed. Once the quality of the water body has been ascertained, it can be determined to be beneficial for various purposes, namely drinking, irrigation and many more.

In addition, water quality information also relates to the level of pollution in the water as it measures the suitability of water for a particular use. Therefore, in order to obtain a comprehensive and representative water quality, selection of a set of correct parameters that changes the water quality over time is vital.

### 2.3 Water Quality Parameters

The presence of contaminants which would alter the quality and characteristics of water are used as an indicator to indicate the overall quality of the water and can be categorised into physical, chemical and biological parameters.

#### 2.3.1 Physical Parameters

##### 2.3.1.1 Temperature

Water temperature is measured on a linear scale of degree Celcius and affects the solubility of oxygen in water as well as water chemistry and the functioning of aquatic organisms. For example, a change in water temperature will affect the rate of photosynthesis, metabolic rates of aquatic organisms and the way that organisms react to toxic wastes. However, water temperature varies with several factors such as season, geographic location, stream flow and input of industrial effluent.
2.3.1.2 Suspended Solids

Suspended solids are an indication of the amount of suspended solids in water. A large volume of suspended sediment will reduce light penetration, thus suppressing photosynthesis activity of phytoplankton. The decline in primary production will impact the survival of aquatic organisms in the water. Sediment deposition may also affect the physical characteristics of the water and lower its functionality for certain purposes such as drinking and recreational. In addition, sediment deposited are generally negatively charged and attracts positively charged molecules such as phosphorus and heavy metals. These positively charged pollutants will further aggravate the declining quality of the water.

2.3.1.3 Oil & Grease

Oil & grease is a good indicator of any indiscriminate dumping of waste oil or oily waste into the water.

2.3.2 Chemical Parameters

2.3.2.1 pH

pH stands for the hydrogen’s potential and is a general measure of the acidity or alkalinity of water. pH measures the hydrogen ion concentration which is subjected to change triggered by wastewater discharge or atmospheric deposition, to name a few. As the pH of water decreases (water becomes more acidic) or increases (water becomes more basic), concentrations of other substances in water will become more toxic.

2.3.2.2 Dissolved Oxygen

Concentration of dissolved oxygen (DO) in water is a measure of the amount oxygen available in water, essential for aquatic life and is often stated in milligrams per liter (mg/l)
or as a percent saturation, the later which is temperature dependent. Percent saturation
denotes the potential capacity of the water to hold oxygen that is present. The solubility
and amount of dissolved oxygen in water is influenced by water temperature, quantity of
sediment among many others.

2.3.2.3 Biological Oxygen Demand

Biochemical oxygen demand (BOD) measures the amount of oxygen used by aerobic
bacteria during decomposition, and indicates organic pollution and poor water quality.
High quantity of organics in water depletes the dissolved oxygen in water and would
threaten the existence of aquatic living things.

2.3.2.4 Chemical Oxygen Demand

Chemical Oxygen Demand (COD) is also a measure of organics in the water. COD test
predicts the amount of oxygen used during the decomposition of organic matter and the
oxidation of inorganic chemicals such as heavy metals.

2.3.2.5 Ammoniacal Nitrogen

Ammonia is a nutrient required for life but is harmful when it is present in excess as it may
accumulate in the organism and alter the metabolism. Sources of ammoniacal nitrogen are
often from ammonia rich fertilizer.

2.3.2.6 Phosphorus

Like nitrogen, phosphorus is an essential nutrient for aquatic living organism and is
typically scarce in water. Therefore, even slight increase in concentration can set off a
whole chain of undesirable events in a given water body. Sources of phosphorus are both
natural and human, namely from soil and rocks, wastewater plants and water treatment.
Nonetheless, human activities contributed to the excessive loading of phosphorus into many freshwater systems (Holtan et al., 1988)

2.3.3 Inorganic Chemical Parameters

2.3.3.1 Heavy Metal (Iron and Manganese)

Heavy metals are elements that normally occur at very low concentrations in the environment, and are essential element for many living things. However, as the releases of these trace metals into the environment can occur through several sources such as natural processes and human activities, toxicity which is associated with excess concentration becomes a concern.

The largest natural source of these metals is from rocks and soils that are directly exposed to water, while anthropological source accounts for the discharge of liquid wastes from various industries and activities into the water body. Nonetheless, the concentration of metals in natural water from natural origin is minor as compared to anthropological source such as through the discharge of liquid wastes into the water body.

Of all common metallic elements present in natural water, Fe is chosen as one of the heavy metal parameters to be studied because Fe is the second most abundant metal (Enthaler et al., 2008) as well as the most essential trace element in living things such as human and animal. Mn is studied because it often occur naturally together with Fe, thus making it imperative to monitor the level of both Fe and Mn in natural water so as to avoid high concentration which could pose risk to the ecosystem. According to Natural Water Quality Standards (NWQS), in natural waters both Fe and Mn are present at concentrations lower than 1.0 mg/L and 0.1 mg/L respectively.
2.4 River Pollution Issues in Malaysia

The current environmental quality report published by DOE in 2014 revealed that 273 out of 473 rivers monitored throughout the nation were classified as clean, 161 as slightly polluted and 34 as polluted. Of the 34 polluted rivers, 19 rivers were classified as Class III, 14 as Class IV and one (1) as Class V using the DOE-WQI evaluation method.

Although only a small portion of the river ecosystem are deemed polluted, the value may increase over time if no action is taken to maintain the existing clean rivers and improve the ones classified as slightly polluted. However, because water pollution status is published as an index, it is difficult to obtain a precise picture of the severity of river pollution in Malaysia, a setback which could further hinder suitable water management effort.

Furthermore, as more industries and factories are established, more effluents containing toxic pollutants are discharged or dumped into the river water, which constituents vary from one industry to another. The overall water quality is sometimes difficult to evaluate due to the excess concentrations of different constituents in water from different sampling points (Bakan et. al., 2010). Therefore, different area with diverse source of pollutants need different evaluation index (Mamun et al., 2009) but the current index system used to evaluate the river water quality has undergone very little changes.

As of recently many attentions have been focused on the potential threat that heavy metals have onto the river environment (Tarique, 2008; Fang & Hong, 1999), many of which are attributed to their toxicity and ability to accumulate in the food chain (Bashir et al., 2013).

Hossain et al. (2012) conducted a study to evaluate the quality of our river water and found that not only does the quality deteriorate over time but it is especially due to input from
industries that are both conventional and non-conventional into the river flow. The literature further revealed that pollution levels are higher in the middle stations of the river, where the industries are discharging effluents, as compared to stations located upstream and midstream.

In an aquatic ecosystem such as Sg. Sejingkat, there are various sources of pollutants into the water body including river discharge, deposition from the atmosphere and industrial waste input. The many studies conducted on the toxic effects of heavy metals have directed the focus towards the impact from industrial discharge, monitoring the level of heavy metals, particularly iron and manganese.

Iron and manganese have been identified as essential elements to the health of both human and organisms at low quantities but toxic at slightly higher quantities (Nobi et al., 2010).

2.5 River Classifications in Malaysia

The traditional water quality report which details each parameter is found to be too technical for those without background knowledge on water quality such as general public and policy makers. Furthermore, adopting foreign criteria to local condition was not suitable due to several factors such as differences in environmental characteristics and climate.

Therefore, in 1978, the Department of Environment (DOE) Malaysia developed Water Quality Index (WQI) guided by the limits stipulated in National Water Quality Standards (NWQS) to communicate such information to those with concern. The WQI is an opinion-poll formula, where a panel of experts was consulted on the choice of parameters to be included as well as the respective weightage to be assigned to each parameter (DOE, 1994).