THE ASSESSMENT OF WATER QUALITY MODELING USING GIS AND QUAL2K SIMULATION ANALYSES FOR THE KLANG RIVER BASIN

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THE ASSESSMENT OF WATER QUALITY MODELING USING GIS AND QUAL2K SIMULATION ANALYSES FOR THE KLANG RIVER BASIN

Abstract:

The amplified pressure on urban areas in Malaysia has been generated by rapid growth in the manufacturing field, especially in the Klang River Basin, which is the most densely populated area of the country. The basin located within two states in Malaysia, i.e. Selangor and Kuala Lumpur. It drains an area of 1,288 square Kilometers. The water quality of the Klang River basin is significantly degraded due to human activities as well as urbanization. As the two states are undergoing tremendous development, Klang River is subjected to pollution from point and non-point sources. Normally the evaluation of the overall river water quality status is represented by a water quality index (WQI), which consists of six parameters, namely dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), ammoniacal nitrogen (AN) and pH. The modeling of the water quality was often employed as a supporting tool for the assessment of the aquatic environment, and the calculated results provided valuable information for improvement water quality management. The water quality modeling was coupled with geographical information system (GIS) to determine the strategy for the water resources management. In this study, GIS tools were used to develop the digital spatial map for the Klang River basin and build its database, as well as to prepare the required spatial data to run the water quality model. The Qual2K was used as a simulation model to predict and evaluate the status of the water quality in Klang River main stem. Two water quality parameters have been chosen for modeling, i.e. DO and BOD. In addition, three model scenarios were simulated to assess the impact of the point sources on the quality of Klang

River water. Furthermore, the model output has been linked to the GIS environment for better analyzing, viewing and evaluation of the results.

The results showed that the developed digital spatial map is an effective map that connects the spatial data of the features with their tabular databases, which make it easy to analyze the data for better results that help for decision-making. It proved that it is more powerful, convenient, interactive and efficient than the traditional paper map. This digital map is a physical map that at any time it can easily be edited and modified.

The simulated results for the current condition indicate that DO upstream of the Klang River's main stem varies between classes I and II, while BOD varies between class II and III. The class of DO decreased from mid-stream toward downstream where it recorded a class IV. The BOD was recorded as class IV at mid-stream and improved downstream to class III. Moreover, the simulated results of the three scenarios indicated that the Sewerage Treatment Plants (STPs) are the main contributor to the source of DO and BOD pollution to the river system. Omitting Sewerage Treatment Plants (STPs) with standards A and B caused an increase in DO amounts (ranging between 0% and 40.5%), whereas the BOD amounts decreased between 0% and 49.4%.

By linking the model output with the GIS platform, the classes of the river quality in terms of DO and BOD were represented clearly along the Klang River catchment. In addition, the results helped for easy analyzing and evaluation of the river quality. These results can be used as a tool in designing a decision support system.

MENILAI PEMODELAN KUALITI AIR MENGGUNAKAN ANALISIS SIMULASI GIS DAN QUAL2K BAGI LEMBANGAN SUNGAI KLANG

Abstrak:

Tekanan yang begitu kuat di kawasan bandar di Malaysia disebabkan oleh pertumbuhan pesat dalam bidang pembuatan, terutamanya di Lembangan Sungai Klang, yang merupakan kawasan yang paling padat dengan penduduk di negara ini. Lembangan ini yang terletak di kedua-dua negeri di Malaysia, iaitu Selangor dan Kuala Lumpur. Ia berkeluasan sebanyak 1,288 Kilometer persegi. Kualiti air lembangan Sungai Klang adalah sangat rendah sejajar dengan aktiviti manusia dan juga pembandaran. Kedua-dua negeri sedang menjalani pembangunan yang amat pesat menyebabkan Sungai Klang adalah tertakluk kepada pencemaran punca titik dan juga punca bukan titik. Biasanya penilaian status kualiti air sungai secara keseluruhannya diwakili oleh indeks kualiti air (WQI), yang terdiri daripada enam parameter, iaitu oksigen terlarut (DO), permintaan oksigen biokimia (BOD), permintaan oksigen kimia (COD), pepejal terampai (SS), ammoniakal nitrogen (AN) dan pH. Permodelan kualiti air yang sering digunakan sebagai alat sokongan untuk penilaian persekitaran akuatik, dan keputusan pengiraan menyediakan maklumat penting untuk penambahbaikan pengurusan kualiti air. Permodelan kualiti air telah ditambah pula dengan sistem maklumat geografi (GIS) untuk menentukan strategi bagi pengurusan sumber air. Dalam kajian ini, alat GIS telah digunakan untuk membangunkan peta digital spatial untuk lembangan Sungai Klang dan membina pangkalan data, dan juga untuk menyediakan data spatial yang diperlukan untuk menjalankan model kualiti air. Qual2K yang digunakan sebagai model simulasi untuk meramal dan menilai status kualiti air di aliran utama Sungai Klang. Dua parameter kualiti air telah dipilih untuk pemodelan, iaitu DO dan BOD. Di samping itu, tiga senario model telah disimulasikan untuk menilai kesan daripada sumber

titik pada kualiti air Sungai Klang. Tambahan pula, pengeluaran model itu telah dikaitkan dengan persekitaran GIS untuk keputusan analisa lebih baik, penyampaian dan penilaian keputusan.

Hasil kajian menunjukkan bahawa peta digital spatial yang dihasilkan adalah peta yang berkesan yang menghubungkan cirri-ciri data spatial daripada pangkalan data jadual mereka, yang membuat ia mudah untuk menganalisis data untuk menghasilkan keputusan yang lebih baik yang membantu menyelesaikan masalah. Ia membuktikan bahawa ia lebih berkuasa, mudah, interaktif dan cekap daripada peta kertas tradisional. Peta digital ini adalah peta fizikal yang pada bila-bila masa ia boleh diperbetulkan dan diubah suai.

Keputusan simulasi untuk keadaan semasa menunjukkan DO di hulu aliran utama Sungai Klang berbeza-beza antara kelas I dan II, manakala BOD berbeza-beza antara kelas II dan III. Kelas DO berkurangan daripada pertengahan aliran ke arah hiliran di mana ia mencatatkan kelas IV. BOD itu direkodkan sebagai kelas IV di pertengahan aliran dan di hiliran adalah kelas III. Selain itu, keputusan simulasi daripada tiga senario menunjukkan bahawa Loji Rawatan Pembetungan (STP) adalah penyumbang utama kepada sumber pencemaran DO dan BOD kepada sistem sungai. Loji Rawatan Pembetungan (STP) ditinggalkan dengan standard A dan B menyebabkan peningkatan dalam jumlah DO (antara 0% dan 40.5%), manakala jumlah BOD menurun di antara 0% dan 49.4%.

Dengan menghubungkan output model dengan platform GIS, kelas-kelas kualiti sungai dari segi DO dan BOD ditunjukkan dengan jelas di sepanjang kawasan tadahan Sungai Klang. Di samping itu, keputusan membantu untuk menganalisis dan menilai kualiti sungai dengan mudah. Keputusan ini boleh digunakan sebagai alat dalam mereka bentuk keputusan sistem sokongan.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	THE CROSS-SECTION AREA
A_c	THE CROSS-SECTIONAL AREA
B_0	BOTTOM WIDTH
BOD	BIOCHEMICAL OXYGEN DEMAND
CAD	COMPUTER-AIDED DESIGN
COD	CHEMICAL OXYGEN DEMAND
D	DEPTH
DEM	DIGITAL ELEVATION MODEL
DID	THE DEPARTMENT OF IRRIGATION AND DRAINAGE MALAYSIA
DO	DISSOLVED OXYGEN
DOE	THE DEPARTMENT OF ENVIRONMENT MALAYSIA
DOS	DISK OPERATING SYSTEM
E	THE DIFFERENCE IN ELEVATION BETWEEN UPSTREAM & DOWNSTREAM OF THE REACH
ESRI	ECONOMIC AND SOCIAL RESEARCH INSTITUTE
G.S	GAUGING STATION
GIS	THE GEOGRAPHIC INFORMATION SYSTEM
H	ELEMENT DEPTH
ha	HECTARE
HW	HEADWATER
IMG	IMAGE

IWK	INDAH WATER KONSORTIUM NATIONAL MALAYSIAN SEWERAGE COMPANY
JUPEM	DEPARTMENT OF SURVEY AND MAPPING MALAYSIA
km^2	SQUARE KILOMETERS
L	LITER
L	DISTANCE ALONG THE REACH
M	THE MEASURED DATA
mg	MILLIGRAMS
n	THE NUMBER OF THE DATA POINTS
n	THE MANNING ROUGHNESS COEFFICIENT
NH_3N	Ammoniacal NITROGE
npai	THE TOTAL NUMBER OF NON-POINT WITHDRAWAL FLOWS FROM ELEMENT *i*
npsi	THE TOTAL NUMBER OF NON-POINT SOURCE INFLOWS TO ELEMENT *i*.
P	THE WETTED PERIMETER
pai	THE TOTAL NUMBER OF POINT WITHDRAWALS FROM ELEMENT *i*
PCs	THE PERSONAL COMPUTERS
PE	POPULATION EQUIVALENT
pH	POTENTIAL OF HYDROGEN
Psi	THE TOTAL NUMBER OF POINT SOURCES TO ELEMENT *i*
Q	THE DISCHARGE
Q2E	QUAL2E STREAM WATER QUALITY MODEL

Q2K	QUAL2K STREAM WATER QUALITY MODEL
Q_i	OUTFLOW FROM ELEMENT i INTO THE DOWNSTREAM ELEMENT $i + 1$
Q_{i-1}	INFLOW FROM THE UPSTREAM ELEMENT $i - 1$
$Q_{in,I}$	THE TOTAL INFLOW INTO THE ELEMENT FROM POINT AND NONPOINT SOURCES
$Q_{npa,i,j}$	THE jth NON-POINT WITHDRAWAL OUTFLOW FROM ELEMENT i
$Q_{nps,i,j}$	THE jth NON-POINT SOURCE INFLOW TO ELEMENT i
$Q_{out,I}$	THE TOTAL OUTFLOW FROM THE ELEMENT DUE TO POINT AND NONPOINT WITHDRAWALS
$Q_{pa,i,j}$	THE jth POINT WITHDRAWAL OUTFLOW FROM ELEMENT i
$Q_{ps,i,j}$	THE jth POINT SOURCE INFLOW TO ELEMENT i
R	REACH
R^2	THE MEASURE THAT SHOWS HOW WELL THE TRENDS IN THE MEASURED DATA ARE REPRODUCED BY THE SIMULATED RESULTS
RSO	RECTIFIED SKEW ORTHOMORPHIC MALAYA
S	THE SIMULATED DATA
S_0	BOTTOM SLOPE
SD	STANDARD DEVIATION
SE	STANDARD ERROR
SIAN	SUB-INDEX OF AN (OR NH3N)
SIBOD	SUB-INDEX OF BOD
SICOD	SUB-INDEX OF COD

SIDO	SUB-INDEX OF DO
SIpH	SUB-INDEX OF PH
SISS	SUB-INDEX OF SS
SS	SUSPENDED SOLIDS
s_{s1} & s_{s2}	THE TWO SIDE SLOPES
ST	STATION
STP	SEWERAGE TREATMENT PLANT
t	TONS
V	THE VELOCITY
VBA	VISUAL BASIC FOR APPLICATIONS
W	WIDTH
WQI	WATER QUALITY INDEX

CHAPTER ONE

1. INTRODUCTION

1.1. Introduction

This chapter shows the significance of the study. It gives a brief background and the reason of conducting this study as well as the outline of the thesis. Therefore, this chapter can be divided into four stages. The first stage gives a background on the rivers and their importance in Malaysia. The second stage states the problem that being the reason of conducting this study. The third stage shows clearly the aims and objectives of the study. While the last stage illustrates the outline of the thesis.

1.2. Background

Water is a natural resource whose availability strongly affects economic development and social welfare (Jaumann et al., 2014). Basically, it is a vital natural resource for every living organism on Earth (Rui, Chao, & Qiang, 2004). Water is an essential element in the sustenance of all forms of life, and most living organisms can survive only for short periods without it. Thus, any change in the natural quality and water distribution has potentially devastating environmental effects (Pringle, 2003; Vijayaraghavan & Raja, 2014).

Besides being a vital resource for the survival of all forms of life, water is also a common vector and significant capital for a wide range of development, whether rural or urban.

Contrary to the past when water was more abundant and populations were smaller, water has now become a scarce commodity in many countries, especially in water-stressed regions such as Australia, Africa, several parts of continental Asia, island states and the Middle East (Pereira, Cordery, & Iacovides, 2009). Furthermore, water has now even become the cause of quarrels between neighbors, confrontations between countries, conflicts between sovereign states and wars among larger groups.

The term “water quality” refers to the physical, biological and chemical status of a water body (Wang, Homer, Dyer, White-Hull, & Du, 2005). In the last decades, countless researchers and managers have been concerned with the challenge of water quality management associated with the principle of sustainable development. Besides the necessity to reinforce established principles and technologies, these also need to be expanded to much higher, wider and freer scopes for the realization of water quality management sustainability (Argent, 2004; Chen, Ma, & Reckhow, 2007; Huang & Xia, 2001; Larson & Edsall, 2010).

The management of water quality has been a critical issue for decades, but the current situation in the world is quite far from satisfactory (Bao & Fang, 2007; Elshorbagy & Ormsbee, 2006; Liu & Xia, 2004). This is due to increasing population pressures as well as economic development (Biswas, 2006; Loucks, 2000; Matthies, Giupponi, & Ostendorf, 2007; Newson, 2008; Paredes-Arquiola, Andreu-Álvarez, Martín-Monerris, & Solera, 2010; Xuequan & Qianzhao, 2002). Several efforts are dedicated to the establishment of water resource management strategies to maintain the supply of sufficient, good quality water (Ning, Chang, Yong, Chen, & Hsu, 2001).

Water on the Earth's surface is called surface water, and this includes lakes, rivers, estuaries, reservoirs and coastal waters. Conversely, water beneath the Earth's surface is called groundwater. Although groundwater is directly associated with surface water, it is considered a separate system that is managed under different laws and rules (Patterson, 2000). People depend on surface water for aquatic life support, water supply, recreation, fisheries and transportation. Subsequently, surface water resource management is important for humans, economic growth and development, and social and ecosystem wellbeing (Ji, 2008). The abundance, presence, diversity and distribution of aquatic species throughout surface waters are reliant upon a myriad of physical and chemical factors, such as pH, suspended solids, temperature, chemicals, nutrients and in-stream and riparian habitats (Wang, 2001).

The key advantage of each body of surface water lies in its watershed, and the runoff from any watershed surface has the possibility of flowing into the surface water body. Consequently, the surface-water body is the recipient of all pollution incorporated in surface runoff from all positions within the watershed. Therefore, surface water quality management at the watershed level is superior and more effective than at an individual water body scale (Chin, 2006).

In Malaysia, rivers are regarded as the main source of water supply. In addition to delivering water supply, healthy river systems provide fish, transport, power generation, recreation and cultural identity (Abdullah, 2002). Although rivers are very important in Malaysia for life and development, their water always looks polluted everywhere. This is a result of hazardous wastes emitted from industries into the water system, as well as untreated waste coming from old houses, small towns, old hotels and farms (both animals and crops), and other activities along the rivers (Weng, 2005).

In terms of water resource management, water quality modeling has often served as a support tool in assessing the aquatic environment, with the calculated results providing valuable information for enhancing water quality management (Fan, Wang, & Liao, 2007). Nearly a century has passed since the first water quality model was developed and many studies have since been presented regarding such modeling (Chapra, 2008; Peng, 2001).

A number of well-known water quality models have been developed and presented over the past several decades, which are characterized by their applicability to different water body types, such as estuaries, rivers, lakes, reservoirs, etc (Eatherall, Boorman, Williams, & Kowe, 1998; Fan, Ko, & Wang, 2009; Horn, Rueda, Hörmann, & Fohrer, 2004). In order to be able to calculate basic water quality indexes, the algorithms in these models can determine complicated water quality criteria such as toxicity impacts and eutrophication levels.

Based on previous research works, water quality modeling has demonstrated the capability of predicting water quality under different circumstances and providing valuable information for water resource management.

According to past experience, the most complex model is not necessarily the most useful one (Lindenschmidt, 2006a). This is owing to the copious amounts of monitoring data required for the calibration, estimation and verification of model parameters, while some complicated simulation models may involve diverse parameters that have never been measured or reported before. In a few examples, other algorithms have estimated these parameters. For this reason, the use of complicated models for the simulation of water quality is problematical, besides the fact that the simulated results might not be as reliable as they are purported to be. Consequently, models with limited parameters have become prevalent on account of the ease of acquiring environmental and geological parameters, as well as the agreement between simulated and measured results for straightforward situations.

Although in assessing river water quality scientists have employed mathematical models, the application of such models in risk assessment and environmental management is quite limited due to the intricacy of preparing input data and explaining the model output. In the works by Tong and Chen (2002) and Lenzi and Luzio (1997) the modeling of water quality was linked with a geographical information system (GIS) to determine a strategy for water resource management. The GIS is a robust tool for understanding, modeling, and managing complex stream water problems (Fletcher, Qingyun, & Strager, 2001).

The GIS is not only a fundamental tool for implementing and presenting results simulated by computer models, but also for manipulating spatial data for screening purposes (Giupponi & Vladimirova, 2006). GIS is increasingly utilized to process spatial data representing pollution factors and to study how vulnerable a particular area is to groundwater pollution or potential risks of surface waters contamination (Dunn, Vinten, Lilly, DeGroote, & McGechan, 2003; Giupponi & Vladimirova, 2006; Lake et al., 2003).

1.3. Problem statement

The amplified pressure on urban areas in Malaysia has been generated by rapid growth in the manufacturing field, especially in the Klang River Basin, which is the most densely populated area of the country (El-Shafie, Jaafer, & Seyed, 2011).

The Klang River supports plenty of industrial activities in Malaysia and is the site for the country's capital (Ismail & Naji, 2011; Naji, Ismail, & Ismail, 2010). The basin's catchment area is 1,288Km^2, it is the most urbanized region in Malaysia, and encompasses the Federal Territory of Kuala Lumpur with part of the state of Selangor. The basin has a population of 4.4 million, or 16% of the national population that is growing at an annual rate of 5%. The basin passes through nine local government authorities (Naji et al., 2010).

The status of the Klang River is generally rated between critical and bad. It faces serious environmental degradation from urbanization, industrialization, and population growth (Angie, 2010). Roughly, 50% of the basin has been urbanized. The water quality is deteriorating as a result of the excessive sediment loads from construction and deforestation, large quantities of litter and rubbish, untreated sewage and industrial and commercial effluents.

According to a report by ADB (2007), the river ecology has endured the removal of vegetation from the riparian corridor and depletion of snags from the watercourses, thus diminishing the habitats of a variety of riparian and aquatic fauna. This has decreased the contamination filtration capacity and increased nutrients and other contaminants that flow into the rivers. The combined effect of poor water quality, high sediment load, and removal of vegetation from the river corridor has caused a decline in the number and diversity of native flora and fauna.

In 2008, the Klang River was one of fourteen rivers in Malaysia categorized by the Department of Environment Malaysia (DOE) as highly polluted rivers. Furthermore, an annual report by DOE (2008) showed that the condition of the water quality of the Klang River remains deemed a polluted river with class III water quality.

1.4. Aim of the study

The aim of this study is to determine and assess the surface water quality of the Klang River in terms of water quality parameters using a river water quality model and GIS. Accordingly, the current research objectives are:

- To develop a digital map of the Klang River and build its database using GIS.
- To assess the Klang River water quality status via river modeling measurements.
- To synthesis the water quality model’s output in the GIS environment and analyze the results according to the ambient spatial data.

1.5. Outline of the thesis

The present study is documented in five chapters, as follows:

- Chapter one introduces the problem statement as well as an overview of the main objectives of this study.
- Chapter two represents the literature review and previous research works related to the current study.
- Chapter three discusses in detail the methodology of data collection and processing applied in this research. In addition, the development and simulation of the water quality model is presented in along with a representation of the model output in the GIS environment. A brief introduction of the study area is provided in this chapter as well.
- The model output results are discussed and analyzed in chapter four.
- Finally, the conclusions of this study and recommendations for future research are given in chapter five.

1.6. Summary

This chapter summarized the significant and the reason of conducting the study. It showed how the rivers and their water are important especially in Malaysia. The chapter, also, highlighted the river water modeling as an effective tool for assessing and managing the river water. The literature indicated that Klang River, which is the most densely populated area of Malaysia, is a polluted river that receives contaminants from different sources of pollution. The status of the river water is between critical and bad. Thus, this study aimed to assess the water quality of the Klang River using river water quality model and GIS techniques. The chapter highlighted three objectives to be achieved in this study. Finally, this chapter showed the outline of the thesis, which contains five chapters.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

This chapter defines and describes the methods that used in this study to achieve the objectives. It is divided into several stages. The first stage describes the surface waters and their importance for human life. The second part defines the river system and its components. Types of pollution sources are defined in the third part. The fourth part of this chapter shows the importance of the rivers in Malaysia. The water quality modelings as well as the types of river water models are discussed in the fifth part. This part also discusses the river water model that selected for this study and its application in previous studies. The last part of this chapter discusses the importance of GIS and its applications in water resources management.

2.2. Surface water

Naturally, surface water systems are exposed to the environment, for instance rivers, reservoirs, estuaries, lakes and coastal waters. Surface waters constantly change on account of human and natural forces. Their ecosystems are interactive systems which include chemical and hydrodynamic characteristics as well characteristics associated with the biological community of the water benthos and water column (Terrado, Barceĺ, Tauler, Borrell, & Campos, 2010). These ecosystems, under a blockade from all directions, are confronted with increasing populations, inadequately planned land use and pollutants originating from houses, farms and industries. People depend on surface water for aquatic life support, water supply, recreation, fisheries and transportation. Subsequently, the quality of surface water is a very sensitive issue. Furthermore, surface water resource management is important for humans, economic growth and development, and social and ecosystem wellbeing (Simeonov et al., 2003).

2.3. River As a Dynamic System

A river is a part of large system. It can be defined as, a dynamic element that drains a landscape (watershed) and transport sediment. It also can be defined as “a large natural stream of water that flowing in channels or large water bodies” (Torontow, Saarela, & Vorano, 2014).

The river system is a group of rivers draining their water into a large water bodies (sea, lake, etc…). It can also be defined as, a basin (watershed) that drains into a large water body by a group of rivers. Figure 2.1 Illustrates sample of a river system (Lord, Germanoski, & Allmendinger, 2009; Trinity-Waters, 2011).

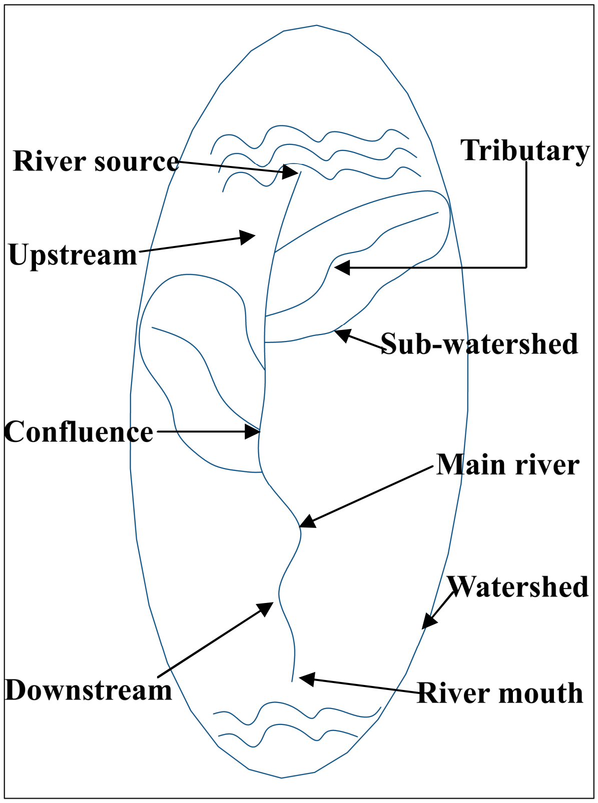


Figure 2.1: The river system

2.3.1. River Source (Headwater)

The river source is the point that the river starts flowing. It is also called the river headwater. This point often located at a mountain, hill or a high-level place. The river headwater fed by different sources, i.e. runoff from rain, snowmelt, glacial melt and underground spring (Brown, 2013).

2.3.2. Main River

The main river is defined as the mainstream (main channel) of the basin that receives the water from all tributaries before discharge into the water body.

2.3.3. Tributary

The tributary is a river or stream, which discharges and joins the main river (mainstream).

2.3.4. Confluence

The confluence is the point of which two or more rivers meet together.

2.3.5. River Mouth

The river mouth is the part of the river that flows into another water body, whether this water body is river, lake, reservoir, sea, ocean, etc.

2.3.6. Sub-Watershed (Sub-Basin)

The sub-watershed (sub-basin) is a watershed that drained by tributary into the main river or other water body.

2.3.7. Upstream and Downstream

The upstream is the river part that nearer to the river source, while the downstream is the river part that nearer to the river mouth.

2.4. River water pollution

Pollution is considered among the biggest threats to river water quality. Essentially, the pollution of any water body (river, lake, reservoir, ocean, etc) is defined as "the contamination that occurs due to pollutant discharge into the water body by direct or indirect ways from different sources" (Merriam-Webster, 2010). These pollutants can be categorized into three types:

- ❖ **Physical pollutants**: Include metals, rubbish, glass and all other substances that do not dissolve in water.
- ❖ **Chemical pollutants**: Include all heavy metals and dissolved chemicals.
- ❖ **Biological pollutants**: Include animal waste that causes the growth of bacteria and other microbes.

A pollution source inventory is the most important part of controlling the quality of river water. Human activities, such as housing, recreation and agriculture contribute to the deterioration of river water quality (Darradi et al., 2012; Kamarudzaman, Feng, Abdul-Aziz, & Ab-Jalil, 2011). Previous studies showed different sources that contaminate the river water. For instance, a study by Wu and Chen (2013) showed that The East River (Dongjiang) receives pollution loads from sewage plants, industrial, forest and agriculture areas. Another study by Su et al. (2011) found that all chemical plants, industrials, fluoride and san mining as well as vehicle exhaust are the main contributors of the pollution in The Qiantang River, China. Likewise, a study on The Thachin River in Thailand by Schaffner, Bader, and Scheidegger (2009) indicate that the river receives pollution loads from different sources, i.e. aquaculture, rice farming, industries, households and pig farms.

The sources of pollution where contaminants derive can be divided into two main types: point sources and nonpoint (diffuse) sources (Wu & Chen, 2013).

- **Point sources of pollution**

Point source pollution entails a contaminant that is discharged from a concentrated originating point (such as industry, workshop, etc.), and it usually comes out of pipes or drainage. In addition, point sources include pollutant loading of pollutant contributed by main river tributaries (USEPA, 2010).

- **Diffuse sources of pollution (nonpoint sources)**

Diffuse (nonpoint) sources of pollution originate from diffused sources (such as agriculture, forests, residential areas, etc), carrying man-made and natural pollutants into a water body (rivers, lakes, estuaries, etc). These sources are usually associated with rainfall runoff through and over the ground (Jiake, Huaien, Bing, & Yajiao, 2011; USGS, 2011).

2.5. Rivers in Malaysia

Water resource management requires the development of suitable water quantities with appropriate quality (Fulazzaky, Seong, & Masirin, 2010). According to DOE (2003), the water demand tendency in Malaysia was estimated to have increased by about 60% between 1995 and 2010 and by roughly 113% between 1995 and 2020.

The main water supply source in Malaysia is rivers. Rivers are natural watercourses that normally end into lakes, oceans or other rivers. Small rivers are usually called streams or brooks. Rivers provide about 97% of the drinking water in Malaysia. They also support the country's economic development.

There are around 1800 rivers in Malaysia, consisting of 150 systems that run up to 38,000km. River water in Malaysia is widely used in households, aquaculture, industries, hydroelectric power and agriculture. Therefore, river water quality is an important issue in Malaysian water management (Kailasam, 2006).

In terms of water resource management, water quality modeling has often been employed as a supporting tool to evaluate the aquatic environment, with the calculated results providing valuable information for the improvement of water quality management (Fan et al., 2007).

Since rivers comprise the main source of water in Malaysia and river water management greatly contributes to the development of the country, river water modeling goes a long way to mitigate pollution problems.

In this research, the Klang River - one of the most important rivers in Malaysia, has been selected as the study area. A river water model was also selected for simulation to define a number of pollution parameters. More details including the position, importance and characteristics of this river are presented in Chapter 3.

2.6. Water Quality Modeling

In the words of Pablo Picasso, "modeling is a little like art. It is never completely realistic; it is never the truth. But it contains enough of the truth, hopefully, and enough realism to gain understanding about environment systems" (Ji, 2012). There are two main reasons to conduct surface water modeling, one of which is to understand physical, chemical, and biological processes and the other is to improve models capable of realistically representing surface waters, thus the models can be used to support water quality management and decision making (Agoshkov, 2002).

Surface water modeling is a complex, evolving matter. For this reason, there is no agreement among professionals regarding the best approach to model the various types of surface water (rivers, estuaries, lakes and coastal waters) (USEPA, 2009).

2.7. Conceptual Design

Water quality models are dependent on the mass conservation principle. Besides such models mathematically representing water quality processes, they utilize several empirical formulations and parameters. Determining these parameters' values is the principal, most important step in the calibration of a water quality model (Ji, 2008).

In Malaysia, the Department of Environment (DOE) program is involved in taking water samples for in-situ measurements and laboratory analysis (DOE, 2005). The samples are normally collected at stations set up by DOE along the rivers.

Although several water quality parameters are analyzed in the DOE water quality monitoring program for rivers, only six parameters are used to identify river class. DOE applies the following parameters to calculate the water quality index and river class: Dissolved Oxygen [DO], Biochemical Oxygen Demand [BOD], Chemical Oxygen Demand [COD], Suspended Solids [SS], Ammoniacal Nitrogen [NH_3N] and pH. The equations below show how the Department of Environment determines river class (Almamun & Idris, 2008):

$$WQI = 0.22SIDO+0.19SIBOD+0.16SICOD+0.16SISS+0.15SIAN+0.12SIpH \qquad \text{Eq. 2.1}$$

where WQI = water quality index; SIDO = the sub-index of DO; SIBOD = the sub-index of BOD; SICOD = the sub-index of COD; SIAN = the sub-index of AN; SISS = the sub-index of TSS; SIpH = the sub-index of pH; all are calculated by the flowing equations:

Sub-index for DO (in % saturation):

$SIDO = 0$	for $DO < 8$	Eq. 2.2a
$= 100$	for $DO > 92$	Eq. 2.2b
$= -0.395 + 0.030DO^2 - 0.00020DO^3$	for $8 < DO < 92$	Eq. 2.2c

Sub-index for BOD:

$SIBOD = 100.4 - 4.23BOD$	for $BOD < 5$	Eq. 2.3a
$= 108e^{-0.055BOD} - 0.1BOD$	for $BOD > 5$	Eq. 2.3b

Sub-index for COD:

$SICOD = -1.33COD + 99.1$	for $COD < 20$	Eq. 2.4a
$= 103e^{-0.0157COD} - 0.04COD$	for $COD > 20$	Eq. 2.4b

Sub-index for AN:

$SIAN = 100.5 - 105AN$	for $AN < 0.3$	Eq. 2.5a
$= 94e^{-0.573AN} - 5\lvert AN - 2\rvert$	for $0.3 < AN < 4$	Eq. 2.5b
$= 0$	for $AN > 4$	Eq. 2.5c

Sub-index for SS:

$SISS = 97.5e^{-0.00676SS} + 0.05SS$	for $SS < 100$	Eq. 2.6a
$= 71e^{-0.0016SS} - 0.015SS$	for $100 < SS < 1000$	Eq. 2.6b

$= 0$ for $SS > 1000$ Eq. 2.6c

Sub-index for pH:

$SIpH = 17.2 – 17.2pH + 5.02pH^2$ for $pH < 5.5$ Eq. 2.7a

$= -242 + 95.5pH – 6.67pH^2$ for $5.5 < pH < 7$ Eq. 2.7b

$= -181 + 82.4pH – 6.05pH^2$ for $7 < pH < 8.75$ Eq. 2.7c

$= 536 – 77.0pH + 2.76pH^2$ for $pH > 8.75$ Eq. 2.7d

The WQI classification according to the Department of Environment is provided in Table 2.1 (DOE, 2012):

Table 2.1: Water quality index classification by DOE, Malaysia

Parameter	**Unit**	**Class**				
		I	**II**	**III**	**IV**	**V**
Ammoniacal Nitrogen	mg/L	< 0.1	0.1 – 0.3	0.3 – 0.9	0.9 – 2.7	> 2.7
Biochemical Oxygen Demand (BOD)	mg/L	< 1	1 - 3	3 – 6	6 – 12	> 12
Chemical Oxygen Demand (COD)	mg/L	< 10	10 - 25	25 - 50	50 - 100	> 100
Dissolved Oxygen (DO)	mg/L	> 7	5 - 7	3 - 5	1 - 3	< 1
pH		> 7	6.0 – 7.0	5.0 – 6.0	< 5.0	> 5.0
Suspended Solids (TSS)	mg/L	< 25	25 - 50	50 - 150	150 – 300	> 300
Water Quality Index (WQI)		**> 92.7**	**76.5 – 92.7**	**51.9 – 76.5**	**31.0 – 51.9**	**< 31.0**

DO is defined as the amount of oxygen that is dissolved in water, which occurs when microscopic bubbles of gaseous oxygen are mixed in water. It is considered one of the most essential water quality parameters, as it is used to measure the amount of oxygen that is available for biochemical activity in water (Ji, 2008). BOD is defined as a measure of the total amount of oxygen removed from water biologically or chemically in a specified time and at a specific temperature. It gives an indication of the total DO concentration required throughout some organic matter degradation and oxidation. The COD is a measure of the equivalent of organic matter susceptible to oxidation by strong chemical oxidants (Viessman & Hammer, 2005). The majority of COD applications determine the amount of organic pollutants found in surface water or wastewater, making COD a valuable measure of water quality. Suspended solids often consist of abundant suspended organic matter, whose decomposition also consumes oxygen. AN represents the amount of ammonia and ammonium compounds (Jafari & Khayamian, 2008). These are transmitted into the environment from different sources, such as waste incineration, sewage treatment, cattle excrement and car exhaust (Mirmohseni & Oladegaragoze, 2003). The pH of surface waters is specified for the protection of fish life and to control undesirable chemical reactions.

WQI has been involved in many previous studies. For instance, Gazzaz, Yusoff, Aris, Juahir, and Ramli (2012) applied the Artificial Neural Network to forecast the WQI along the Kinta River in Malaysia for better assessment of the river water quality. Another study by Fulazzaky, Seong, and Masirin (2010) involved the WQI to assess the status of the water quality of Selangor River in Malaysia. Likewise, WQI involved in different researches and many case studies. It proved that it can be an effective tool to assess the river water quality for better management.

2.8. River water quality models

According to Fowler, Fowler, and Allen (1990), a model is defined as “a simplified description of a system that helps calculate and predict system conditions in a given situation.” In other words, a water quality model is “a mathematical representation of water quality processes that occur within a water body” (AEE, 2005). The management of water quality increasingly depends on precise modeling. Water quality models enable decision makers to select, scientifically, the more defensible choices among alternatives for management of the water quality. The water quality models are frequently employed to recognize which one of the alternatives will be most efficient in solving a long-term water quality issue. Taking existing conditions into consideration is important and necessary for management decisions, as well as to predict anticipated future changes of a water system. Besides being required to represent existing conditions, the models in these applications also need to predict and provide conditions that do not yet exist. The models additionally provide an economic analysis grounds, such that the model results can be utilized by decision makers to evaluate the environmental significance of a project in order of cost–benefit ratio.

Personal computers (PCs) have rapidly improved and become a unified platform for most engineering applications. Without much difficulty, a model developed on a computer can be transformed to other computers. Furthermore, the low computer prices make modeling more cost effective. Surface water modeling studies are now widely applied in PCs owing to the fast advances in computer technology.

Models play a crucial role in advancing the state of water quality, water resource management, hydrodynamics and sediment transport. Due to the models’ requirements for accurate and precise data, they basically contribute to the design of field data collection as well as serve to characterize data gaps in identifying water bodies. They are also employed to analyze the impact of different management alternatives in order to select the ones that result in minimal negative impact on the environment (Ji, 2008).

2.8.1. Types of river water models

River transport normally controlled by dispersion and advection processes. To characterize these processes, one, two and three-dimensional models were developed. The main factors that determine the applicability of a model are the study objectives, river characteristics and data availability.

1-D models are typically used in cases of small rivers, while the 2- and 3D models are employed in instances demanding more detailed analysis of flow velocities and directions. Besides, 2D models are used when vertical stratification is an important feature of the river. 3D models are generally called for in circumstances involving large rivers (Ji, 2008).

Different models regarding to the steams and river water quality were developed through the past several decades.

- **WASP**

In 1970, the United States Environmental Protection Agency (USEPA) has developed the Water Quality Analysis Simulation Program (WASP). The program helps the users to interpret and predict water quality responses to natural phenomena and manmade pollution for various pollution management decisions (DiToro, Fitzpatrick, & Thomann, 1983; Ambrose, Martin, & Wool, 2006). It allows the modelers to develop one, two and three-dimensional models. Furthermore, the model is a dynamic compartment-modeling program for aquatic systems including the water column and the underlying benthos.

During the past few decades, USEPA has developed and upgraded the model through different versions. The old versions developed to be run under the Disk Operating System (DOS), while the upgraded new versions developed to be run under Windows operating system with a graphical user interface for input files generating and output files visualizing for easy evaluation of simulation results. Furthermore, the model output can be transferred and used by the tools of Geographical Information System (GIS) and the programs of the water quality statistics. In addition, the program interface can read the results that generated by the Hydrological Simulation Program – FORTRAN (HSPF) (Kannel, Kanel, Lee, Lee, & Gan, 2011; Lindenschmidt, 2006b).

The model package includes a heat balance model to simulate water temperature. It also includes models to simulate toxicant fate, including general toxicants, organic chemicals and mercury. Another two models are included, as well, to simulate conventional water quality, including a basic eutrophication model and an advanced eutrophication model. Bothe mass balance and the specific chemical kinetics equations with the input dataset are uniquely define a special set of water quality equations. The model integrates these equations numerically using an adaptive time step Euler scheme as the simulation proceeds in time. The model has been widely applied for a variety of water bodies to investigate dissolved oxygen, bacteria, eutrophication, suspended solids, and toxic substance problems such as (Ambrose (1987); Ambrose, Tsiros, and Wool (2005); Caruso (2005); Lung, Martin, and McCutcheon (1993); Thomann and Center (1975); Wool, Davie, and Rodriguez (2003)).

- **CE-Qual-W2**

In 1975, CE-Qual-W2 model has been developed by the US Army Corps of Engineers (USACE) (Edinger & Buchak, 1975; Norton & Bradford, 2009). CE-Qual-W2 model is a hydrodynamic and water quality model for surface water systems. It is a two-dimensional model (longitudinal-vertical) (Cole & Wells, 2003; Deus et al., 2013; Ostfeld & Salomons, 2005). Since 1975, the model has been under continuous development. The model assumes lateral homogeneity that is particularly suitable for narrow and long water bodies, which presenting longitudinal and vertical water quality gradients. It uses a numerical scheme for a direct coupling between water quality and hydrodynamic simulations. Furthermore, the model simulations can be made over seasonal, annual, or multi-year cycles. CE-Qual-W2 simulates the longitudinal and vertical mixing and transport of water, temperature and a number of other water quality parameters. The hydrodynamic runs in the model applications provide real-time simulations of temperature, velocities and a conservative tracer. CE-Qual-W2 able to simulate about 21 water quality constituents, i.e. dissolved oxygen (DO), carbonaceous biochemical oxygen demand (CBOD), pH, alkalinity, conservative tracer, coliform bacteria, total dissolved solids, algae, detritus, suspended soils, total phosphorus, ammonia, nitrate, labile and refractory dissolved oxygen matter, sediment, total inorganic carbon, carbon dioxide, bicarbonate, carbonate and iron. The model has been applied in many applications to stratified water systems, including reservoirs, lakes and estuarine environments. For instance (Garvey et al. (1998); Gunduz, Soyupak, and Yurteri (1998); Kuo et al. (2003); Kuo et al. (2006); Kurup, Hamilton, and Phillips (2000); Lung and Bai (2003); Martin (1988); McKee, Thackston, Speece, Wilson, and Cardozo (1992)).

❖ QUASAR

The QUASAR is a water quality and flow model that developed to assess the environmental impact of pollutants on non-tidal river water quality, which combines upstream inputs from tributaries, point and non-point effluents, to calculate the water chemistry in the river at points further downstream as well as the water flow. The model runs in two modes, dynamic and planning mode (Ferrier, Whitehead, Sefton, Edwards, & Pugh, 1995; Kannel et al., 2011). The time series data in the dynamic mode are used as model input to generate flow and quality estimates at each reach boundary over a period of time. In the planning mode, the Monte Carlo simulation method used to provide a cumulative frequency distribution of selected water quality variables from a given set of hydrological inputs and operating conditions. QUASAR able to model dissolved oxygen, biochemical oxygen demand, ammonium, pH, E.coli, nitrate, temperature, algae and conservative pollutant. The model has been applied for many studies. It used to assess heavy metal pollution in Pelenna River (in Wales, UK) (Whitehead, Mccartney, Williams, Ishemo, & Thomas, 1995). It was also used to assess the movement and distribution of nitrates and algae along the Fiver system for Thames River (UK) (Whitehead & Williams, 1982).

❖ QUAL2E

The Qual2E is a one-dimensional stream water quality model that developed by the United States Environmental Protection Agency (USEPA) (Ning, Chang, Yong, Chen, & Hsu, 2001). It has been approved as a planning tool in river-basin study. Furthermore, the model is a versatile for determining the quality of flowing waters. It simulates up to 15 water quality parameters including dissolved oxygen (DO), Biochemical oxygen demand

(BOD), Temperature, Algae as chlorophyll A, Organic nitrogen, Ammonia, Nitrite, Nitrate, Organic phosphorus, Dissolved phosphorus, Coliform, arbitrary non-conservative constituents and three conservative constituents (Dai, 1997). Qual2E is also applicable to well-mixed streams as well as it considers the transport mechanisms dispersion and advection significant only along the main direction of flow (longitudinal direction). Moreover, the model is able to simulate the two conditions, the steady state and the dynamic conditions, of the stream water quality. The model limited to simulate 25 reaches with no more than 20 computational elements per reach. Since it was developed, Qual2E has been applied in different studies and countries such as Spain, Poland, the United States, Slovenia, Chile and India (Chaudhury, Sobrinho, Wright, & Makam, 1998; Cubillo, Rodriguez, & Barnwell, 1992; Drolc & Končan, 1996; Drolc & Končan, 1999; Dussailant & Munoz, 1997; Ghosh & McBean, 1998; Gremiec, 1997; Little & Williams, 1992; Walton & Webb, 1994).

2.9. The Qual2k model

An essential aspect of the current study is to provide a water quality model for the study area that can simulate the quantity and quality of the water following various forms of pollution discharge along the river. Water quality model selection depends on the model’s suitability and capability to fulfill the required task, data availability and the period allocated.

In seeking a water quality model, the QUAL2K model was employed to conduct the water quality simulation for the Klang River Basin. The model simulates flow and water quality in rivers and streams. It is a one-dimensional model (1D) applicable to a well-mixed laterally and vertically dendritic river. The selection was done according to the objectives of this research and data availability, as well as the project cost.

Qual2K (or Q2K) is a free open source that specializes in river and stream water quality modeling and it is intended to represent a modernized version of the QUAL2E (or Q2E) model (Chapra, Pelletier, & Tao, 2007).

Qual2K has been applied previously in many case studies. For instance, (Mathew et al., 2011; Vasudevan, Nambi, & Suresh, 2011; Zainudin., 2010; Zhang, Qian, Li, Yuan, & Ye, 2012). The model proved that it can be a useful tool for assessing the river water quality. Furthermore, it proved that it can help decision making for projects involving river management. Besides that, Qual2K proved as an easy model since it runs on Excel platform as well as the easiness of the data input comparing with the other models.

2.9.1. Qual2K framework

The Qual2K framework includes former elements similar to Qual2E. It is a one-dimensional model and the channel is well-mixed vertically and laterally. As well, the system can contain a main river stem with branched tributaries. In Qual2K model, the steady flow (non-uniform) is simulated. In addition, both temperature and heat budget are simulated as a function of meteorology on a diel time scale. Furthermore, all water quality variables are simulated, on a diel time scale as well. Point and nonpoint load and withdrawal are simulated.

The novel Qual2K elements include new features. It is implemented within the Microsoft Windows environment. An Excel workbook serves as the model interface and the numerical computations are programmed in Fortran 90. Furthermore, all interface operations are programmed in the Microsoft Office macro language Visual Basic for

Applications (VBA). Although, Q2E and Q2K divide (or segment) the system into river reaches comprised of equally spaced elements, the element size for Q2K can vary from reach to reach in contrast to Q2E. Moreover, multiple withdrawals and loadings can be performed for any element. Furthermore, there are two carbonaceous forms (BOD) that Q2K uses to represent organic carbon, namely a slowly oxidizing form (slow CBOD) and a rapidly oxidizing form (fast CBOD). Q2K, as well, accommodates anoxia by reducing oxidation reactions to zero at low oxygen levels. Furthermore, the denitrification is modeled as a first-order reaction that becomes pronounced at low oxygen concentrations. The sediment-water fluxes of dissolved oxygen and nutrients can be simulated internally rather than being prescribed. The Qual2K model explicitly simulates attached bottom algae with varying stoichiometry. Light extinction in the model is calculated as a function of algae, detritus and inorganic solids. In addition, both alkalinity and total inorganic carbon can be simulated, so the pH of the river is then computed based on these two quantities. The model allows the generic pathogen to be simulated and the pathogen removal is determined as a function of temperature, light, and settling. Q2K also allows users (or modelers) to specify many parameters of the kinetic on a reach-specific basis. Additionally, the model framework includes the hydraulics and effect of weirs as in order to waterfalls on gas transfer.

2.9.2. River segmentation in Qual2K

For a system without tributaries (only one river), the Q2K model represents the river as a series of reaches. These reaches in turn signify river stretches that have constant hydraulic characteristics (channel slope, bottom width, etc.). As shown in Figure 2.2, the reaches are number-ordered from the river's main stem headwater so that both point and nonpoint sources along with point and nonpoint withdrawals (abstractions) can be positioned anywhere along the channel’s length.

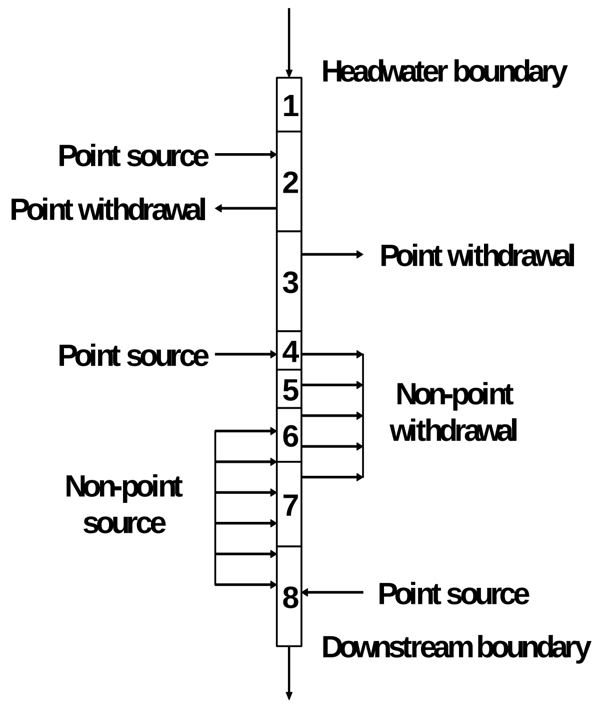


Figure 2.2: River segmentation in Q2K (River without tributaries)

As for systems with tributaries, the reaches are numbered beginning with reach 1 at the main stem’s headwater until it reaches a junction with a tributary, after which the numbering continues toward the tributary’s headwater (Figure 2.3). Both headwater and tributaries are numbered consecutively following a sequencing scheme similar to that for the reaches. Furthermore, the system’s major branches (the main stem and the tributaries) are referred to as segments.

Qual2K provides plots of model output on a segment basis. It generates individual plots for the main stem as well as each of the tributaries. Consequently, any reach of the model can be divided into a series of several equally spaced elements by specifying the desired element numbers. Figure 2.4 depicts an example of a reach divided into equally elements.

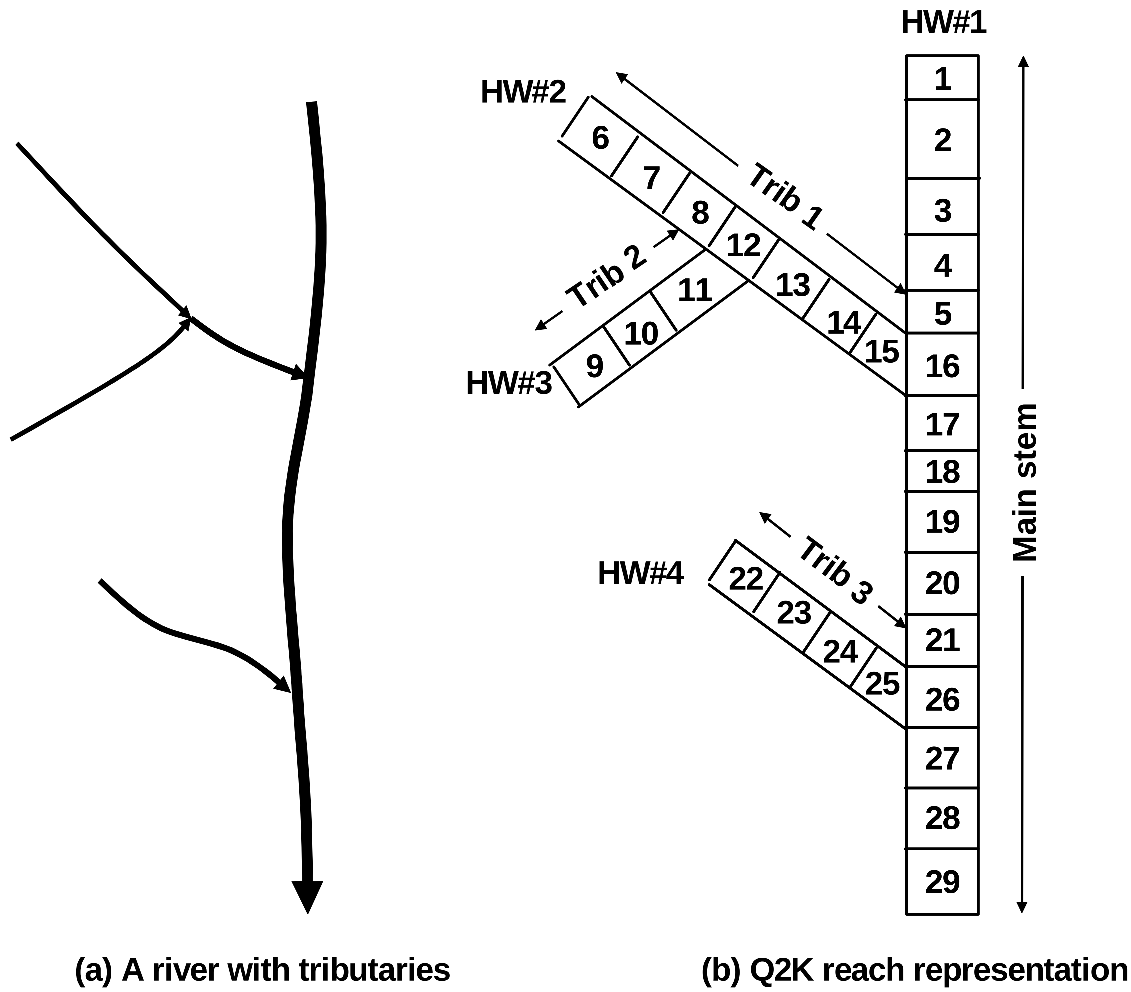


Figure 2.3: River segmentation in Q2K (River with tributaries)

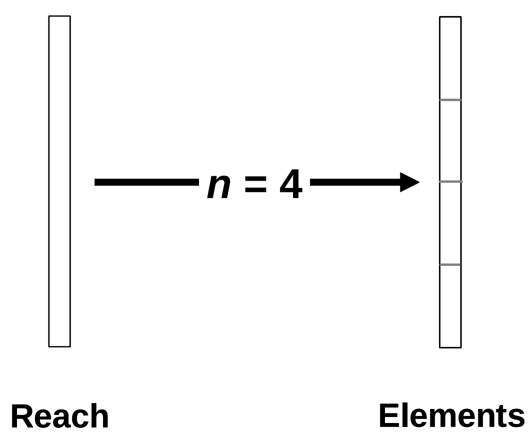


Figure 2.4: An example of a reach divided into elements in Q2K

2.9.3. Flow calculations in Q2K

The Qual2K model calculates discharge using one of three formulas: Rating Curves, Weirs or the Manning formula. For this work, Manning's formula was performed based on the available data. In this formula each element in a particular reach can be idealized as a trapezoidal channel (Figure 2.5). Under steady flow conditions, the Manning formula may be able to express the relationship between depth and flow, as in Eq. 2.8:

$$Q = \frac{1}{n} A.R^{2/3} S^{1/2} \qquad \text{Eq. 2.8}$$

where Q = flow [m^3/s], n = the Manning roughness coefficient, A = the cross-sectional area (m^2), R = hydraulic radius, S = bottom slope (m/m)

$$R = \frac{A}{P} \qquad \text{Eq.2.9}$$

Where P = wetted perimeter (m)

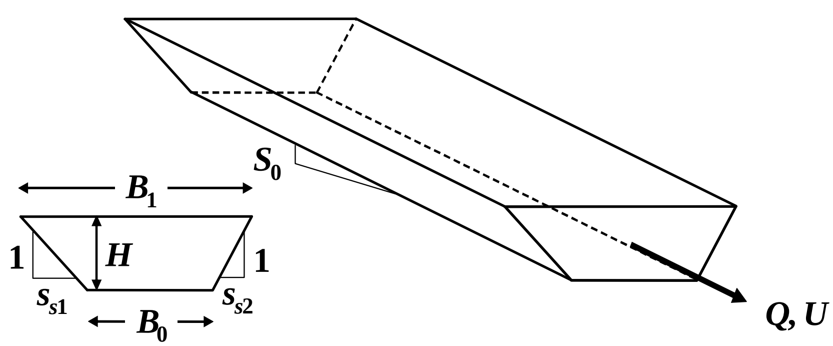


Figure 2.5: Trapezoidal channel

The cross-sectional area of a trapezoidal channel is calculated as:

$$A_c = [B_0 + 0.5(s_{s1} + s_{s2})H]H \qquad \text{Eq. 2.10}$$

where B_0 = bottom width [m], s_{s1} and s_{s2} = the two side slopes as Per Figure 2.5 [m/m], and H = element depth [m].

The wetted perimeter is computed as follows:

$$P = B_0 + H\sqrt{s_{s1}^2 + 1} + H\sqrt{s_{s2}^2 + 1} \qquad \text{Eq. 2.11}$$

Then Eq. 2.11 can be solved iteratively for depth as follows (Chapra & Canale, 2006):

$$H_k = \frac{(Qn)^{3/5}\left(B_0 + H_{k-1}\sqrt{S_{s1}^2 + 1} + H_{k-1}\sqrt{S_{s2}^2 + 1}\right)^{2/5}}{S^{3/10}\left[B_0 + 0.5(S_{s1} + S_{s2})H_{k-1}\right]} \qquad \text{Eq. 2.12}$$

where k = 1, 2, …, n; and n = the number of iterations. An initial presumption that H_0 = 0 is made. The method is terminated when the estimated error falls below the specified value of 0.001%. The estimated error is calculated as:

$$\varepsilon_a = \left|\frac{H_{k+1} - H_k}{H_{k+1}}\right| \times 100\% \qquad \text{Eq. 2.13}$$

As shown in Figure 2.6, the steady-state flow balance in Q2K is implemented for each model element according to Eq. 2.14:

$$Q_i = Q_{i-1} + Q_{in,i} - Q_{out,i} \qquad \text{Eq. 2.14}$$

where Q_i = the outflow from element i into the downstream element $i + 1$ [m^3/d]; Q_{i-1} = inflow from the upstream element $i - 1$ [m^3/d]; $Q_{in,i}$ = the total inflow into the element from point and nonpoint sources [m^3/d]; and $Q_{out,i}$ = the total outflow from the element due to point and nonpoint withdrawal [m^3/d].

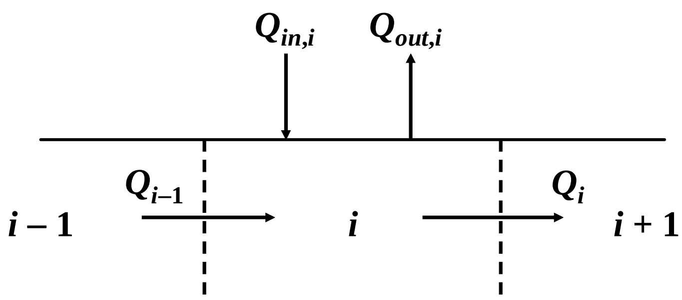


Figure 2.6: Flow balance for one element

The total inflow from the sources is computed with Eq. 2.15:

$$Q_{in,i} = \sum_{j=1}^{psi} Q_{ps,i,j} + \sum_{j=1}^{npsi} Q_{nps,i,j} \qquad \text{Eq. 2.15}$$

where $Q_{ps,i,j}$ = the jth point source inflow to element i [m^3/d]; psi = the total number of point sources to element I; $Q_{nps,i,j}$ = the jth nonpoint source inflow to element i [m^3/d]; and $npsi$ represents the total number of nonpoint source inflows to element i.

The total outflow from withdrawals is computed as follows:

$$Q_{out,i} = \sum_{j=1}^{pai} Q_{pa,i,j} + \sum_{j=1}^{npai} Q_{npa,i,j} \qquad \text{Eq. 2.16}$$

where $Q_{pa,i,j}$ = the jth point withdrawal outflow from element i [m^3/d]; *pai* = the total number of point withdrawals from element *I*; $Q_{npa,i,j}$ = the jth nonpoint withdrawal outflow from element i [m^3/d]; and *npai* = the total number of nonpoint withdrawal flows from element *i*.

The nonpoint sources and withdrawals are modeled in Q2K as line sources. These are demarcated by their starting and ending kilometer points, as illustrated in Figure 2.7; then flow is distributed to or from each element in a length-weighted fashion.

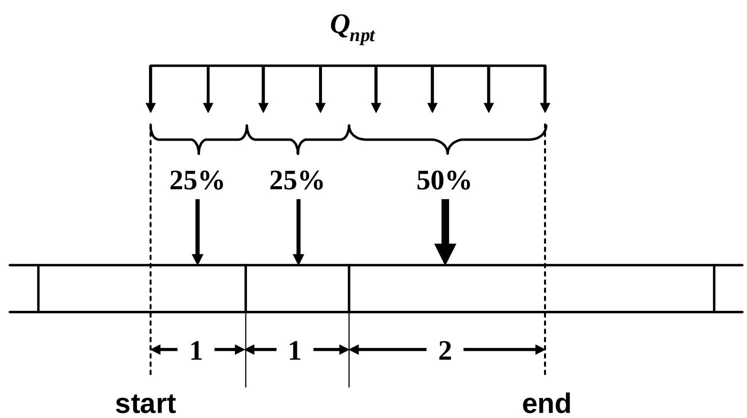


Figure 2.7: The distribution of non-point source flow to an element

2.9.4. Water Quality Calculations

The Qual2K model simulates several water quality parameters. In this research, DO and BOD represent the river water quality along the Klang River's main stem. Qual2K calculates the DO according to the following formula:

$$\begin{aligned} S_o = {} & r_{oa}\,\text{PhytoPhoto} + r_{oa}\,\text{BotAlgPhoto} - r_{oc}\,\text{FastCOxid} - r_{on}\,\text{NH4Nitr} \\ & - r_{oa}\,\text{PhytoResp} - r_{oa}\,\text{BotAlgResp} + \text{OxReaer} \end{aligned} \qquad \text{Eq. 2.17}$$

where r_{oa}PhytoPhoto = phytoplankton oxygen produced (g O_2d^{-1}), r_{oa}BotAlhPhoto = bottom phytoplankton oxygen produced (g O_2d^{-1}), r_{oc}FastOxid = O_2 required for carbon decay (gO_2

gC^{-1}), r_{on}NH4Nitr = O_2 required for NH_4 nitrification (gO_2 gN^{-1}), r_{oa}PhytoResp = phytoplankton oxygen consumption (dO_2 d^{-1}), r_{oa}PhytoResp = phytoplankton oxygen consumption (gO_2 d^{-1}), r_{od}BotAlgResp = bottom phytoplankton oxygen consumption (gO_2 d^{-1}), and roa, rod, roc, and ron are parameters whose values were suggested by Chapra. OxReaer as calculated by:

$$OxReaer = k_a(T)\left(o_s(T, elev) - o\right) \qquad \text{Eq. 2.18}$$

where k_a (T) = the temperature-dependent oxygen reaeration coefficient (d^{-1}); o_s (T, elev) = the saturation concentration of oxygen (mg O_2^{-1}) at temperature, T, and elevation above sea level, elev.

The DO can increase due to plant photosynthesis and become lost via fast Carbonaceous Biochemical Oxygen Demand (CBOD) oxidation, plant respiration and nitrification. Furthermore, the DO gained or lost via reaeration is dependent on whether the water is under- or oversaturated.

Regarding carbonaceous BOD, Qual2K represents organic carbon in two forms, i.e. slow oxidizing form (slow CBOD) and a rapidly oxidizing form (fast CBOD). The slow oxidizing CBOD increases owing to detritus dissolution and is lost through hydrolysis and oxidation. In contrast, the fast oxidizing CBOD is gained via the dissolution of detritus and the hydrolysis of slowly reacting CBOD, and it is lost as a result of oxidation and denitrification. Therefore, the obtained BOD data is considered fast CBOD for the model input.

2.9.5. The Hydraulic Characteristics in Qual2K

After the outflow for each element is calculated, the depth and velocity are computed in one of three ways: weirs, rating curves, or Manning's equation. The selection decision will be made by the model according to the following conditions:

- ❖ If the height and width of the weir are entered, the weir option is implemented.
- ❖ If the height and width of the weir are zero and rating curve coefficients are entered (*a* and α), the rating curve option is applied.
- ❖ If neither of the above two conditions is met, Qual2K computes Manning's equation.

2.9.6. Qual2K Model Simulation

Qual2K is capable of modeling a wide range of chemical and biological pollutants in a river, such as nitrogen and phosphorus species, carbonaceous biochemical oxygen demand (CBOD), pathogens, algae, phytoplankton suspended solids and detritus. The model simulates physical-chemical processes including chemical equilibrium, water quality kinetics, dispersion, advection, settling and interactions with the atmosphere and riverbed (sediment oxygen demand). The predicted water quality parameters throughout the modeled river include salinity and temperature, pH, dissolved oxygen concentration and the various pollutant quantities.

2.9.7. Data Input in Qual2K

Water quality models generally require physiographic data, such as channel network, slopes, soil and other geometric properties of the catchment (Vittala, Govindaiah, & Gowda, 2006). The Qual2K model necessitates several input data distributed into many

Excel worksheets, namely hydraulic data, rates and constants as well as the quality data of the pollutant sources. Hydraulic data consists of elevations, channel lengths, channel slopes, widths and roughness coefficient. Flow rates are calculated from these parameters using Manning's equation. The Qual2K model requires the flow rates of the river entering and for each pollution source. The rates and constants data needed includes the processes to be simulated such as re-aeration rate, CBOD decay coefficients, turbulent eddy diffusivity, algal growth rate and settling velocity. Several parameters are indicators of pollutant source quality, such as CBOD, dissolved oxygen, pH, alkalinity, and nitrogen and phosphorus species.

2.9.8. Qual2K Output

Qual2K produces two output types, i.e. spatial output, which is defined by pink tabs for each parameter, and temporal output, which is defined by light blue tabs for each parameter. The generated graphs for spatial output show the change in each parameter through the entire river section defined in one specified period. On the other hand, the generated graphs for the temporal output indicate the concentration change in a specified river reach over a 24-hour period. Figures 2.8 and 2.9 illustrate an examples of the model output.

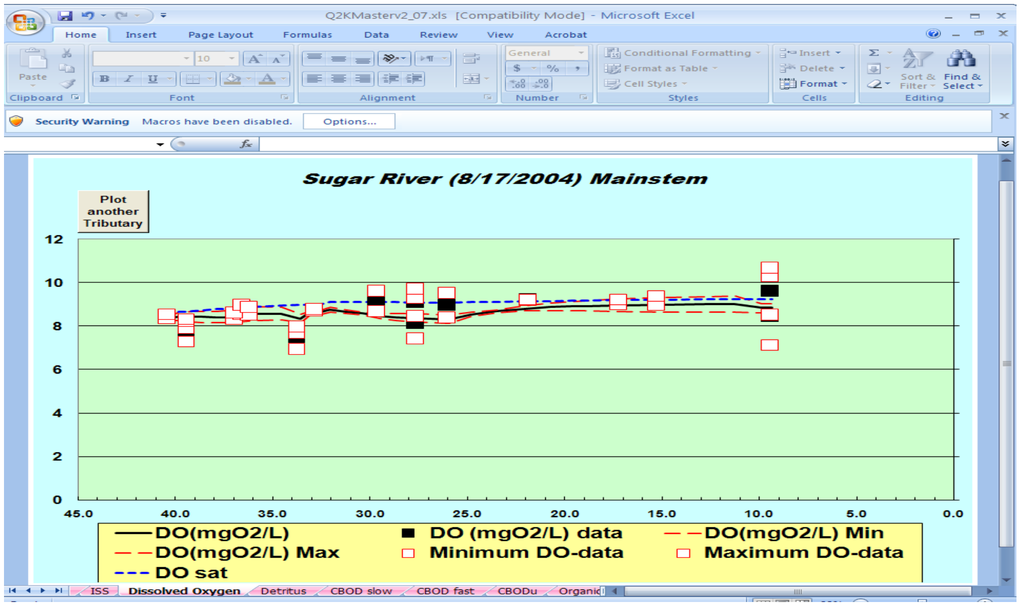


Figure 2.8: The spatial output of Qual2K (DO as example)

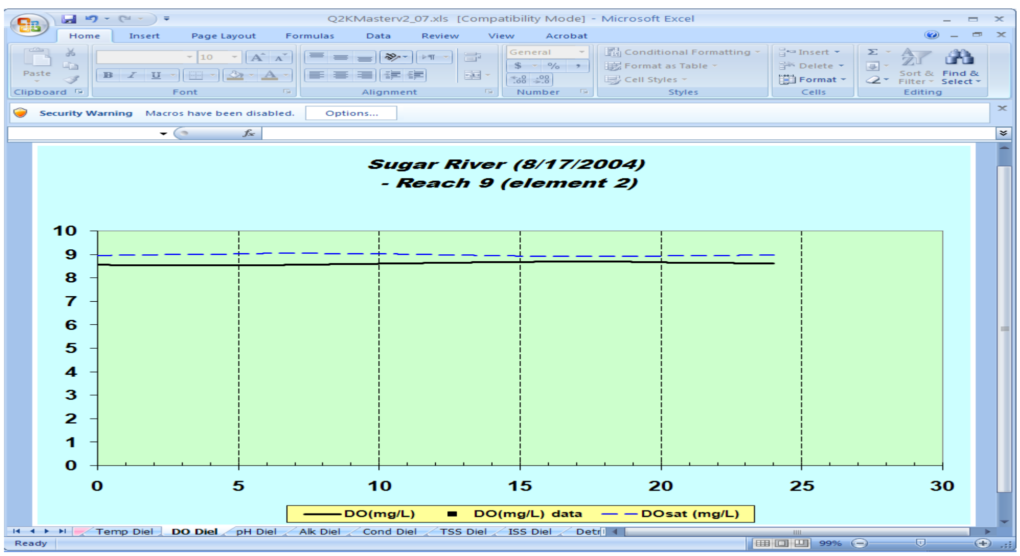


Figure 2.9: The temporal output of Qual2K model (DO as example)

2.10. R^2 Coefficient

The coefficient R^2 is the measure that shows how well the trends in the measured data are reproduced by the simulated results. It provides the ratio of the variance of one variable that is predictable from other variable (Roberts & Roberts, 1998). The value of R^2

ranges from 0 to 1 ($0 \leq R^2 \leq 1$). R^2 for n number of measured and simulated data can be calculated using the following formula:

$$R^2 = \frac{\left(n\sum_i^n M_i * S_i - \sum_i^n M_i * \sum_i^n S_i\right)^2}{\left[n\sum_i^n \left(M_i\right)^2 - \left(\sum_i^n M_i\right)^2\right] * \left[n\sum_i^n \left(S_i\right)^2 - \left(\sum_i^n S_i\right)^2\right]} \qquad \text{Eq. 2.19}$$

where M = the measured data, S = the simulated data and n = the number of the data points. According to Henriksen et al. (2003), R^2 value of ≥ 0.85 considered an excellent, between 0.65 and 0.85 considered very good, between 0.5 and 0.65 considered good, between 0.2 and 0.5 considered poor, while the values less than 0.2 considered very poor.

2.11. Geographic information system (GIS)

Given that Qual2K is a one-dimensional model, a tool to represent and manage the spatial data is considered necessary.

In many past studies, the geographic information system (GIS) has proven to be a tool capable of organizing, analyzing and representing the spatial characteristics of soil, land use and all natural phenomena (Herrmann, Slamova, Glaser, & Köhl, 2014; Huang et al., 2003; Liu & Fuller, 2001).

GIS is defined as "an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information" (Chang, 2006). In other words, it is a common purpose technique that handles geographic data in a digital format (Slamova, Glaser, Schill, Wiesmeier, & Köhl, 2012).

The potential of GIS lies in its ability to link spatial and non-spatial data. Spatial data is represented as a map of features that can be points, lines or polygons. Meanwhile, GIS represents non spatial data as spatial and descriptive information in topological and attribute tables (Nobel & Allen, 2000).

Many previous studies used GIS techniques as a main tool to achieve their objectives. For instance, Ko and Cheng (2004) applied the GIS with some statistical techniques in attempt to relate the meteorological data to the hydrological data in Oak Ridges Moraine Area in Ontario. They mainly used to develop the spatial data such as the watershed maps as well as to map the gauging and stream gauging stations used in that study. Another study by Huang, Cai, and Peng (2006) involved the GIS with the Multiple Logistic Regression to construct a model to predict the farmland spatial pattern based on available spatial data for the Maotiao River Basin, China. Likewise, Chubey and Hathout (2004) utilized the GIS as a main tool to develop a geomatics-based approach to predict flood risk for the Red River basin in Canada.

2.11.1. GIS components

As per Figure 2.10, GIS consists of five components:

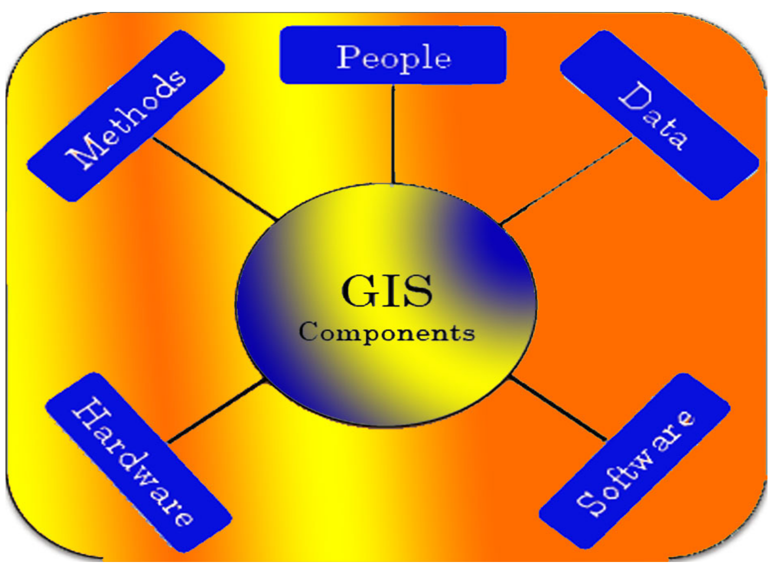


Figure 2.10: GIS components

- **Hardware**

This encompasses all types of hardware that contributes to the data input and output, for instance personal computers, scanners, printers, etc.

- **Data**

Accurate data employed in the GIS environment is more important for the GIS quality, as quality is what defines the questions and problems to be asked (Murayama & Estoque, 2010).

- **People**

The most essential GIS component is people. People, or users, play a significant role in defining the methods that will be used for data managing. Furthermore, people are capable of overcoming the shortcomings of the other four components (Murayama & Estoque, 2010).

- **Methods**

Methods entail all techniques and procedures utilized for data input, analysis and defining the query data.

- **Software**

This includes all the software which assists with map production and result output The full-service GIS American company ESRI is one of the most renowned companies that produces and develops GIS software. It has been supporting organizations since 1969. The methodologies and tools of the GIS software provided by ESRI permit organizations to make better decisions by analyzing and managing their geographic information (ESRI, 2010). Very experienced and knowledgeable ESRI staff along with business extensive network partners and international distributors employs these tools and methodologies. The company also assists with GIS technology implementation on desktops, servers, mobile devices and online services.

In pursuit of GIS software, ArcGIS Desktop v.9.3 has been chosen for this study to organize and manage the digital data of the selected study area. The data includes the digital elevation model (DEM), a map of the Klang study area, and so on.

ArcGIS Desktop is ESRI GIS software that facilitates the detection of relationships, trends and patterns in the data, which do not easily appear in statistical packages, spreadsheets or databases. ArcGIS Desktop has the ability to manage and integrate data, as well as perform advanced analysis and display the results in high-quality maps (Esri, 2007).

With ArcGIS Desktop software, all types of data can be effortlessly integrated for visualization. The complete set of geographic tools in this software automates numerous aspects of cartography. In addition, the completed maps can be exported, printed, saved and embedded in other documents or applications.

The fundamental ArcGIS Desktop frameworks are ArcMap, ArcCatalog and ArcToolbox. ArcMaps used to make maps, edit data and display analysis results. ArcCatalog is utilized for previewing and managing geographic data as well as build the GIS database (ESRI, 2006).

2.11.2. GIS data types

The strength of GIS lies in its aptitude to make connections between spatial and non spatial data. Spatial data in GIS is in the form of map features, which can be grid cells, points, lines or polygons; meanwhile, non spatial data is portrayed in GIS as spatial and descriptive information in topological and attribute tables (CIL, 2009).

- **Spatial data**

The spatial data consists of two types, namely raster and vector data

- **Raster data**

In this type of data, the features are represented as regularly spaced cells that are organized in a square grid of rows and columns (ArcGIS10, 2011). Each cell has a specific value signifying a property of interest. Figure 2.11 depicts and explains the features in raster data. For instance, the vegetation in the figure is denoted by cells with a value of 1, a value which only applies to trees, meaning that if any other type of vegetation is present, such as grass, it will receive a different number value. Another example is of the buildings layer where the cells are given a value with code number 2 – a value that represents only houses, meaning that if there are any other types of buildings, e.g. factories, they will get a different number value.

The method of referencing raster data is quite simple, with the raster layer georeferenced at one corner, either the upper left or lower right (Lawler, 2010). As seen in Figure 2.12, the upper-left corner was chosen for georeferencing the raster layer, while the X and Y-axes denote the cell locations. Moreover, all the cells are given a different numerical value according to the phenomenon type represented in the layer.

In hydrologic studies, the Digital Elevation Model (DEM) is considered a highly important category of raster data. Generally, “the Digital Elevation Models are raster data that comprise a matrix of grid cells or pixels, and each cell or pixel represents the height or the elevation” (Antipolis, 2006). DEMs are typically used to delineate various terrain parameters like watershed boundaries, drainage networks, contours, etc., in order to obtain the elevations and slopes.

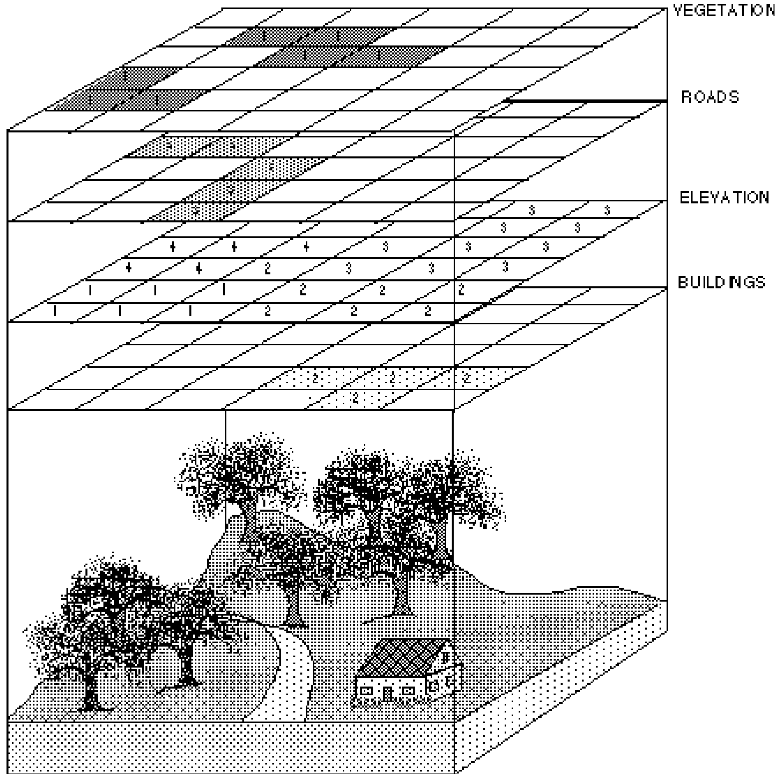
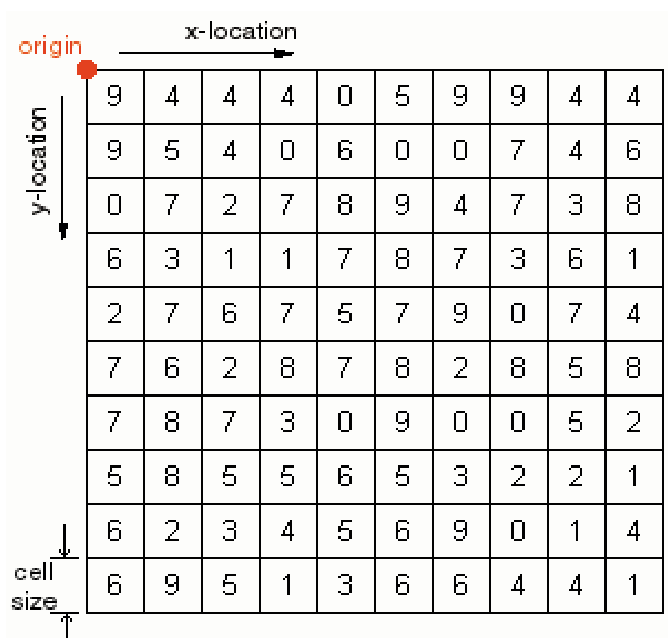


Figure 2.11: The representation of different features in raster format



9	4	4	4	0	5	9	9	4	4
9	5	4	0	6	0	0	7	4	6
0	7	2	7	8	9	4	7	3	8
6	3	1	1	7	8	7	3	6	1
2	7	6	7	5	7	9	0	7	4
7	6	2	8	7	8	2	8	5	8
7	8	7	3	0	9	0	0	5	2
5	8	5	5	6	5	3	2	2	1
6	2	3	4	5	6	9	0	1	4
6	9	5	1	3	6	6	4	4	1

Figure 2.12: The raster layer with cell locations and feature code values

❖ **Vector data**

The geographic features in this sort of data correspond to one of three types, i.e. points, lines or polygons.

➢ **Points**

The point data encompasses the separated features or locations, for instance city locations, wells, GPS locations and any features that need to appear as points.

➢ **Lines**

All geographic linear features, such as rivers and roads, are manifested in GIS as line data shapes.

➢ **Polygons**

All enclosed features, among which are land use and countries, are presented as polygon data. These types of information are formed by bounding arcs.

Figure 2.13 illustrates one example of both types of spatial data for the same features.

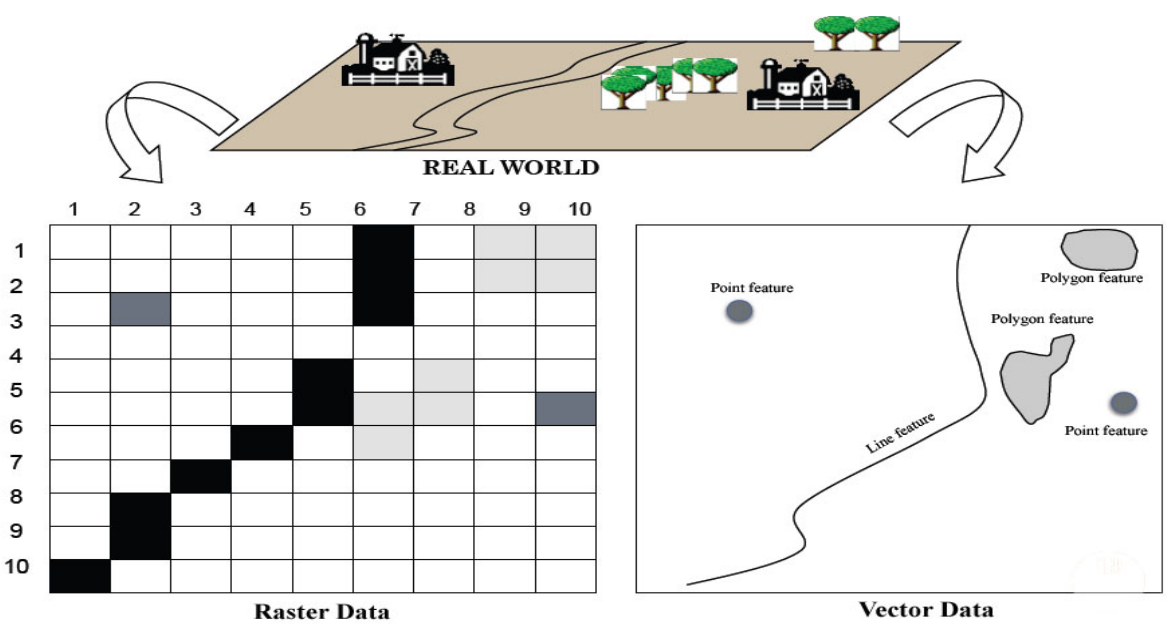


Figure 2.13: Feature representation in both types of spatial data

- **Non-spatial data**

Non-spatial data essentially entails descriptive attributes or tables. These attributes comprehensively describe all information regarding spatial data. For instance, in the linear vector layer signifies a road network in the city, the attribute data of this layer may contain several columns and rows. Each column describes one property, such as road length, road type, city name, etc. As another example, the attribute data for the raster layer of a specific area could contain columns describing the layer such as cell size, number of columns and rows, cell values, and so forth.

2.11.3. The importance of GIS in hydrology

GIS is able to develop information in various geographically referenced thematic layers and integrate them with adequate accuracy within a short period of time (Ghayoumian, Saravi, Feiznia, Nouri, & Malekian, 2007).

With respect to hydrologic models, the GIS can provide them with the essential spatial database to potentially enhance the model's performance and boost result accuracy (Abel, Kilby, & Davis, 1994; Maidment, 1993; Sui & Maggio, 1999).

Coupling GIS with the models has several benefits:

- Develops a user interface for the model input and output
- Integrates spatial data from various sources
- Enhanced handling of temporal variations in spatially oriented data.
- Various data comparisons on different spatial scales.

Many studies have ascertained the potential GIS has in developing the application, calibration, and validation of a range of environmental models (Akbar, Lin, & DeGroote, 2011; Jha, Chowdhury, Chowdary, & Peiffer, 2007).

In this research, GIS is primarily used to satisfy the water quality model requirements, then to represent the model's output in a real georeferenced map to analyze the output against the phenomena covering the study area.

2.12. Summary

This chapter presented the a literature on the method that used in this study. Comparing with the previous studies and other river models, Qual2K model has been chosen simulate and assess the Klang River water. The model selection was done based on the objectives of this research and data availability, as well as the project cost. Furthermore, it runs on Excel platform as well as the easiness of the data input comparing with the other models. Previous studies proved that GIS tools and techniques play an effective role in hydrology and water resources management due to the ability of the GIS to link the spatial data to the non-spatial data, which make it easy to analyze and decision making. This chapter, also, discussed the GIS tool that chosen to modify and manage the data used in this study, i.e. ArcGIS V.9.3. The tool has been chosen based on its ability to manage and integrate data, as well as perform advanced analysis and display the results in high-quality maps. Furthermore, the complete set of geographic tools in this software automates numerous aspects of cartography.

CHAPTER THREE

3. STUDY AREA AND METHODOLOGY

3.1. Introduction

This chapter discusses two main parts. The first part gives detailed information on the study area, i.e. Klang River Basin, including the geometric information and environmental dilemma as well as the monitoring program conducted by the Department of Environment Malaysia (DOE). On the other hand, the second part explains the methods and tools applied to achieve the objectives of this research including the spatial data processing and the river model simulation. This part also discusses the primary and secondary data collection used for this study.

3.2. Study Area

In Asia, Malaysia is considered one of the countries with the fastest urbanization, and it is facing massive environmental challenges. Increasing pressure on urban areas has been generated by rapid manufacturing, especially in the Klang River Basin, which is the most densely populated area of the country (El-Shafie et al., 2011). The Klang River supports a lot of industrial activities in Malaysia in order to serve as the site for the country's capital (Ismail & Naji, 2011).

The basin's catchment area is 1,288km^2, and it is the most urbanized region in Malaysia. It encompasses the Federal Territory of Kuala Lumpur and includes parts of the state of Selangor. Its population is 4.4 million, or 16% of the national population that is growing at an annual rate of 5% (Naji et al., 2010). The river basin is shown in Figure 3.1.

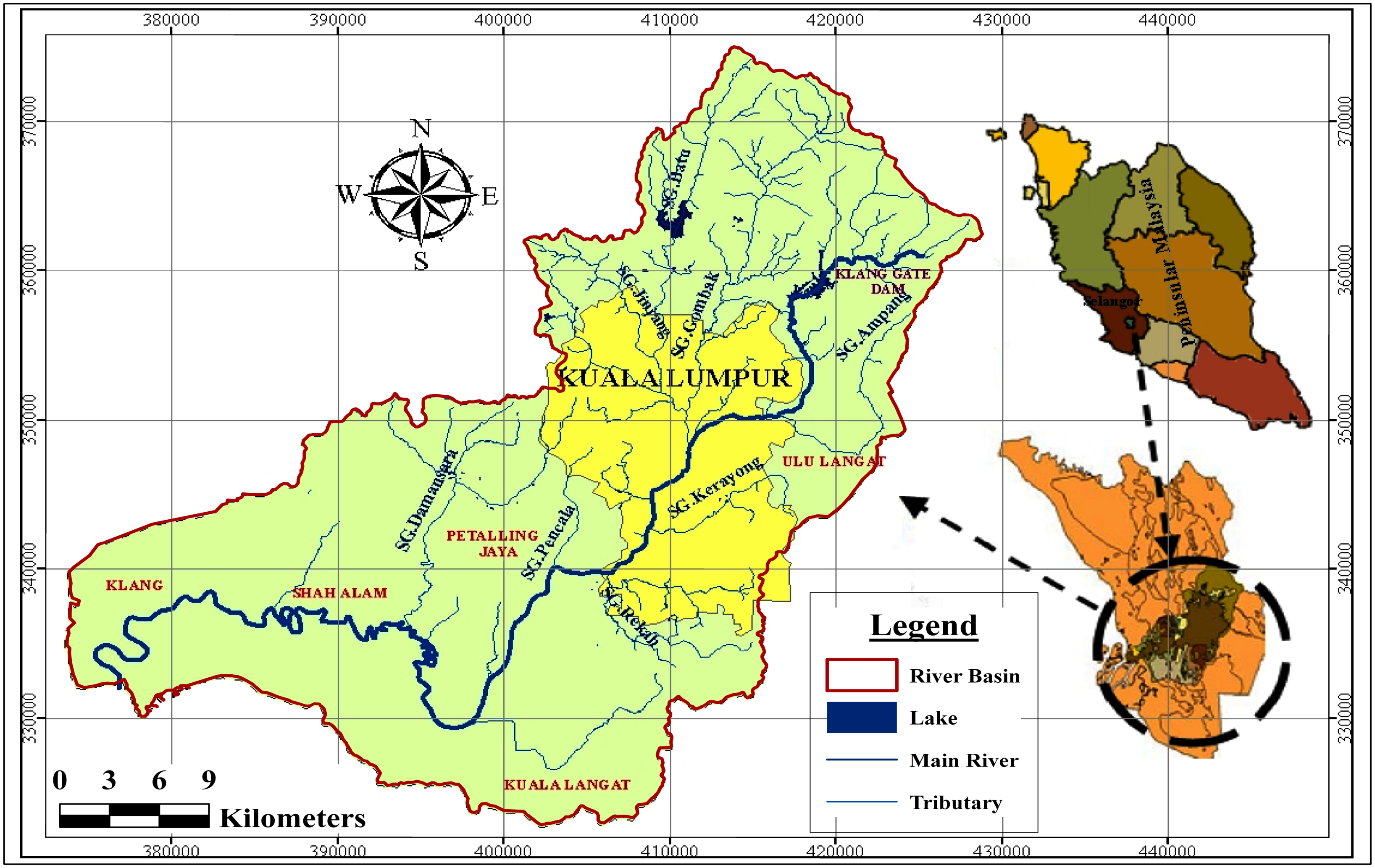


Figure 3.1: The Klang River catchment

3.2.1. Environmental Degradation in the River Basin

About 50% of the basin area has been civilized, and much of this continuing urban development has taken place on land that is prone to flooding. Generally, the status of the Klang River is between critical and bad. The basin faces serious environmental degradation from urbanization, industrialization, and population growth (ADB, 2007; Angie, 2010). These problems include soil erosion and sedimentation, solid waste and water quality management, which are the focus of this study.

3.2.2. Soil Erosion and Sedimentation

Soil erosion and sedimentation are viewed as the main management issues in the Klang River Basin. It is estimated that yearly, 18 metric tons per hectare (t/ha) in the river catchment, or approximately 2.3 million tones of annual soil is lost from the entire basin (ADB, 2007). The areas under urbanization are considered the major sources of erosion that mainly occurs on the construction sites where large areas of earth are exposed. Construction has caused soil erosion and massive sediment discharge into waterways. As a result, the enlarging impervious surface area in the watershed causes flooding. Water quality has deteriorated because of the high sediment loads from construction and deforestation, large quantities of litter and rubbish, untreated sewage and industrial and commercial effluents. Despite much of the soil erosion in the Klang River Basin being caused by inappropriate land use, inadequate erosion control measures are seen as a major contributing factor.

3.2.3. Solid Waste

Another crucial environmental dilemma in the Klang River Basin regards solid waste management. The buildup of solid waste in rivers, especially in urban areas, impedes flow and subsequently causes critical environmental issues besides compounding flooding. As enforcement is hampered by the lack of legal power and capacity of local authorities, the illegal dumping of waste and unsafe solid waste into landfills remains a problem. Furthermore, since some areas are served poorly, settlers generally dispose of their solid waste into the rivers, which leads to deteriorating water quality as well as reducing river conveyance capacities.

3.2.4. Water quality Management

Monitoring the water quality is essential to integrated river basin management. The river ecology suffers from vegetation removal in consequence to the riparian corridor and removal of snags from the watercourses; thus, habitats for a variety of riparian and aquatic fauna are diminishing. In turn, the contamination filtration capacity is on the decrease while nutrients and other contaminants that flow into the rivers have increased. The combined effect of poor water quality, high sediment load, and vegetation removal from the river corridor has caused a decline in the number and diversity of native flora and fauna.

The Department of Environment Malaysia (DOE) plays the most important role in managing water quality by licensing, emission control and monitoring. The DOE started its monitoring program in 1978 by establishing a baseline to detect changes in river water quality as well as identify the sources of pollution. In 2011, 14 out of 119 major rivers that were monitored in Malaysia were identified as highly polluted, and the Klang River was one of them. The DOE collects water samples at regular intervals from designated stations for in-situ and laboratory analysis to determine the physical-chemical and biological characteristics of the rivers. These designated water quality monitoring stations have been set up within 812 river basins. Thirty of these water quality monitoring stations are situated within the Klang River Basin (DOE, 2011) as shown in Table 3.1.

Table 3.1: The water quality monitoring stations for the Klang River Basin

Station Number	State	River Name	Station Number	State	River Name
ST.01	Selangor	Klang	ST.16	Federal Territory	Kerayong
ST.02	Selangor	Klang	ST.17	Federal Territory	Gombak
ST.03	Selangor	Klang	ST.18	Federal Territory	Gombak
ST.04	Selangor	Klang	ST.19	Federal Territory	Batu
ST.05	Selangor	Klang	ST.20	Selangor	Batu
ST.06	Federal Territory	Klang	ST.21	Federal Territory	Keroh
ST.07	Federal Territory	Klang	ST.22	Federal Territory	Jinjang
ST.08	Federal Territory	Klang	ST.23	Selangor	Ampang
ST.09	Federal Territory	Klang	ST.24	Selangor	Gombak
ST.10	Selangor	Semelah	ST.25	Federal Territory	Klang
ST.11	Selangor	Damansara	ST.26	Selangor	Kerayong
ST.12	Selangor	Damansara	ST.27	Federal Territory	Bunos
ST.13	Selangor	Damansara	ST.28	Selangor	Keroh
ST.14	Selangor	Pencala	ST.29	Federal Territory	Jinjang
ST.15	Federal Territory	Kuyoh	ST.30	Federal Territory	Keroh

Source: (DOE, 2011)

3.3. Methodology and Data Collection

The methodology employed in this study includes collecting data from both field and government agencies. Moreover, the methodology entails processing and analyzing collected data using GIS techniques and tools to extract the geometric information to be used to satisfy the Qual2K model requirements. Furthermore, the methodology includes the running of the Qual2K model in order to the use of GIS techniques to transfer the model output to the GIS platform.

Therefore, the methodology of this study is divided into four stages. The first phase consists of primary and secondary data collection. The second stage demonstrates the GIS processing for data analysis to satisfy the QUAL2K model requirements. In the third stage, the QUAL2K model is developed, and the last stage is the process of transforming the Qual2K output into GIS platform (Figure 3.2).

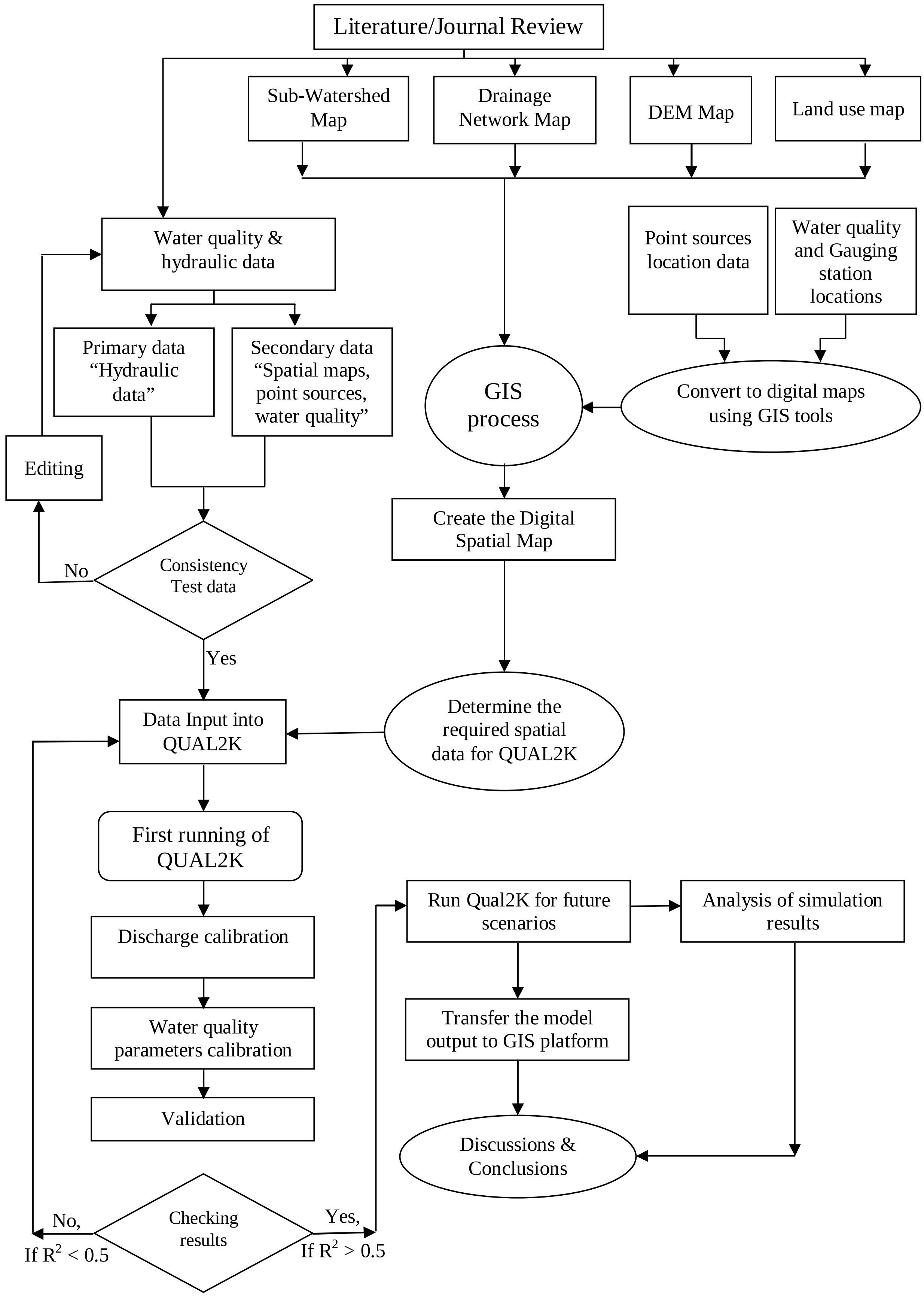


Figure 3.2: The flow chart of the research methodology

3.4. Data Collection

According to the method of collection, there are two types of data: primary and secondary data. Primary data is the data collected first-hand from the original source, while secondary data is defined as the data collected indirectly from other sources. The methods applied for collecting primary data include experiments, surveys and direct measurements, while secondary data is obtained from several sources such as literature, compilations from computerized databases, computerized or mathematical models, and information systems. Secondary data is normally more economical, as well as easier and less time consuming to collect than primary data.

In the current study, the primary data contains hydraulic data measurements from the Klang main river and its tributaries to determine the river flow as input data for the QUAL2K model. The primary data additionally contains water sample collection and in-situ measurements for QUAL2K model result evaluation. On the other hand, the secondary data for this research was gathered from various sources and agencies like the Department of Environment (DOE), Department of Drainage and Irrigation Malaysia (DID), etc. The secondary data gathered consists of spatial information, such as Digital Elevation Model (DEM), a Klang River network map, Klang River sub-watershed map and land-use digital map. Furthermore, secondary data comprises the non-spatial data, for instance water quality monitoring data, sources of pollution and climatology data.

3.4.1. Primary Data

The hydraulic data plays an essential role in running the Qual2K model. This information includes flow rates at the headwater, the length of each reach, channels slope, cross-sections data, locations and heights of the up and downstream for each reach and roughness coefficient values "n".

- **Gauging Stations**

A gauging station is a place on a water body where observations are made and hydraulics data is obtained. Such stations are surface water monitoring infrastructures and they are located near streams. Several sorts of information can be gained at these stations, such as water discharge, height, and some water quality parameters. For the current study area, nineteen gauging stations have been set out along the mainstream of the Klang River and its tributaries.

A hydrographic survey was performed at the stations to gather physical river data like cross section, velocity and roughness coefficient "n" values. Figure 3.3 shows photos from field work at some stations. The cross-section data pertains to the top and bottom width as well as channel depth. The velocity was measured at each gauging station to determine the discharge. The discharge at each station was calculated with the following equation:

$$Q = V * A \qquad \text{Eq. 3.1}$$

where Q = the discharge, V = the velocity and A = the cross-section area as determined using the equation bellow:

$$A = D * W \qquad \text{Eq. 3.2}$$

where D = depth and W = width.

The roughness coefficient “n” represents the resistance to flood flows in open channels (Barnes, 1987). The roughness coefficient value of the channel at each gauging station was determined based on the channels’ surface materials. Chow (1959) concluded that the roughness coefficient value for each channel is in relation to its surface material (Appendix A).

3.4.2. Secondary Data

- **Digital Elevation Model (DEM)**

Among the most highly essential data for the QUAL2K model are the elevations upstream and downstream, as well as the channel slope for each reach. Generally, the raster-based digital elevation models (DEMs) are applied in hydrologic studies to represent the surface elevations supported by the geographic information system (GIS). Thus, a DEM is indispensable to satisfy the model requirements (Wu, Li, & Huang, 2005). In this research, the DEM for the Klang River Basin was generated by Akbari (2011) and obtained in an image format file with 10m cell size. Figures 3.4 illustrates the DEM for the Klang River Basin.

- **The River Network and Sub-basins Maps**

The network map for Klang River was obtained from the Department of Irrigation and Drainage Malaysia for the year 2008. The map obtained in a shape file format.

The sub-basin map for Klang River was obtained from the Department of Survey and Mapping Malaysia (in Malaysia it is known as Jabatan Ukur dan Pemetaan Malaysia “JUPEM”) for the year 2008.

Figure 3.3: photos from field work at some stations

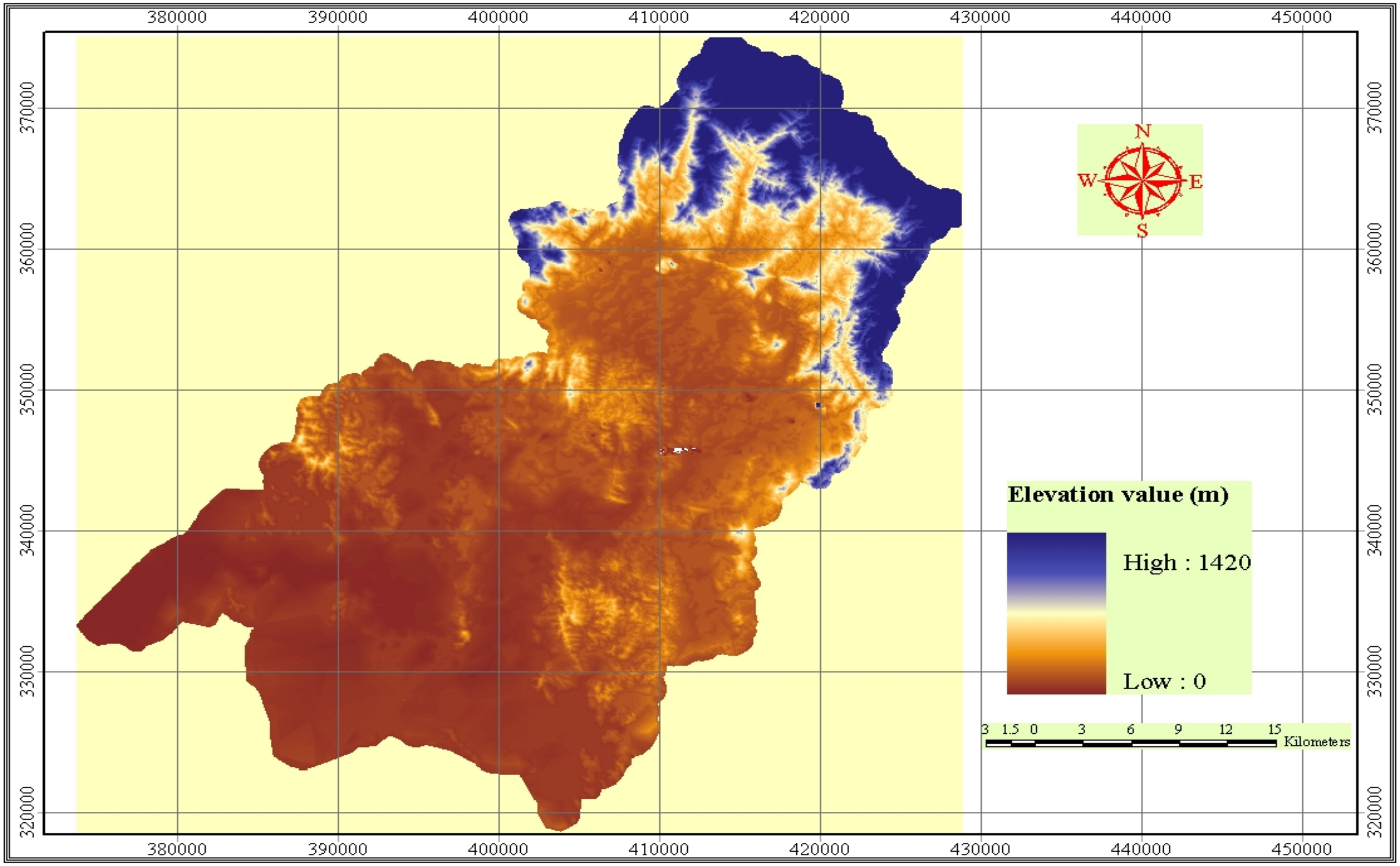


Figure 3.4: The DEM for the Klang River (Akbari, 2011)

- **Land Use Map**

More recently, water resource managers have began focusing on the pollution loading into lakes, rivers estuaries and reservoirs, which occurs as a result of increasing water treatment costs caused by such pollution as well as eutrophication that leads to significant amenity losses in terms of water supply, fisheries and recreation. There are two types of sources of pollution, i.e. point source and nonpoint source pollution (Howarth et al., 2000).

The Klang River's main stem and its tributaries receive wastewater and storm water along the reaches through many point sources like city drains, sluice gates and effluent outfall of the Sewage Treatment Plant and industries. Furthermore, the river is given wastewater from ambient land use activities along the basin. To satisfy the Qual2K model requirements, both point and nonpoint sources are necessary.

For the current study, the land use map of the Klang River basin was obtained from the Malaysian Department of Agriculture (DOA). The map obtained in shape file format for the year 2008. As shown in Figure 3.5, the Klang River basin is classified into several major classes: agriculture, forests, urban areas, water bodies and open land areas. It is clear from the figure that two types of land use, namely forests and urban land use with 28% and 41% respectively dominate the basin. Table 3.2 shows the land use ratio for the Klang River Basin.

Table 3.2: Land use percentage for the Klang River Basin

Land Use Type	Percentage (%)
Water body	3.668234
Forests & Shrubs	28.08968
Urban Land Use	41.89199
Agricultural & Animal Farming	20.07496
Open Land and Recreation	5.765197
Others	0.509938

Source: (DOA, 2008)

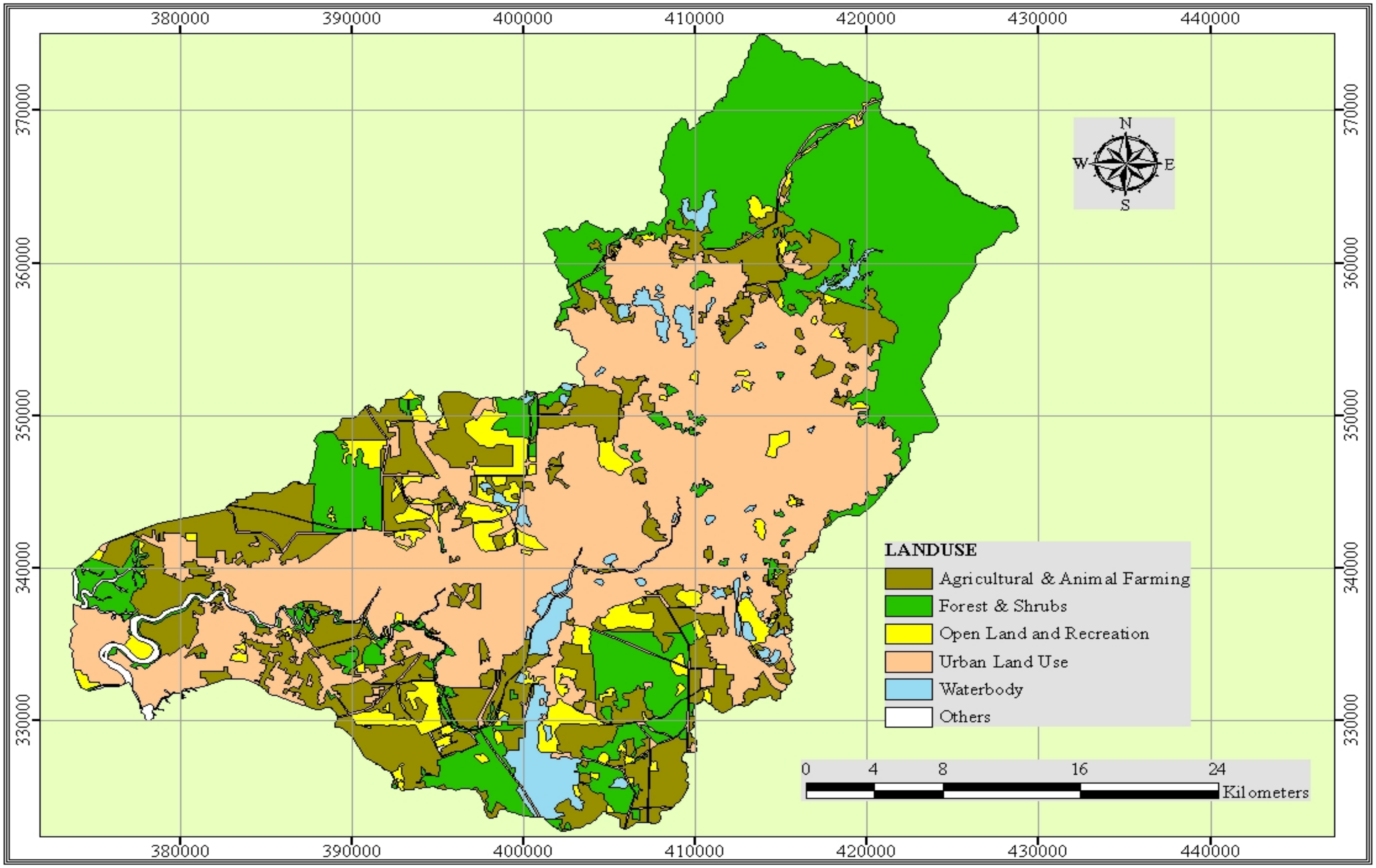


Figure 3.5: Land uses in the Klang River watershed (DOA, 2008)

- **Point Sources Data**

There are several point sources of wastewater discharge into the Klang River and its tributaries, among which are the wastewater from industries, food courts, workshops, wet markets, landfills, etc. The point sources data was obtained for the year 2008 from different sources, i.e. previous studies, field inventory, Department of Environment Malaysia (DOE). Sewage treatment plants are treatment facilities that receive wastewater from households, commercial sewage and industrial areas via sewerage pipe systems (Imhoff & Novotny, 1989). These facilities may be oxidation ponds, activated sludge, trickling filters, aerated lagoons and rotating biological contactors. Initially, any sewerage system should be designed for a specific amount of sewage based on the population equivalent (PE) at that time PE is defined as the number of people required to contribute an equivalent wastewater quantity to the flow quantity and strength of Biochemical Oxygen Demand.

The average daily flow design of sewerage systems depends on the daily wastewater produced by people. It was assumed previously that a person generates about $0.225m^3$ or 225 liters of wastewater per day (Abd-Rahman, Alias, Salleh, & Samion, 2007). Thus, the daily flow design of a sewerage plant can be calculated using the following equation:

$$Q = 0.225 * PE \text{ (m3/day)} \qquad \text{Eq. 3.3}$$

where Q = the design of daily flow and PE = the population equivalent.

The IWK Company determines the PE values according to Table 3.3:

Table 3.3: PE values for different establishments

Type of Establishment	**Population Equivalent (PE)**
Residential	5 per house
Commercial : * Includes offices, shopping complexes, * entertainment / recreational centers, * restaurants, cafeterias and theatres	3 per $100m^2$ gross area
Schools / Educational Institutions : 1- Day schools / Institutions 2- Fully residential 3- Partial residential	1- 0.2 per student 2- 1 per student 3- 0.2 per non-residential student & 1 per residential student
Hospitals	4 per bed
Hotels with dining and laundry facilities	4 per room
Factories, excluding process water	0.3 per staff
Market (Wet Type)	3 per stall
Market (Dry Type)	1 per stall
Petrol kiosks / Service stations	15 per toilet
Bus Terminals	4 per bus bay
Taxi Terminals	4 per taxi bay
Mosques / Churches / Temples	0.2 per person
Stadiums	0.2 per person
Swimming Pools or Sports Complexes	0.5 per person
Public Toilets	15 per toilet
Airports	0.2 per passenger/day 0.3 per employee
Laundromats	10 per machine
Prisons	1 per person
Golf Courses	20 per hole

Source: (IWK, 2011)

There are two standard types of the sewerage treatment plants that set by the Environmental Quality Act 1974, i.e. standard A and B (IWK, 2012). These standards have been established based on the quality of the effluents that discharged from the treatment plants to the water bodies. Several parameters were chosen to determine the standard type for a cleaner and safer environment that improves the living conditions of Malaysians. Table 3.4 shows the parameters values that determine whether the standard is A or B. However, the most important measured parameters are Biochemical Oxygen Demand (BOD) and Suspended Solids (SS).

Table 3.4: The measured parameters value for determining the sewerage standard type

Parameter	**Unit**	**Standards**	
		A	**B**
Temperature	C	40	40
pH Value	-	6.0-9.0	5.5-9.0
BOD5 at 20C	mg/l	20	50
COD	mg/l	50	100
Suspended Solids	mg/l	50	100
Mercury	mg/l	0.005	0.05
Cadmium	mg/l	0.01	0.02
Chromium, Hexavalent	mg/l	0.05	0.05
Arsenic	mg/l	0.05	0.1
Cyanide	mg/l	0.05	0.1
Lead	mg/l	0.1	0.5
Chromium, Trivalent	mg/l	0.2	1
Copper	mg/l	0.2	1
Manganese	mg/l	0.2	1
Nickel	mg/l	0.2	1
Tin	mg/l	0.2	1
Zinc	mg/l	1	1
Boron	mg/l	1	4
Iron (Fe)	mg/l	1	5
Phenol	mg/l	0.001	1
Free Chlorine	mg/l	1	2
Sulphide	mg/l	0.5	0.5
Oil and Grease	mg/l	not detectable	10

Source: (IWK, 2012)

In this study, STPs data was obtained for the year 2008 from Indah Water Konsortium Sdn Bhd (IWK), which is wholly-owned by the Minister of Finance Incorporated (IWK, 2012). The IWK Company has located over 1,490-sewage treatment plants along the Klang River Basin. The STPs data was obtained from IWK in Excel file format.

- **Water Quality Monitoring Data**

The water quality monitoring data was acquired from the Department of Environment (DOE) from 1997 to 2007.

The DOE program involves collecting water samples from each station for in-situ measurements and laboratory analysis. The parameters for in-situ measurements are pH, temperature, conductivity, dissolved oxygen, salinity and turbidity, while the other parameters were collected for laboratory analysis.

3.5. Spatial Data Processing and Digital Map Generation

Similar to other water quality models, the development of a Qual2K model requires the spatial data of the river. The data consists of the dimensions of each river reach (upstream and downstream elevations, reach length, and reach slope), upstream and downstream location of each reach, locations of the point and nonpoint sources as well as the locations of data used for model calibration.

In the step following the collection of primary and secondary data, the GIS techniques and tools were utilized to achieve the first objective of this study as well as prepare the required spatial data to fulfill the model requirements.

This stage includes three steps. The first step entails organizing the collected data; the second step represents the achievement of the first research objective, which regards generating a digital map of the Klang River Basin; while the third step involves determining the necessary spatial data from the digital map to satisfy the Qual2K model requirements. Figure 3.6 elucidates the flow of steps in the GIS processing of spatial data.

3.5.1. Spatial Data Processing

Constructing the Qual2K model is dependent on the river network with the main river and branch tributaries. According to this research funding and data availability, seven main tributaries and the main river were selected to represent the Klang River network. The tributaries chosen are the Ampang River, Gombak River, Kerayong River, Rekah River, Pencala River, Rasau River and the Damansara River. Furthermore, GIS tools were employed to modifying and mapping the obtained text data, i.e. the water quality monitoring stations data, gauging stations data, point sources data. Moreover, all maps were projected to the local projection Kertau_RSO_Meter_Malaya.

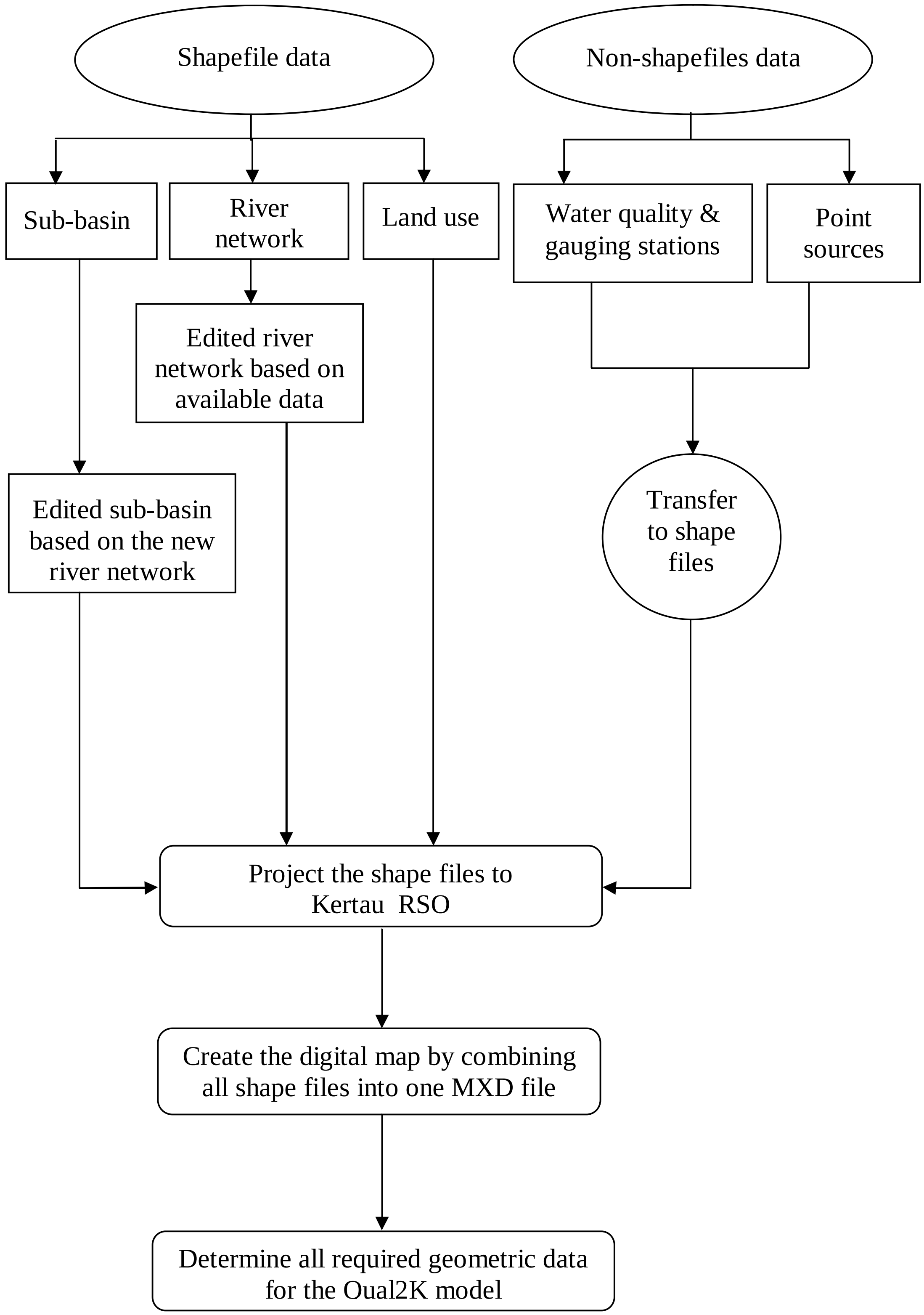


Figure 3.6: The flow of steps in the GIS processing of spatial data

3.5.2. The Digital Map of the Klang River Basin

Creating this map is intended to facilitate easy access to current and historical location information, effortless modification and editing of feature locations and datasets, and determining the required spatial data to develop the Qual2K model. A digital map for the Klang River Basin was generated by importing all shapefiles into the GIS environment using GIS methods.

3.5.3. Determining the Required Geometric Data for Qual2K

GIS tools were applied to attain the necessary spatial data from the generated digital map.

Qual2K model represents the point's locations according to their distances from the downstream of the specific reach. Based on that, the locations of the gauging and water monitoring stations were determined for the model calibration. Likewise, the locations of the point sources were identified from a point source layer, while the non point sources locations obtained from the land use layer. In addition, the upstream and downstream elevation and location at each reach were found from DEM and river network layers. Moreover, using GIS measuring tools, the length of each reach of the Klang River network was calculated from the river network layer. The reaches' slopes were determined to satisfy the model requirements using the following formula (Hill, 2011):

$$Slope = E/L \qquad \text{Eq.3.4}$$

where E = the difference in elevation between the reach's upstream and downstream, and L = the distance along the reach.

3.6. Development of Qual2K Model

Figure 3.7 illustrates the steps sequence of developing and transforming the water quality model, i.e. Qual2K to GIS environment.

3.6.1. Klang River Segmentation

It was discussed earlier that applying the Qual2K model requires that the river system be divided into several reaches and each reach segmented into equally spaced elements. Based on the available data that obtained, seven main tributaries were chosen together with the Klang River’s main stem to comprise the river system and satisfy the Qual2K model requirements. The seven tributaries are the Ampang River, Gombak River, Kerayong River, Rekah River, Pencala River, Rasau River and Damansara River. Subsequently, the system was divided into several reaches that were numbered beginning with reach 1 at the main stem’s headwater up to the junction with the first tributary, after which the numbering continued toward the tributary’s headwater. Both headwaters and tributaries were numbered consecutively following a sequencing scheme similar to that of the reaches as shown schematically in Figure 3.8. The figure also shows the headwaters of the network. These headwaters were identified at the main stem and tributaries to fulfill the model requirements. Each individual reach of the Klang River network was segmented into equally spaced elements of approximately 1km length to satisfy the model requirements, as per Figure 3.9.

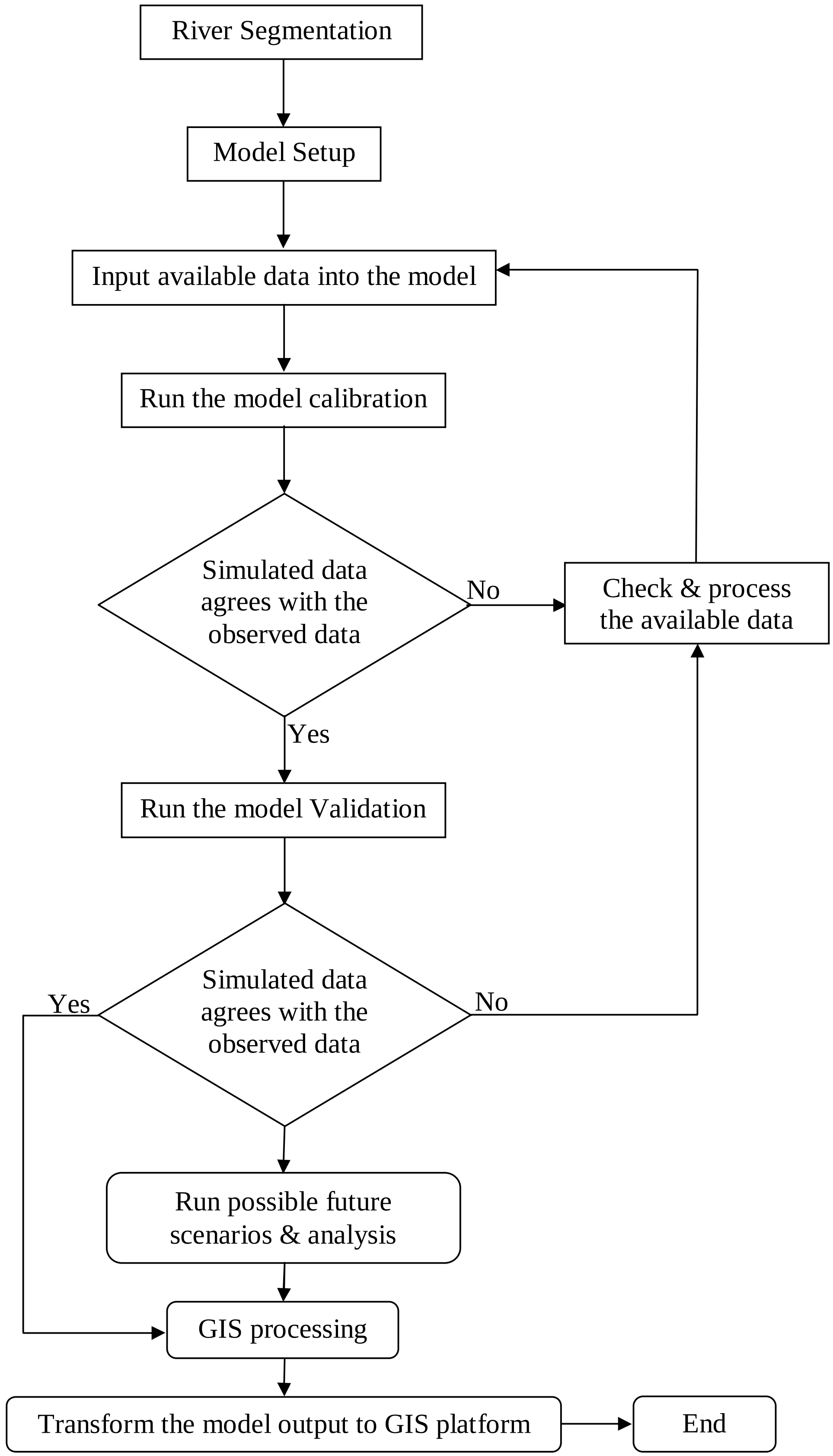


Figure 3.7: The flow of steps in developing and transforming the Qual2K model

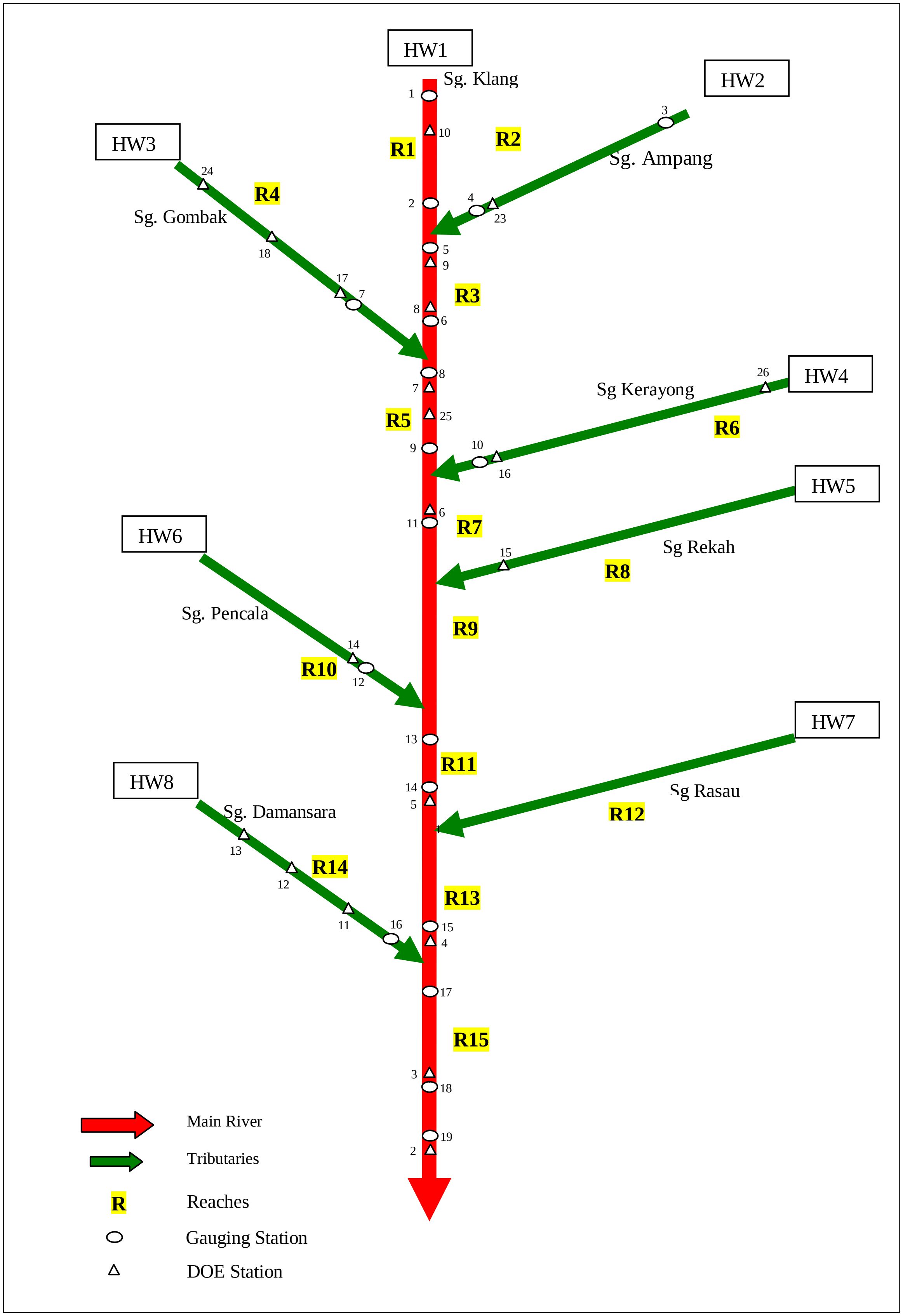


Figure 3.8: Schematic of the Klang River network

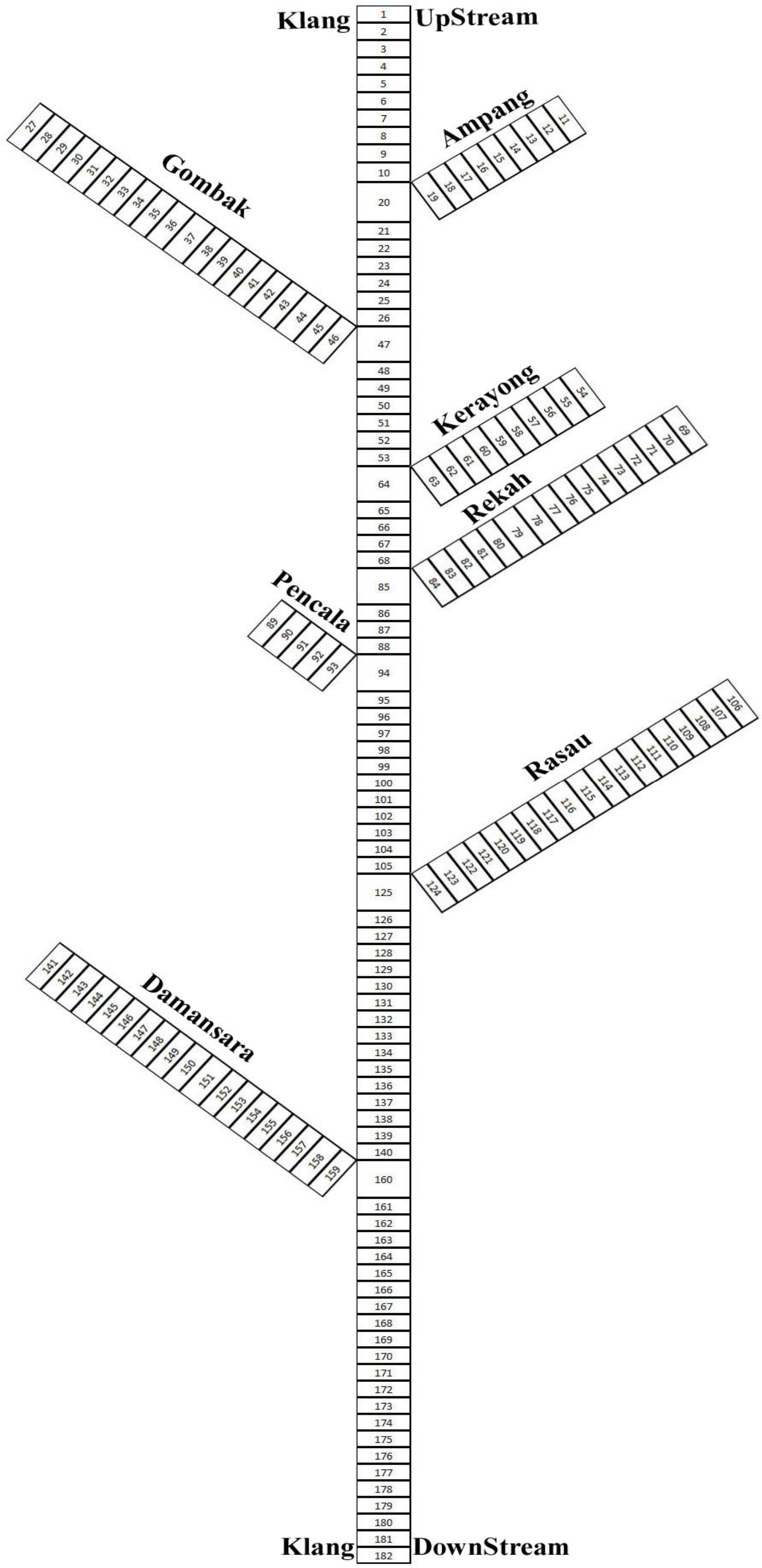


Figure 3.9: The segmentation of the Klang River network

3.6.2. Model Setup and Data Input

As mentioned before, Qual2K requires several data spread on several worksheets. There are two worksheet types regarding data input in Qual2K, i.e. simulation data worksheets and calibration data worksheets. Simulation data worksheets are Headwater, Reach, Diffuse sources, Point sources, while calibration data worksheets are Hydraulic data and Water quality data. Table 3.5 shows the data input in the worksheets and their sources.

Table 3.5: Qual2K data input in the worksheets and their sources

No	Worksheet name	Data	source
1	Headwater	Q, Channel Slope, roughness ‘n’, Bottom width	Gauging station data
		Elevation	DEM
		Water quality parameters	Water quality data
2	Reach	Location (Up and downstream of each reach), Downstream Long/Lat,	Digital map
		Elevation (up and downstream)	DEM
		Channel Slope, roughness ‘n’, Bottom width	Gauging station data
3	Diffuse sources	Location	Digital map
		Inflow	Estimated
		Water quality parameters	Previous study
4	Point sources	Location	Digital map
		Inflow	Secondary data
		Water quality parameters	Previous study
5	Hydraulic data	Gauging stations locations	Digital map
		Q	Gauging station data
6	Water quality data	Water quality stations locations	Digital map
		Water quality parameters	Water quality data

➢ Headwater Data

The necessary headwater data for input into the Qual2K model is water quality parameters and hydraulic data. The model allows several water quality parameters to be input in accordance with data availability as well as the study objectives.

The hydraulic data needed by Qual2K at the headwaters includes elevation, discharge, cross-section (bottom width), channel slope and the roughness coefficient "n." These data determined at the gauging stations from both the field measurements as well as the GIS techniques. On the other hand, the water quality parameters were obtained from the water quality monitoring data.

➢ Reaches Data

Similar data are required for each reach with an addition of the number of elements as well as the location of up and down stream for each segmented reach in kilometers. These data were obtained from the digital spatial map, DEM and the gauging stations data. Table 3.6 illustrate the lines and nodes used for running the model

Table 3.6: The used nodes and lines for Qual2K model

Reach Label	Reach No	Reach length (km)	Location		Num of Elements
			Up-stream (km)	Down-stream (km)	
SgKlang	1	10.00	81.254	71.254	10
SgAmpang	2	8.12	8.122	0.000	9
SgKlang	3	6.37	71.254	64.881	7
SgGombak	4	19.60	19.598	0.000	20
SgKlang	5	6.91	64.881	57.975	7
SgKerayong	6	10.08	10.080	0.000	10
SgKlang	7	4.39	57.975	53.586	5

Table 3.6, continued

Reach Label	Reach No	Reach length (km)	Location		Num of Elements
			Up-stream (km)	Down-stream (km)	
SgRekah	8	15.41			16
SgKlang	9	3.65	53.586	49.939	4
SgPencala	10	4.50	4.501	0.000	5
SgKlang	11	11.74	49.939	38.203	12
SgRasau	12	18.18	18.175	0.000	19
SgKlang	13	15.20	38.203	23	16
SgDamansara	14	18.47	18.472	0.000	19
SgKlang	15	23.00	23	0	23

➢ **Diffuse Sources Data**

The model represents the nonpoint source as two points based on their distance from the reach’s downstream. Therefore, the locations of the pollution sources are determined using GIS tools.

Regarding inflow, the GIS tools were utilized to determine the distribution ratio for each sub-basin (Appendix B). Thereafter, the inflow from each land use was estimated based on their ratios for each sub-basin.

➢ **Point Sources Data**

With respect to the point sources, the model defines the location as a single point based on its distance from the reach’s downstream. Thus, GIS tools were used to determine the locations of the point sources.

The inflow data for each point source was obtained from the collected point sources data.

- **Hydraulic Data**

This worksheet represents the data used for hydraulic calibration. The gauging stations locations were measured using GIS tools and inserted in this worksheet. Furthermore, the discharge for each station was inserted based on the gauging stations data.

- **Water quality data**

Data used for water quality calibration are represented in this worksheet. The water quality monitoring stations locations were measured using GIS tools and inserted in this worksheet. Regarding the water quality parameters, the data obtained from DOE were used.

3.6.3. Qual2K Calibration and Validation

Model calibration and validation are critical steps in achieving good model performance. Model calibration is defined as the process of tuning the parameter values to attain optimal agreement between the simulated and observed data. In other words, model calibration is the method of justifying the input data of the parameters until the model's output matches the observed data set (Mohamed, 2008). Value estimation of different parameters and constants in the model structure is involved. Model calibration should be supplied with the numerical parameter values as well as the initial condition of the state variables and boundary conditions. The process of parameter justification can be done either manually (trial and error method) or automatically, by searching for an optimal value of a given criterion (Balin, 2004; Iorgulescu, Beven, & Musy, 2007). However, the manual means is the most common and is recommended by the authors. Model validation, on the other hand, entails assessing the degree of reliability of the calibrated model using one or more independent data sets, but not the same data that is utilized for model calibration.

In this study, two model calibration stages have been done, i.e. hydraulic and water quality parameter calibration. Water discharge was chosen for hydraulic calibration, while the DO and BOD parameters were selected for water quality calibration. The calibration was done using an average data of 2001-2005, while an average data of 2006-2007 was used for model validation.

3.6.4. Standard Error

The standard error can be defined as the standard deviation of a sample that used to estimate the value. In other word, it is the measure of the accuracy with which a sample represents the real value (Everitt & Skrondal, 2010). It can be calculated by the following equation:

$$SE = {}^{SD}\!/\!_{\sqrt{n}} \qquad \text{Eq. 3.5}$$

Where, SE = standard error, SD = standard deviation, n = number of samples

In this research, water quality data was tested for SE before using for model.

3.7. Representing the Model Output in a GIS Environment

The parameters simulated in the Qual2K model were represented as two types of output, namely graphical and text output. These forms of output show the simulation result data for each segmented element along the river network. However, these outputs are restricted as they merely show the relation between the parameter values and distances along the river.

To achieve a better representation of the results, Qual2K output ought to be linked with natural phenomena for enhanced analysis and ease of water monitoring. As a contribution made by this study, the Qual2K model output was linked with the GIS platform to connect the model output with the natural phenomena within the river basin. Moreover, the objective of linking the Qual2K output with the GIS platform is to show the classes of simulated water quality parameters.

In this process, the generated digital map of the Klang River basin served as a GIS platform. With GIS techniques the spatial output of the simulated water quality parameters, which are represented in the “WQ output” worksheet, was transferred and presented into the GIS platform according to the water classification shown in Table 2.1. Figure 3.10 shows the process of transferring the model output into the GIS environment.

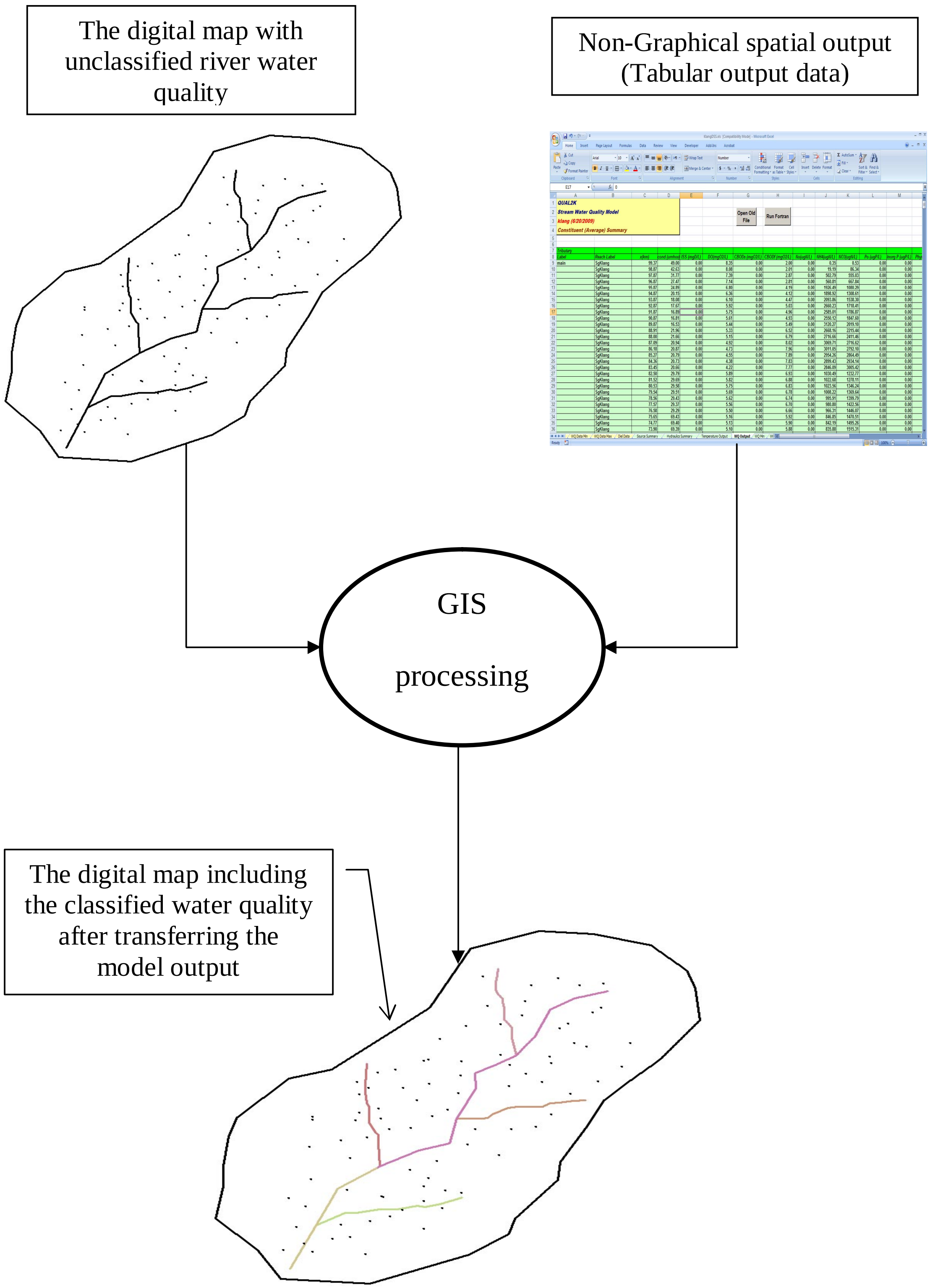


Figure 3.10: The process of transferring the tabular model output into the GIS environment

3.8. Summary

Klang River basin, the case of the study and the most urbanized region in Malaysia, was introduced in this chapter. The basin's catchment area is 1,288km^2. It encompasses the Federal Territory of Kuala Lumpur and includes parts of the state of Selangor. The basin occupied by population of 4.4 million. The basin faces serious environmental degradation from different sources of pollution, in order to the status of the river water is between critical and bad.

This chapter also introduced the methods used to achieve the objectives of the current study. The methods initiated by collecting the primary and secondary data that needed for this research. The primary data, i.e. hydraulic data, was collected by field work. The hydraulic data was measured on nineteen gauging stations set out along the Klang River main stem and its tributaries. On the other hand, several secondary data were collected from different sources; the Digital Elevation Model (DEM) was done by Akbari (2011). The river network map was obtained for the year of 2008 from the Department of Irrigation and Drainage Malaysia (DID). In addition, the sub-basins map was collected from the Department of Survey and Mapping Malaysia (JUPEM) for the year of 2008. Furthermore, the land use map was collected from the Malaysian Department of Agriculture (DOA) for the year of 2008. Regarding the point sources, the data was obtained for the year of 2008 from different sources, i.e. the Department of Environment Malaysia (DOE), field inventory, previous studies and Indah Water Konsortium Sdn Bhd (IWK). Moreover, the water quality monitoring data was obtained from the Department of Environment Malaysia (DOE) from 1997 to 2007.

Following data collection, the methods involved utilization of GIS to modify the collected data and, thus, to develop the spatial digital map for the Klang River basin. GIS tools were, then, used to determine the required geometric data for running Qual2K model. Based on the available data, seven tributaries along with the main stem were chosen to represent the Klang River network. The network was divided into fifteen reaches with eight headwaters to satisfy Qual2K model. The model was calibrated using an average data of 2001-2005, while the data of 2006-2007 were used for model validation step. Finally, GIS techniques and tools were used to link the Qual2K output to the natural phenomena for better assessing and managing the river water.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1. Introduction

This chapter describes and discusses the results of the study. It is divided into four parts. The first section contains the generated database as well as the developed digital map of the Klang River Basin. In the second part, the output results of the Qual2K model are given. The third part shows the linking output between the Qual2K model results and the GIS environment. The last part of this chapter discusses the simulation results of the Qual2K model scenarios.

4.2. The GIS Database of the Klang River Basin

The Qual2K model, as previously mentioned, requires the river's spatial data including the dimensions of each river reach (upstream and downstream elevations, reach length, reach slope), upstream and downstream location of each reach, the point and nonpoint source locations as well as the sites of the data employed for model calibration.
GIS techniques were applied to modify and analyze the collected spatial data and to determine all the geometric data necessary to satisfy and fulfill the Qual2K model requirements. In addition, the GIS process entails generating a digital map of the Klang River Basin to achieve the first objective of this study. The digital map of the river watershed is very powerful because the features are represented as physical layers, meaning that modifications may be made for each and every individual feature in the map without changing the position or the actual feature shape. Furthermore, new features within the Klang River Basin can be added to the map at anytime. The GIS tools additionally allow for data to be analyzed, and such analysis is deemed the most important and powerful benefit of the map. Analysis can be done between several feature layers or among features

within the same layer, according to the required output or the questions that need to be answered from the map.

4.2.1. The River Network and the Sub-watersheds

Qual2K model construction depends on the river network, which consists of the main river and branch tributaries. Thus, with GIS tools, the obtained river network was modified. Seven tributaries with the main river were chosen based on the available data that obtained to represent the Klang River network. The selected tributaries are the Ampang River, Gombak River, Kerayong River, Rekah River, Pencala River, Rasau River and the Damansara River. Figure 4.1 illustrates the river network and sub-basins. As seen in the figure, ten sub-basins were obtained, namely the Klang upstream, Ampang, Gombak, Kerayong, Rekah, Pencala, Rasau, Damansara, Klang downstream and coastal. However, the last, coastal sub-basin is in a coastal area and will not be useful to the model simulation. Furthermore, with the GIS tools, the water quality and gauging stations were located based on their coordinates.

4.2.2. Point Sources Map

It was indicated previously that the nonpoint source data was acquired from relevant authorities and previous studies. Subsequently, these data were located based on their coordinates using GIS tools (Figure 4.2).

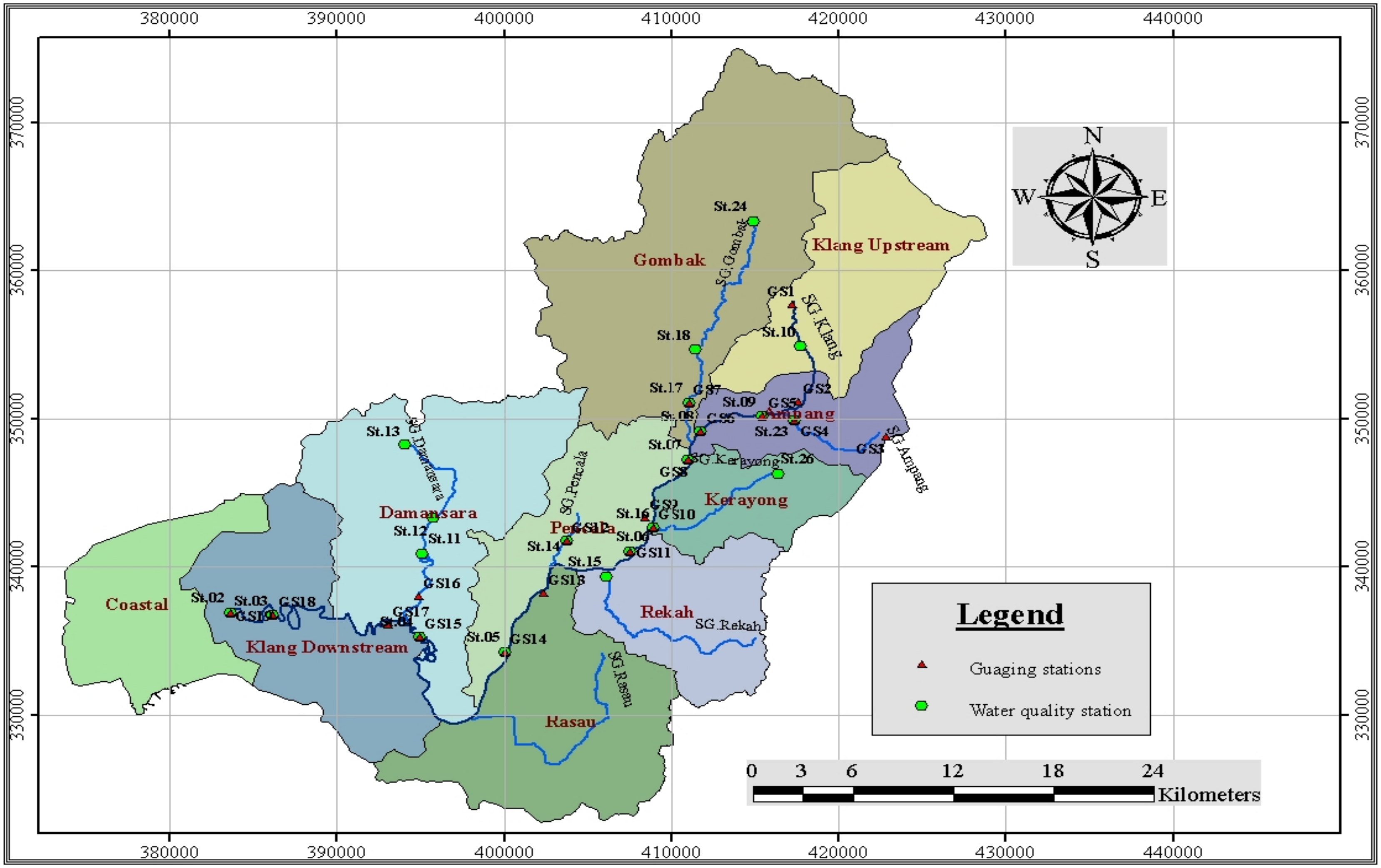


Figure 4.1: Klang River network with the sub-watersheds

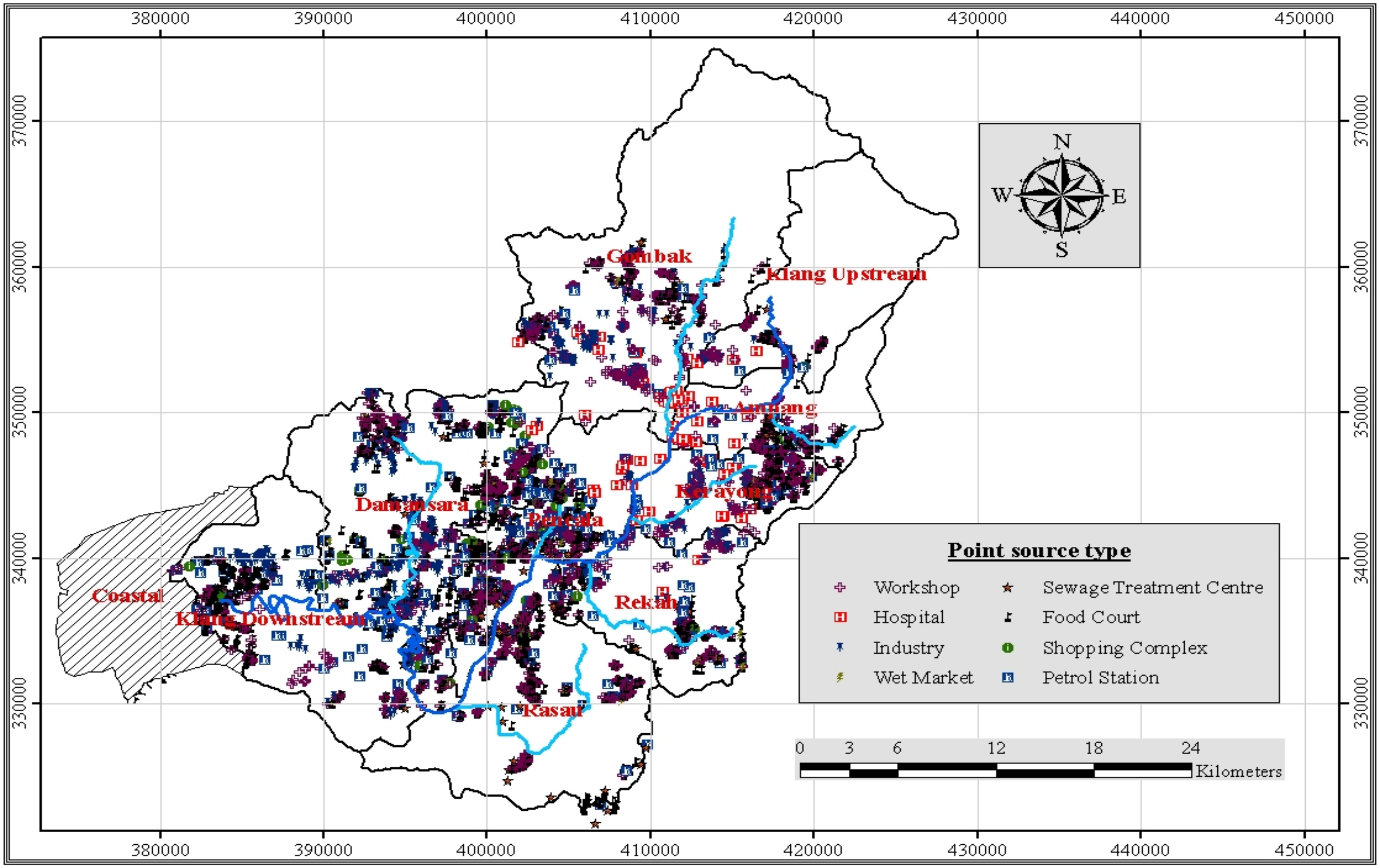


Figure 4.2: The point source locations throughout the Klang River Basin

4.2.3. Digital Map of the Klang River Basin

After transferring all the data into GIS shapefiles, GIS tools were employed to re-project all the shapefiles into one projection system, i.e. Kertau_RSO_Meter. Thereafter, to achieve the first research objective a digital map of the Klang River Basin was generated by importing all the shape files as different layers into one MXD file. Figure 4.3 portrays the generated digital map of the Klang River Basin.

4.2.4. Discussions on the Generated Digital Map

In the previous studies, the digital maps have been proved as an effective features for providing the database including the spatial and non spatial information. An example of these studies that have been done by (Bishop, McBratney, and Whelan (2001); Dill and Weber (2013); Frigeri et al. (2011); Jiménez, Aparicio, and Estrada (2009); Li (2012); Odgers, Sun, McBratney, Minasny, and Clifford (2014); Tsogas, Floudas, Lytrivis, Amditis, and Polychronopoulos (2011); Vartziotis et al. (2012)).

The generated digital map of the Klang River basin is more convenient, interactive and efficient than the traditional paper map. Unlike the traditional paper map, which is difficult to be edited, this digital map is a physical map that at any time it can easily be edited and modified using the GIS tools. For instance, the process of adding or removing point sources as well as the process of expanding the river network and the sub-watersheds. Furthermore, it is a real-time projected map, where it provides the real location of the features. Moreover, the digital map connects the spatial data of the features with their tabular databases, which make it easy to analyzing the data for better results that help for decision-making. This generated map is very useful for the subsequent analysis work in the current study.

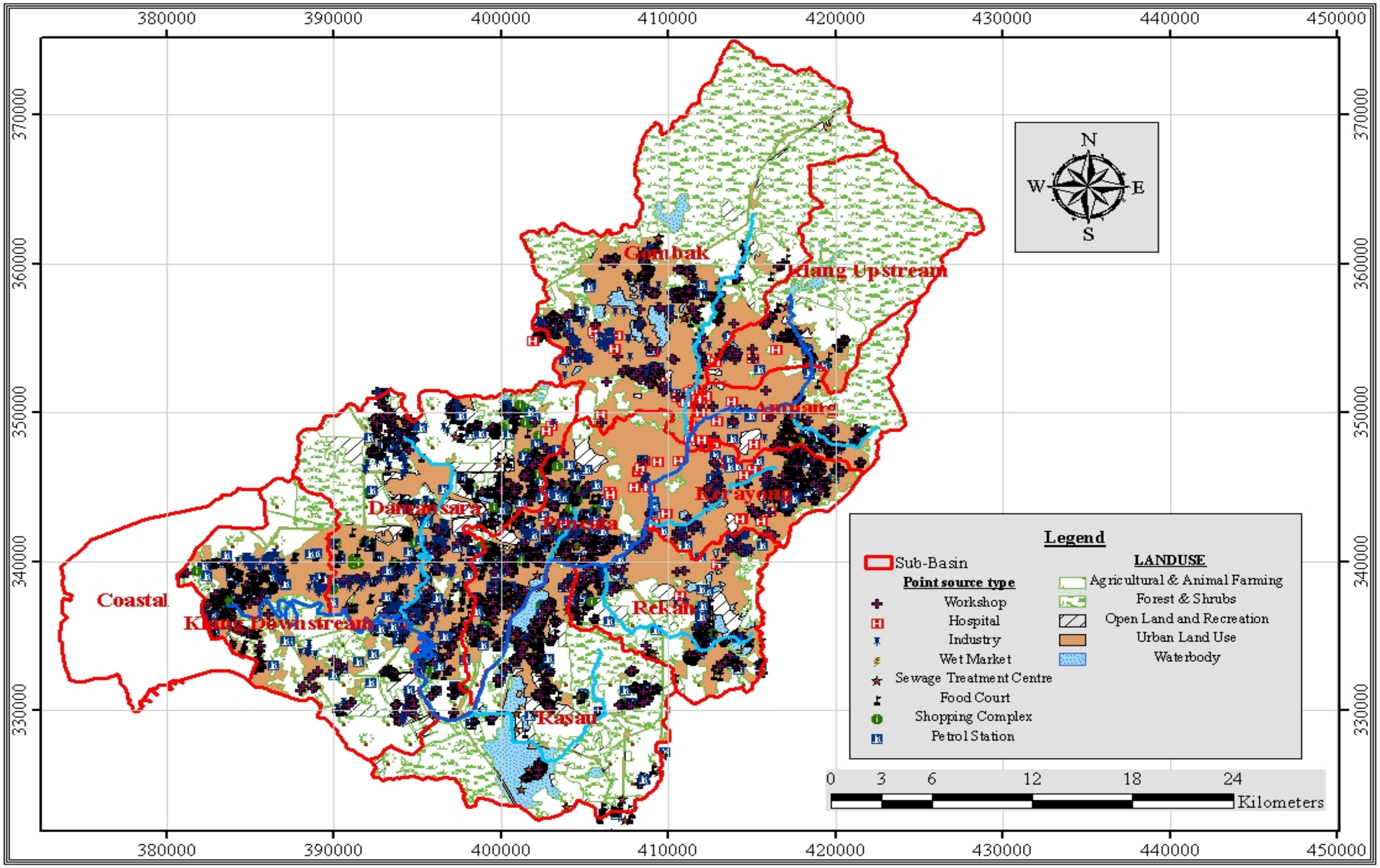


Figure 4.3: The generated digital map of the Klang River Basin

4.3. Water Quality Modeling

4.3.1. Model Calibration and Validation

Model calibration and validation are critical steps toward obtaining adequate model performance. Model calibration is the process of justifying the parameters' input data until the model output matches the observed data set. Model validation, on the other hand, is the process of testing a model using an independent data set without further parameter adjustment.

❖ **Model Calibration**

Qual2K simulates several hydraulic and water quality parameters. Thus, two model calibration stages have been done in this study, i.e. hydraulic and water quality parameter calibration. Water discharge was chosen for hydraulic calibration, while the DO and BOD parameters were selected for water quality calibration.

➢ **Discharge Calibration**

The discharge calibration in this research was performed on the observed discharge at the gauging stations, while adjustments was made for the discharge rates at the headwaters and diffuse sources to attain a reasonable match between measured and calculated discharge. The graph in Figure 4.4 represents the comparison between the observed and simulated discharge for the main stem of the Klang River. It shows that the pattern of observed discharge is similar to that of simulated discharge with respect to high and low discharge. The flow began increasing steadily upstream toward downstream, and this rate abruptly ascended after the confluence with the Damansara River due to the coastal effect as well as the point source amount downstream. As shown in Figure 4.5, the correlation between the observed and simulated discharge R^2 is 0.951. According to Henriksen et al. (2003), this correlation value is considered excellent.

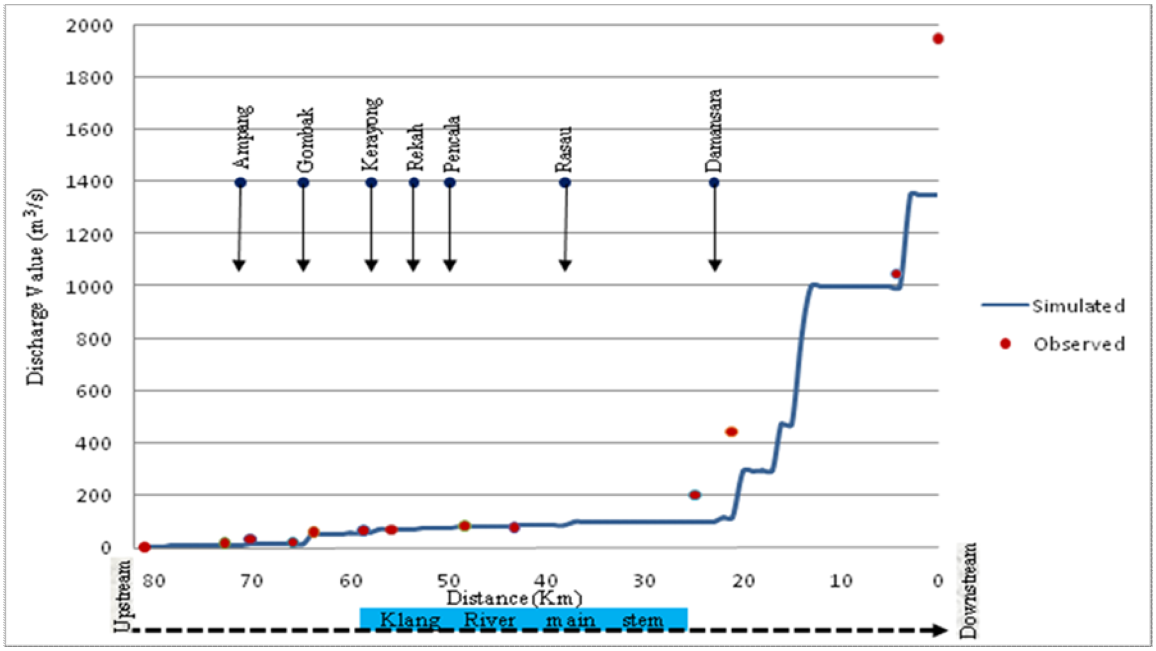


Figure 4.4: Comparison between the observed and simulated discharge for the main stem of the Klang River

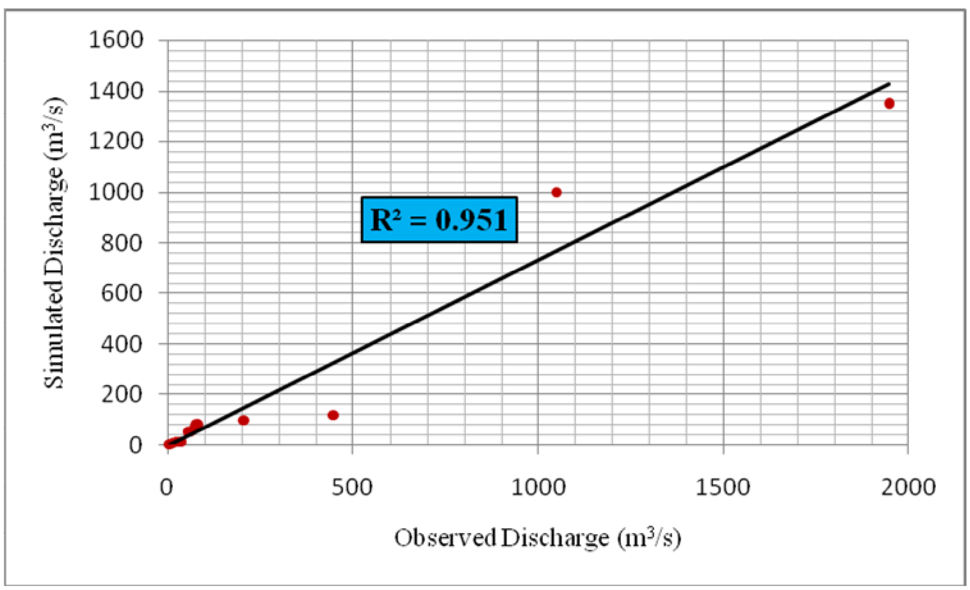


Figure 4.5: Plot of discharge calibration for the main stem of the Klang River

- **Water Quality Calibration**

The two water quality parameters applied in this work are DO and BOD for water quality calibration. The average water quality data (2001 to 2005) was used as observed data. An adjustment was made for the missed water quality data at the headwaters during model calibration. Furthermore, an adjustment was done in model calibration for the water quality variables at the pollution sources to achieve a reasonable match between observed and calculated data. According to Edwards (1992), the adjusted variables data can be input either by direct measurements or by using the input parameters and constant values of a model accomplished for a study area similar to that of the current study. The rates and coefficient values (Appendix C) of the water quality parameters were adjusted using values from literature as a first approximation, after which the values were fine-tuned through the process of Qual2K calibration.

Figure 4.6 illustrates the comparison between the observed and simulated DO for the main stem of the Klang River. The observed DO pattern is comparable to that of the simulated DO upstream and downstream areas of the river. The correlation between the observed and simulated DO (R^2), as per Figure 4.7 is equal to 0.912. Henriksen et al. (2003) indicates that this correlation value is deemed excellent.

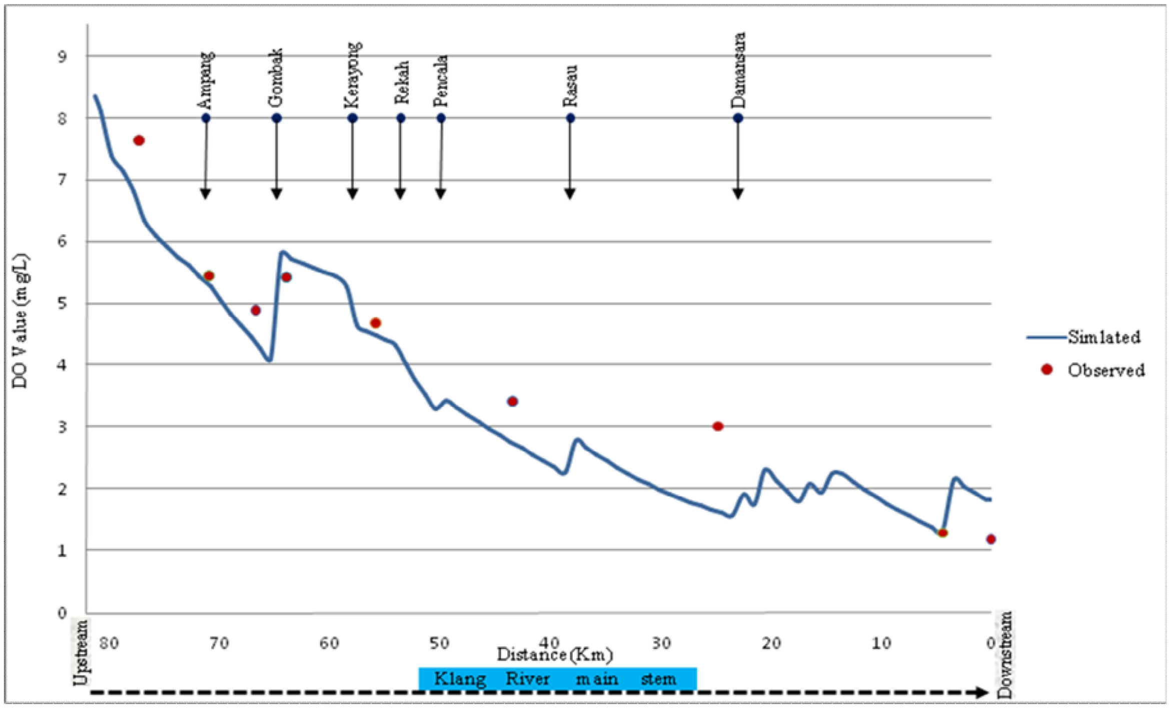


Figure 4.6: Comparison between observed and simulated DO for the Klang River

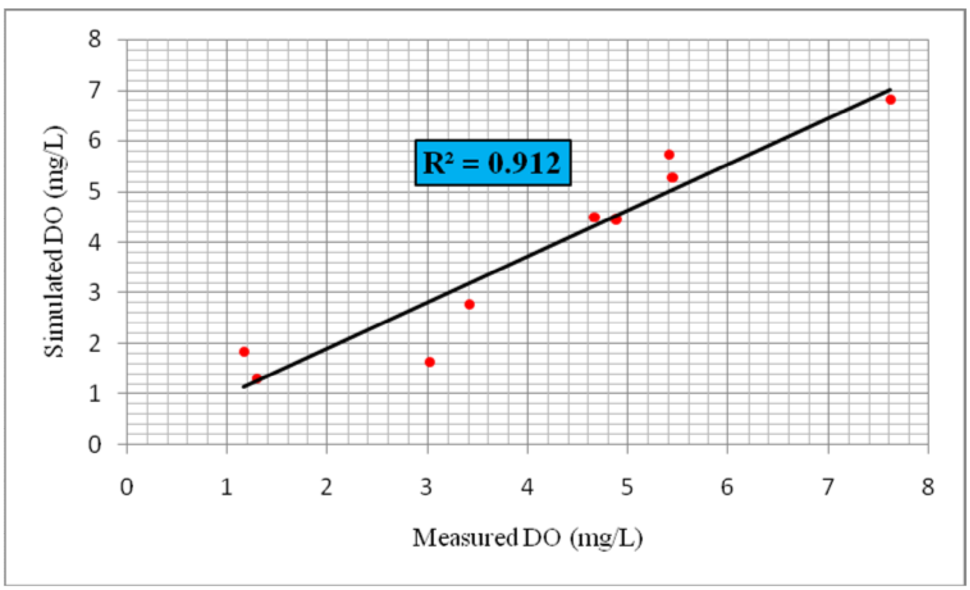


Figure 4.7: Plot of DO calibration for the main stem of the Klang River

The comparison between the observed and simulated BOD for the main stem of the Klang River is given in Figure 4.8 bellow. The observed BOD pattern looks similar to the pattern of the simulated BOD along the river, except downstream where the measured BOD at the monitoring station, which is about 4.4km from the downstream location, is not in sync with simulated data. Figure 4.9 demonstrates that the correlation between the observed and simulated BOD (R^2) is 0.689. Consistent with the literature, this correlation value is seen as very good (Henriksen et al., 2003).

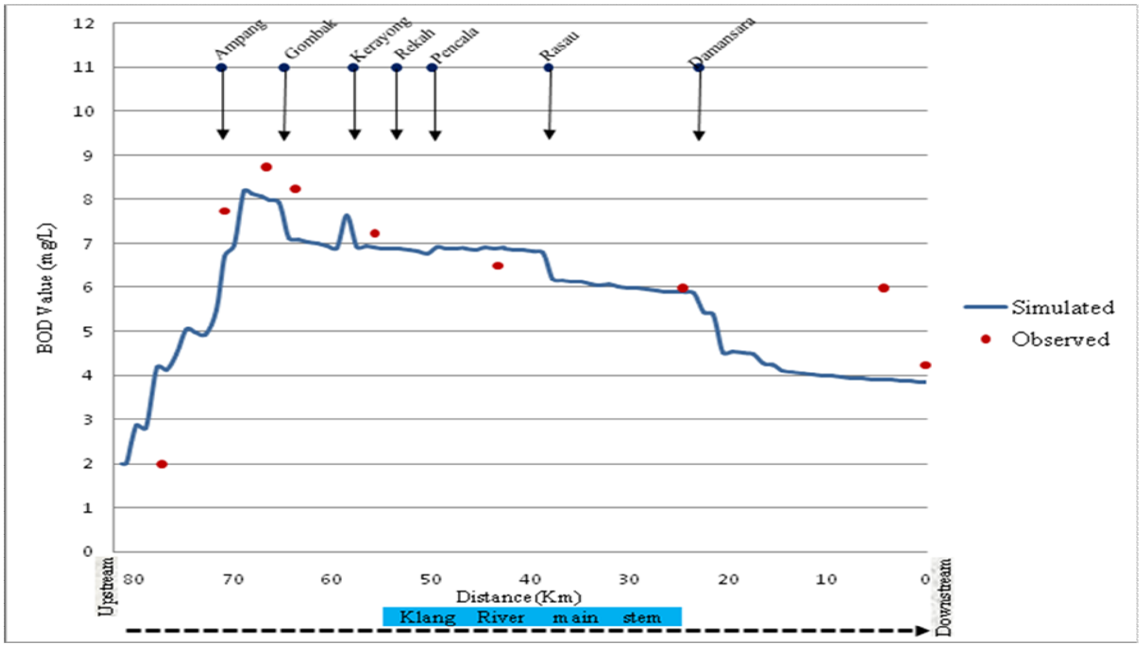


Figure 4.8: Comparison between observed and simulated BOD for the Klang River

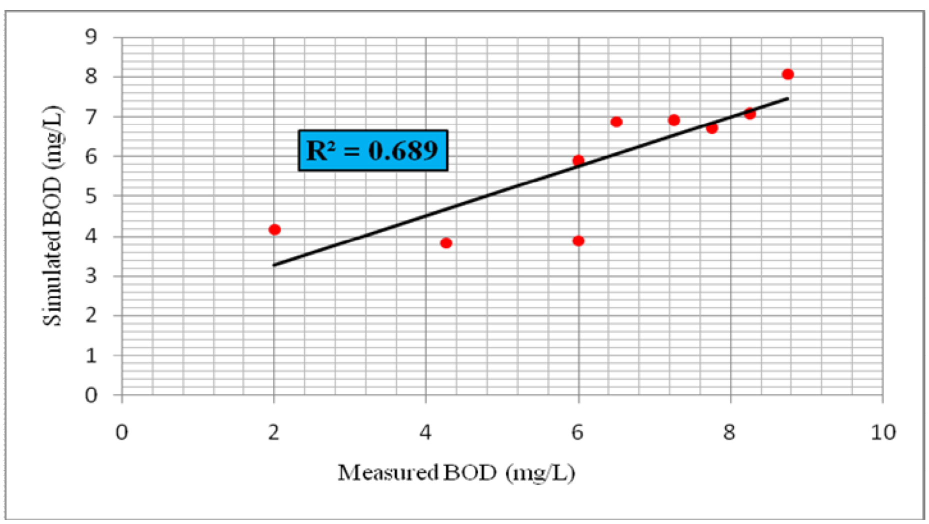


Figure 4.9: Plot of BOD calibration for the main stem of the Klang River

❖ Model Validation

The model was validated using an average of 2006 and 2007 data due to its availability.

Figure 4.10 illustrates the comparison between the observed and simulated DO for the main stem of the Klang River throughout the validation process. The pattern of observed DO seems similar to the pattern of simulated DO upstream and downstream of the river. The correlation between the observed and simulated DO (R^2), as seen in Figure 4.11 is equal to 0.884. According to Henriksen et al. (2003), this correlation value is regarded as excellent.

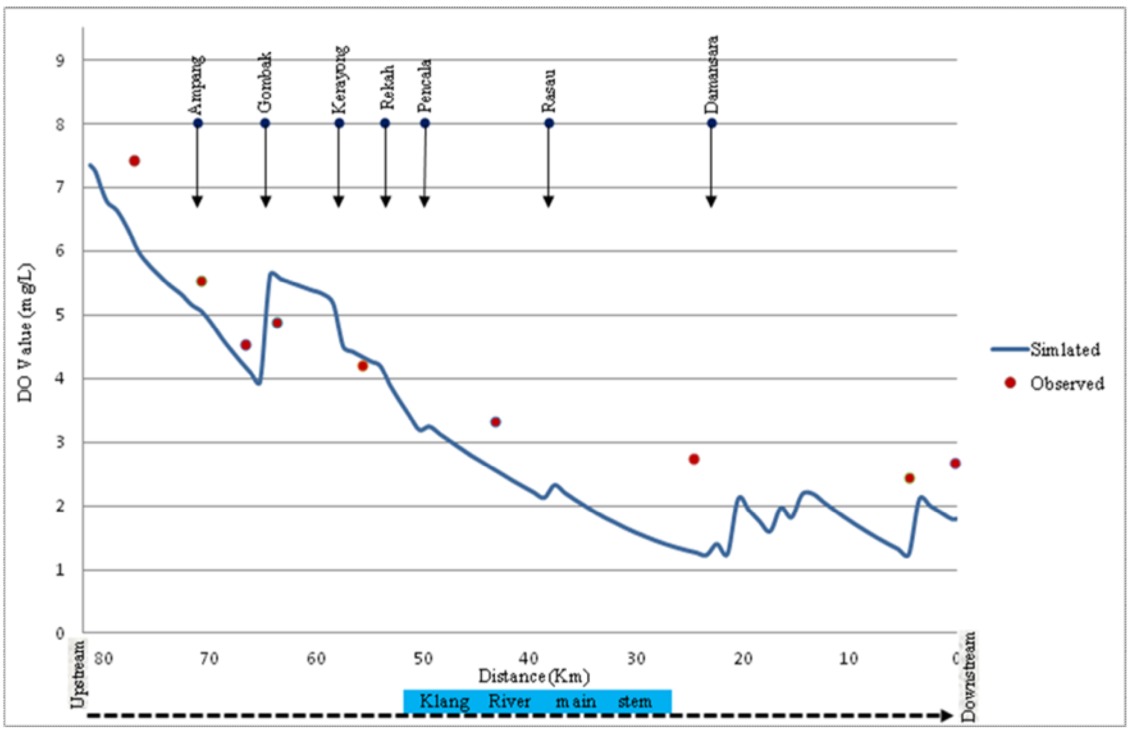


Figure 4.10: Comparison between observed and simulated DO for the Klang River

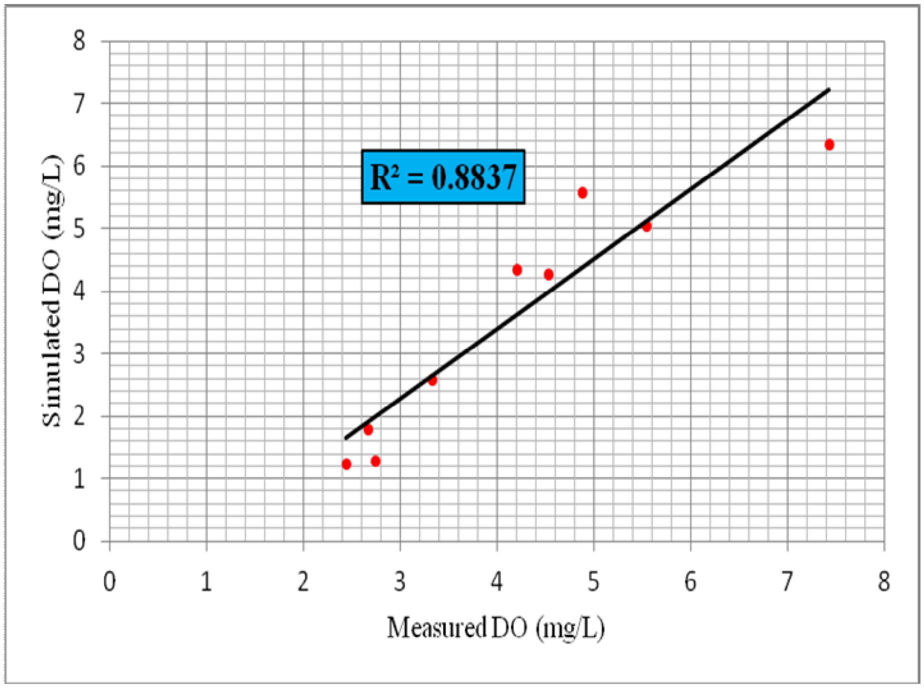


Figure 4.11: Plot of DO calibration for the main stem of the Klang River

The graph in Figure 4.12 is a comparison between the observed and simulated BOD for the main stem of the Klang River. The pattern of observed BOD seems similar to the pattern of simulated BOD along the river, apart from downstream where the measured BOD does not match the simulated data. In Figure 4.13, the correlation between the observed and simulated BOD (R^2) is 0.52. In line with literature, this value is considered good (Henriksen et al., 2003).

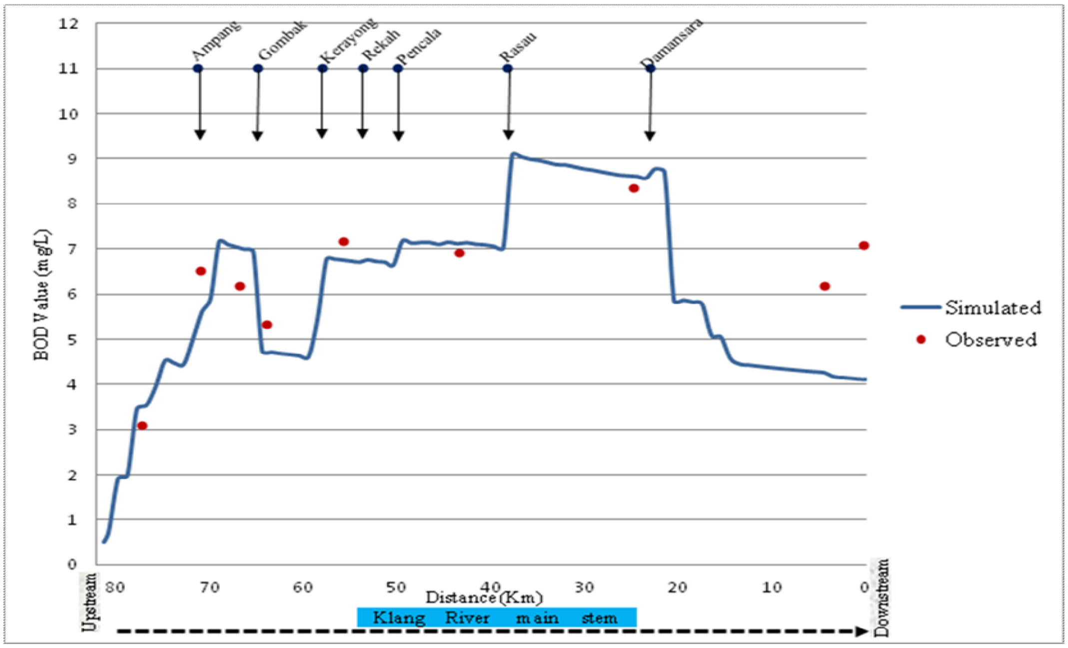


Figure 4.12: Comparison between observed and simulated BOD for the Klang River

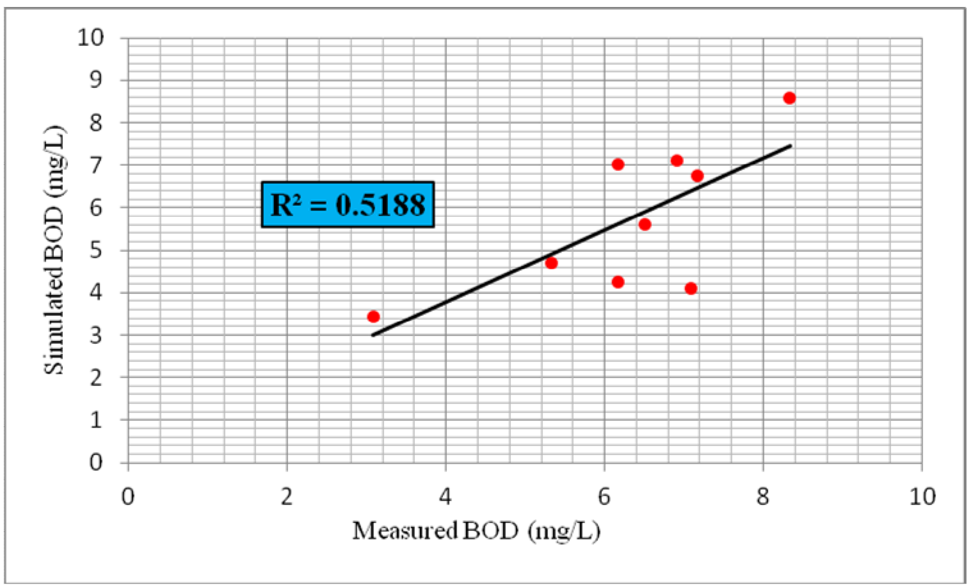


Figure 4.13: Plot of BOD calibration for the main stem of the Klang River

4.3.2. Scenario Analysis

Model scenarios were run to assess the impact of the point sources loads on the quality of the Klang River. Although several types of point sources are located along the

Klang River basin, only three types are spread along each reach of the river network, i.e. sewerage treatment plants, industries and workshops. Based on that, three model scenarios were conducted to investigate the impact of the three types of point sources on the water quality in terms of DO and BOD. The simulated scenarios and their analysis are as follow:

- **Scenario I: The Impact of the Sewerage Treatment Plants**

The sewerage treatment plants (standard A & B) along the Klang River basin are shown in Figure 4.14. The first scenario has been done to detect the impact of the sewerage treatment plants by omitting the treatment plants with standard A and B, while the other point sources remain at the same rates. Figures 4.15 and 4.16 show the changes on DO and BOD after omit the sewerage treatment plants. Section A in each figure represents the change on DO and BOD respectively after omit the treatment plants with standard A. While Section B in each figure shows the change on DO and BOD respectively after omit the treatment plants with standard B. Table 4.1 summarizes the percentage change in DO and BOD along the Klang River main stem due to simulation of scenario I.

It can be noticed that the simulation of scenario I caused an increase on DO and decrease on BOD along the Klang River main stem. However, the rate of change on DO and BOD at the upstream is less than the mid and downstream of the main stem due to the exclusion of standard A, while the rate of change on DO and BOD at the upstream is more than the mid and downstream of the main stem due to the exclusion of standard B. This is because the STP's with standard A are dominating the Klang River basin from Gombak River to the Klang River downstream as well as the downstream of Ampang River, while the STP's with standard B are dominating only the upstream of the river basin up to the confluence with Gombak River as shown in Figure 4.14. Subsequently, the exclusion of standard A caused an increase of DO between 1.14% at the upstream of reach 3 and 179.19% at the downstream of reach 13, while the BOD decreased between 2.05% at the downstream of reach 3 and 26.17% at the upstream of reach 15. On other hand, the exclusion of standard B caused an increase of DO between 1.8% at the downstream of reach 15 and 40.50% at the downstream of reach 3, while the BOD decreased between 1.04% at the downstream of reach 15 and 49.40% at the downstream of reach 3.

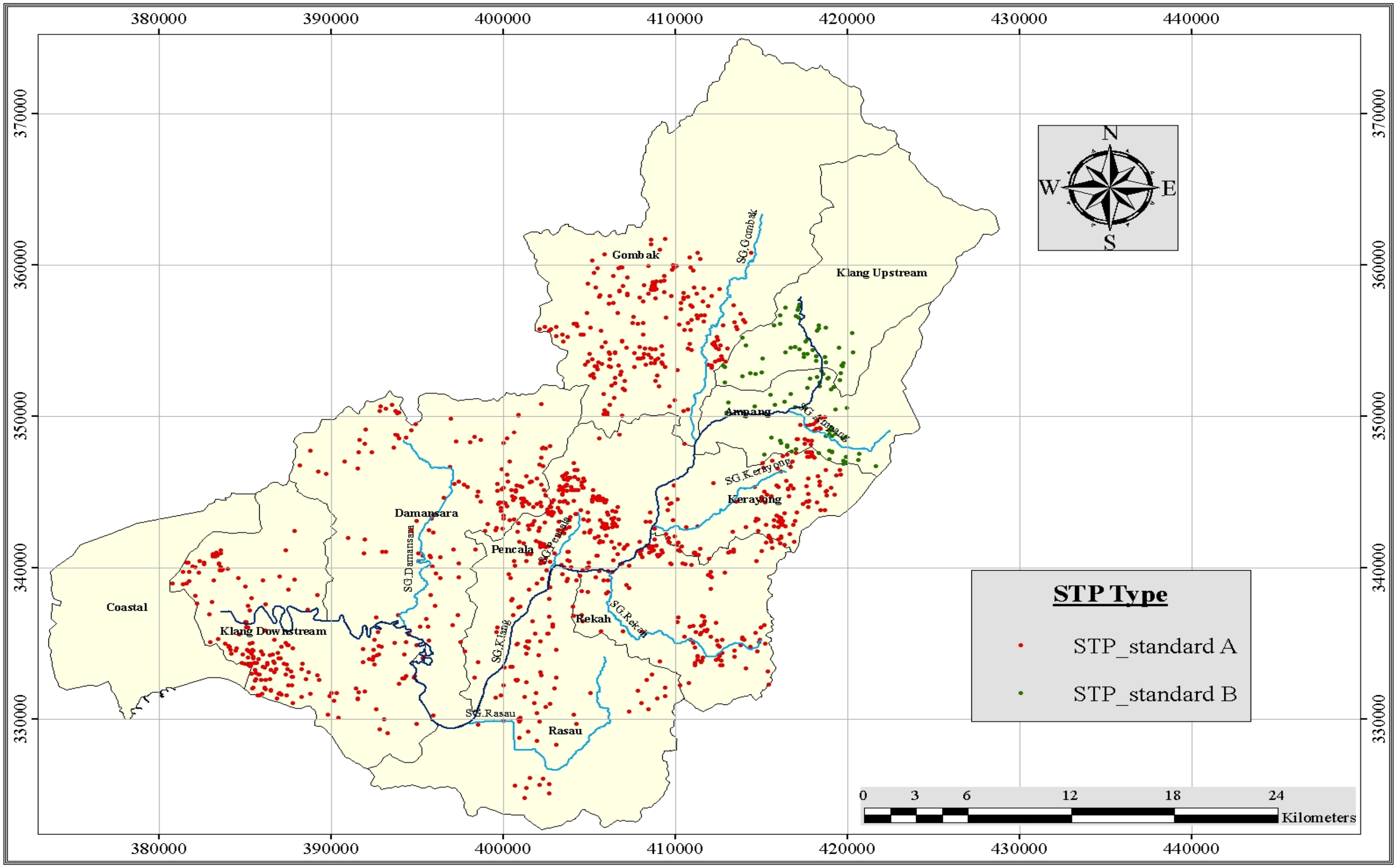
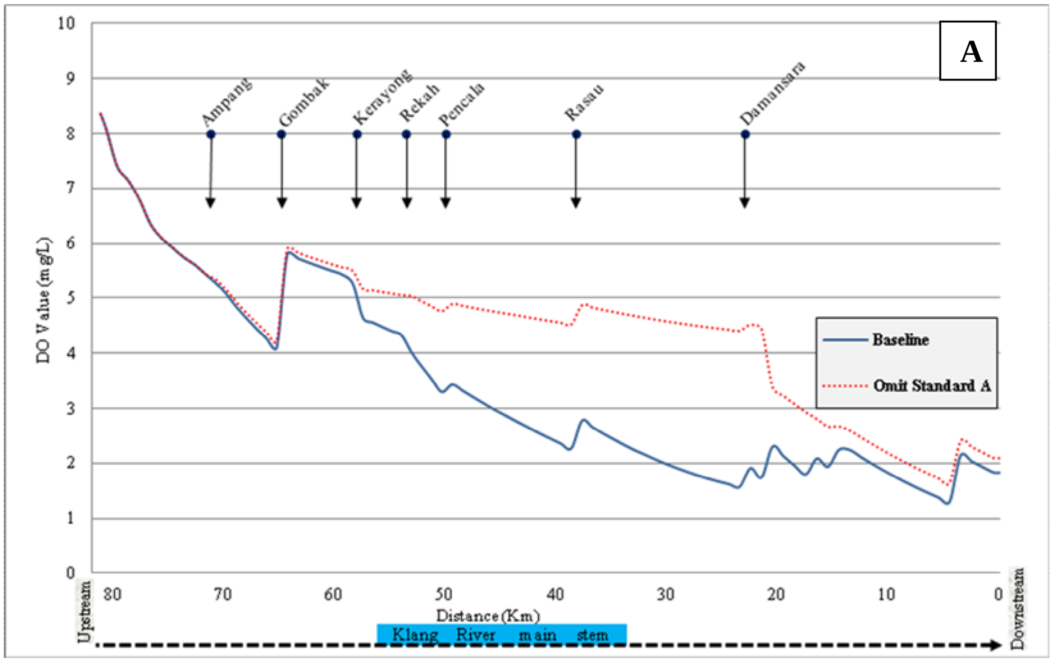


Figure 4.14: The locations of the STP (standard A & B) along the Klang River network



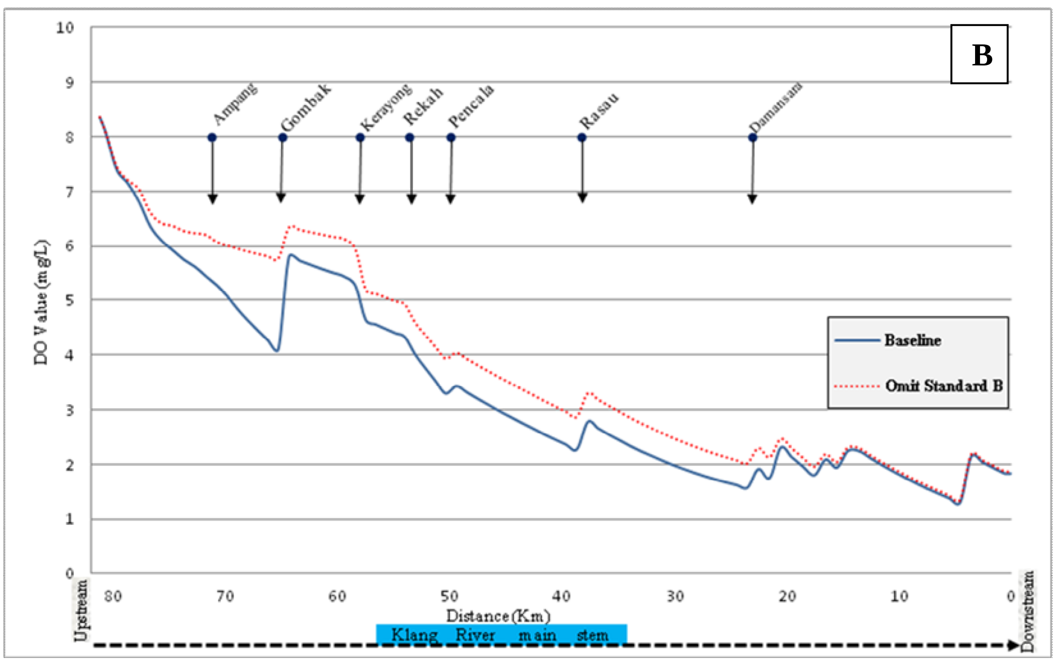


Figure 4.15: The change on DO due to simulation of scenario I

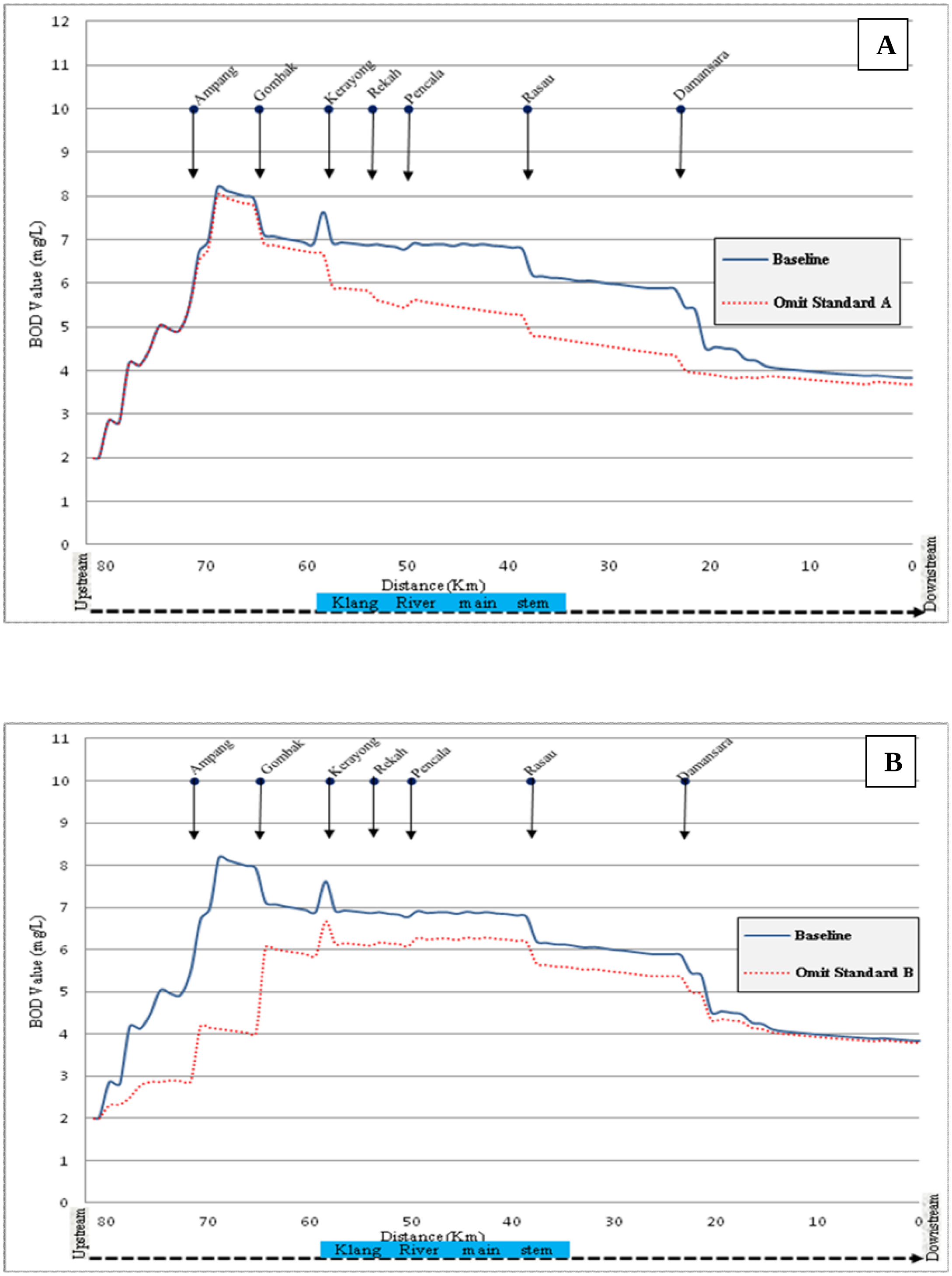


Figure 4.16: The change on BOD due to simulation of scenario I

Table 4.1: Summary of the percentage change in DO and BOD along the Klang River main stem due to simulation of scenario I

Parameter	Scenario Type		Change in percentage							
			Reach Number							
			1	3	5	7	9	11	13	15
DO	Omit Standard A	U/S	0	1.145369	1.549038	11.18204	25.32882	42.31218	74.8505	135.4812
		D/S	0	2.782166	4.320903	16.70686	44.06014	98.30439	179.1871	13.8016
	Omit Standard B	U/S	0	15.04061	9.20433	11.79571	14.38868	17.41917	18.48885	19.8801
		D/S	14.01229	40.49449	12.77878	13.6157	19.12015	26.02438	27.81739	1.758343
BOD	Omit Standard A	U/S	0.00	-2.94	-2.85	-14.58	-18.51	-18.85	-22.18	-26.17
		D/S	0.00	-2.05	-12.77	-15.14	-19.57	-22.51	-25.93	-3.90
	Omit Standard B	U/S	0	-37.5819	-15.118	-11.3842	-10.433	-9.26385	-8.453	-8.2708
		D/S	-47.4048	-49.3925	-12.5488	-11.2943	-10.2774	-8.987	-8.89615	-1.04447

- **Scenario II: The Impact of Industrial Loads**

The second scenario has been done to detect the impact of the industries loads on the DO and BOD. Figure 4.17 shows the location of the industries along the Klang River basin. This scenario was simulated to test the increasing as well as to test the exclusion of industries load, while the other point sources remain at their normal rates. It has been assumed that the industries load increased by 100%. Figures 4.18 and 4.19 illustrate the changes on DO and BOD due to increasing and excluding of the industries load. Section A in each figure represents the change on DO and BOD respectively due to the exclusion of the industries load. While, section B in each figure shows the change on DO and BOD respectively due to the increase of industries load by 100%. Table 4.2 summarizes the percentage change in DO and BOD along the Klang River main stem due to simulation of scenario II.

It can be noticed from Figures 4.18 and 4.19 that the industries along Klang River basin have a very light effect on the water quality in term of DO and BOD. As shown in Table 4.2, the exclusion of industrial wastewater caused an increase in DO except at the downstream of reach 3, as well as an increase in BOD except at the downstream of reach 1. The greatest increase of DO was recorded upstream at reach number 13 after the confluence with the Rasau River, where it increased by 0.78%, while the greatest increase of BOD was recorded downstream at reach number 11 before the confluence with the Rasau River, where the BOD decreased by 1.08%. On other hand, the increase of industrial wastewater by 100% caused a decrease in DO and BOD amount along the main stem of the Klang River. The greatest decrease of DO was recorded upstream at reach number 13 after the confluence with the Rasau River, where it decreased by 0.76%, while the greatest decrease of BOD was recorded downstream at reach number 11 before the confluence with the Rasau River, where the BOD decreased by 1.05%.

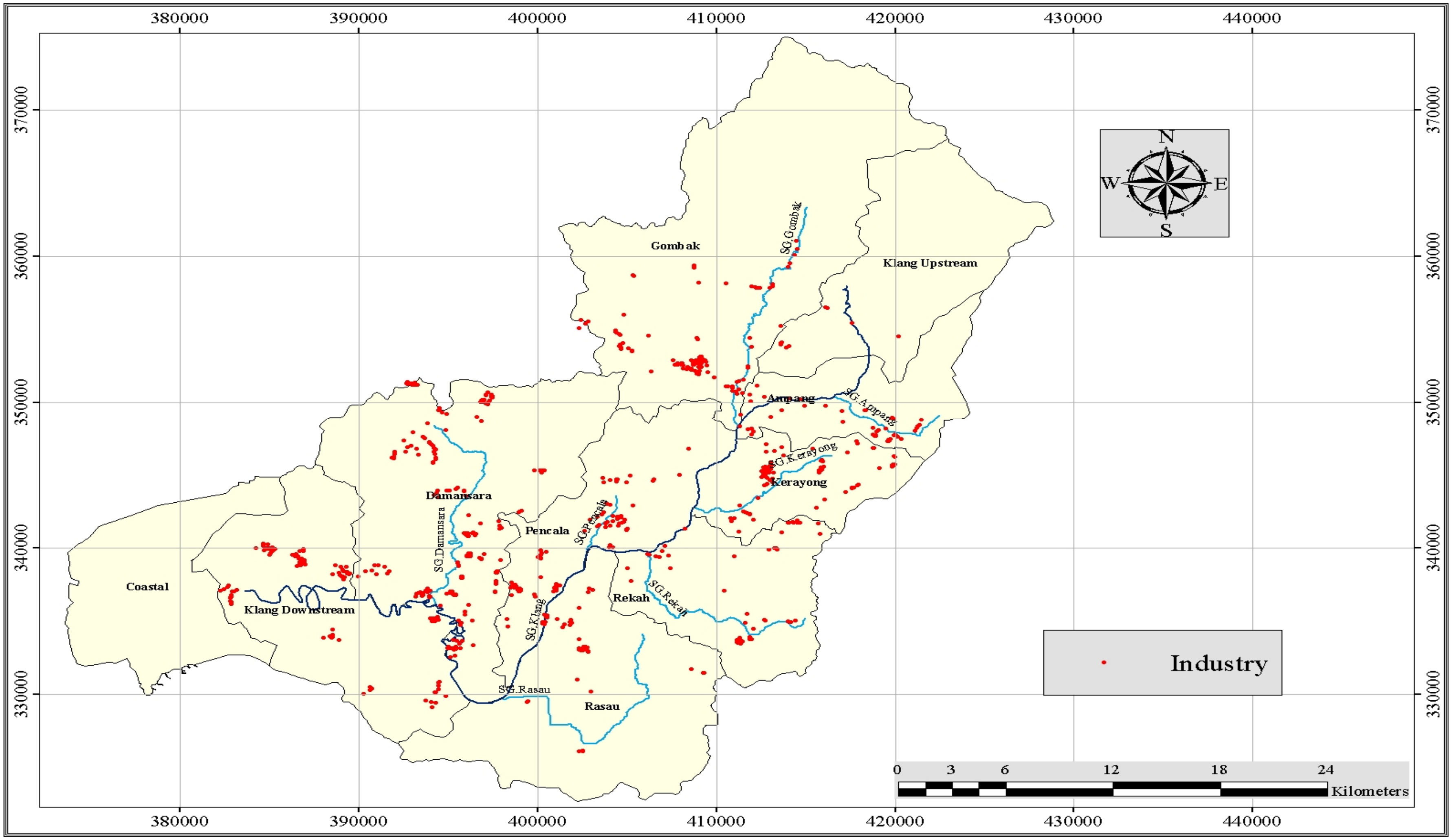
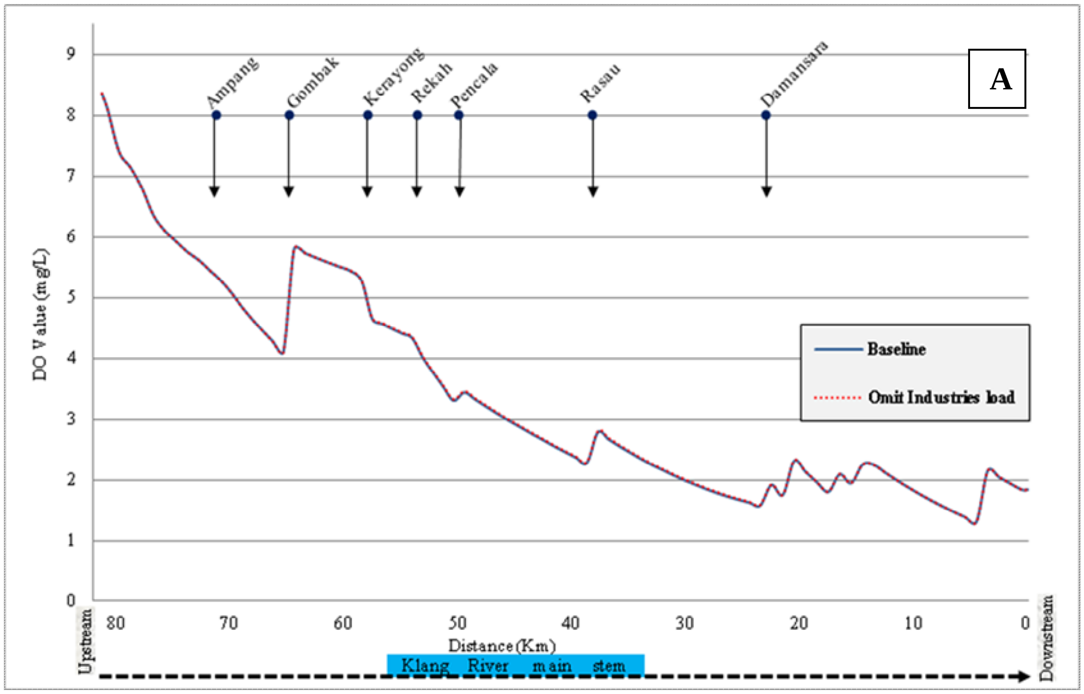


Figure 4.17: The location of the industries along the Klang River network



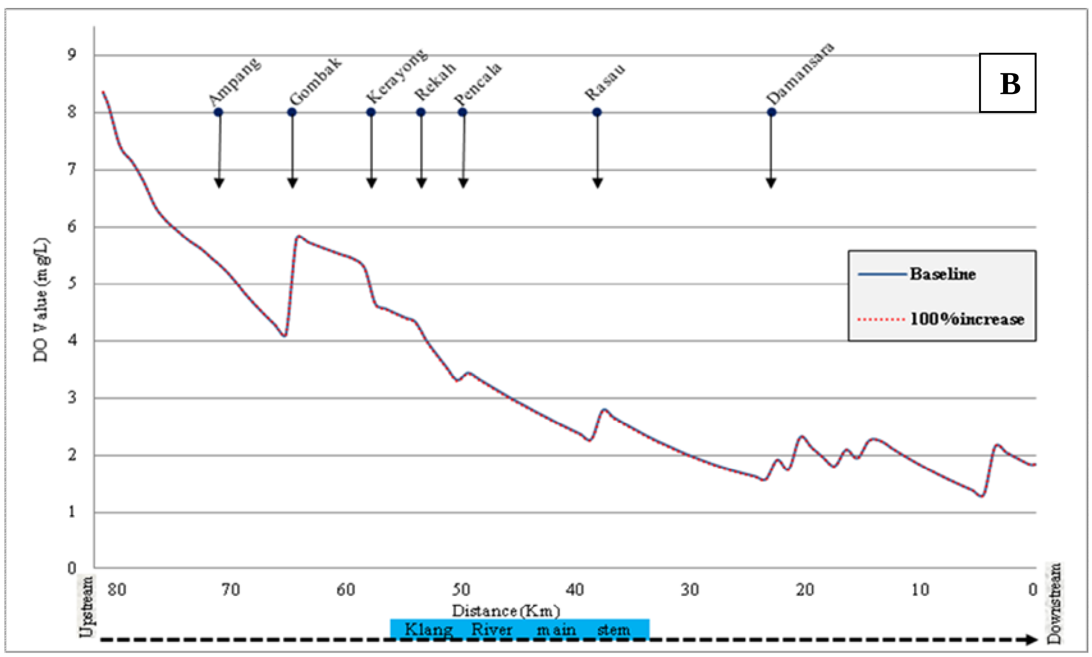
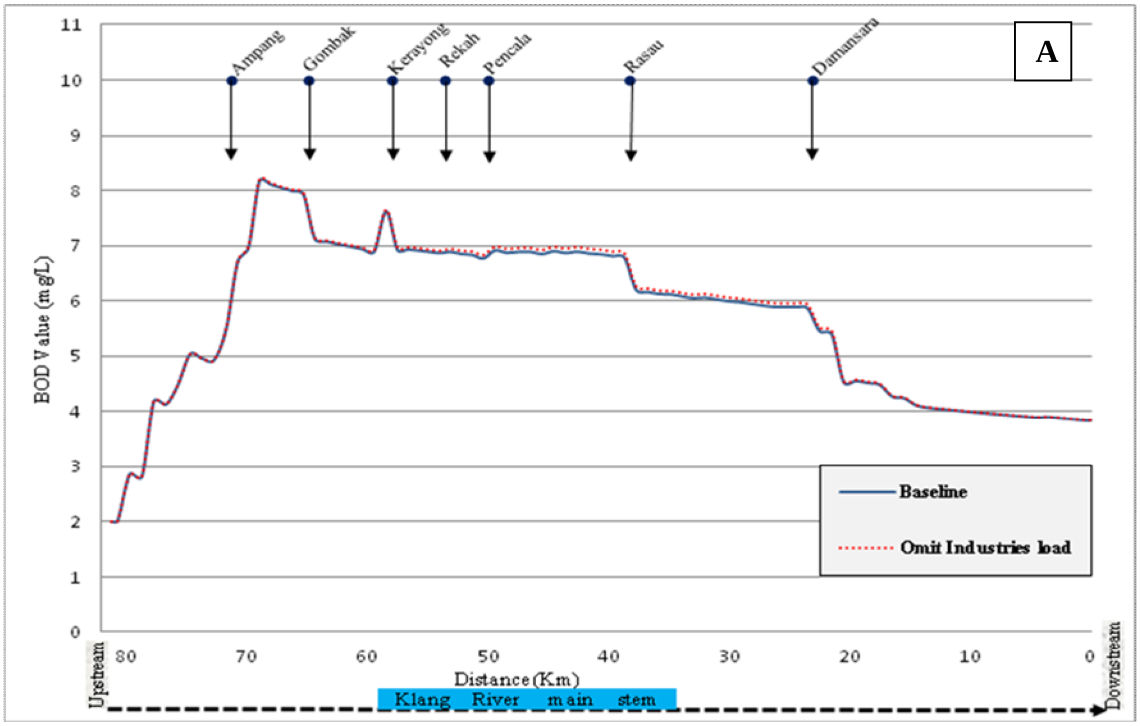


Figure 4.18: The change on DO due to simulation of scenario II



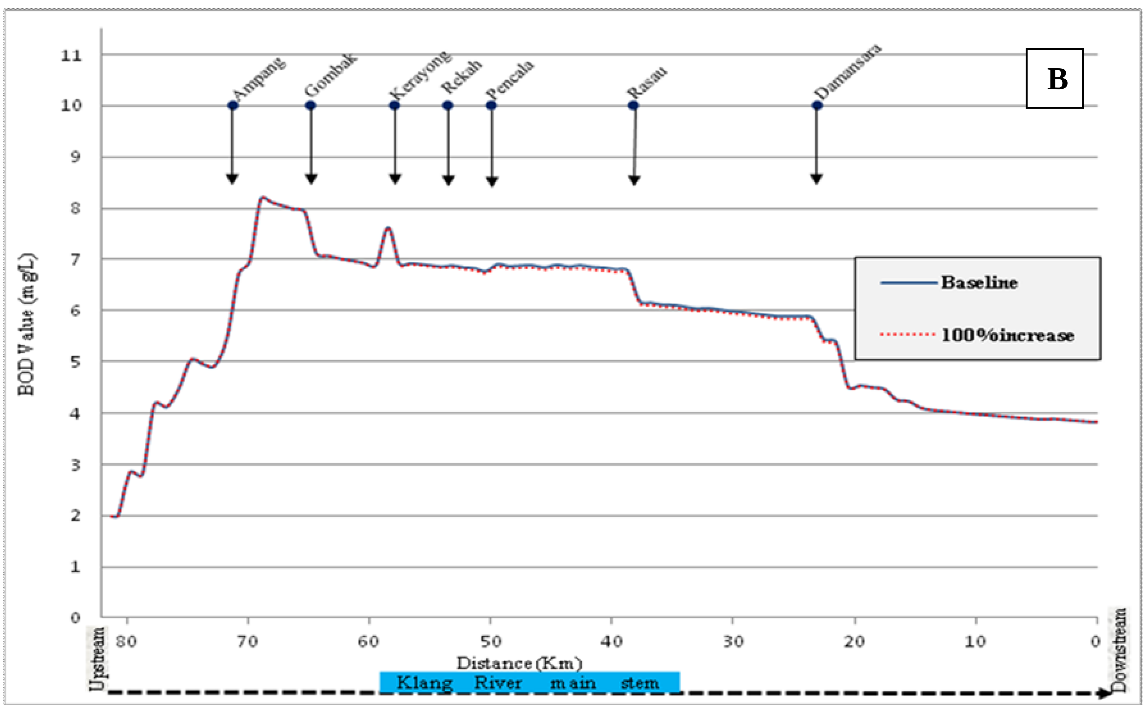


Figure 4.19: The change on BOD due to simulation of scenario II

Table 4.2: Summary of the percentage change in DO and BOD along the Klang River main stem due to simulation of scenario II

Parameter	Scenario Type		Change in percentage Reach Number 1	3	5	7	9	11	13	15
DO	**Omit Industrial**	**U/S**	0	0.023253	0.02668	0.293663	0.462869	0.57332	0.783074	0.436511
		D/S	0.011	-0.06428	0.136431	0.391702	0.636593	0.70096	0.754448	0.154099
	Increase Industrial 100%	**U/S**	0	-0.0231	-0.02658	-0.28897	-0.45255	-0.55717	-0.75987	-0.41872
		D/S	-0.01102	0.063912	-0.13537	-0.38479	-0.61964	-0.67548	-0.72541	-0.15361
BOD	**Omit Industrial**	**U/S**	0.00	0.00	0.08	0.45	0.69	0.88	0.91	1.06
		D/S	-0.04	0.21	0.26	0.52	0.81	1.08	1.07	0.07
	Increase Industrial 100%	**U/S**	0	-0.00268	-0.07824	-0.44123	-0.67854	-0.85754	-0.88587	-1.02819
		D/S	0.036028	-0.20685	-0.25545	-0.51509	-0.79637	-1.05155	-1.04	-0.0681

- **Scenario III: The Impact of Workshop Loads**

The third scenario has been done to detect the impact of the workshop loads on the DO and BOD. Figure 4.20 shows the location of the workshops along the Klang River basin. This scenario was simulated to test the increasing as well as to test the exclusion of workshop load, while the other point sources remain at their normal rates. It has been assumed that the workshops load increased by 100%. Figures 4.21 and 4.22 show the changes on DO and BOD due to increasing and excluding of the workshop load. Section A in each figure represents the change on DO and BOD respectively due to exclude the workshop loads. While section B in each figure shows the change on DO and BOD respectively due to the increase of workshop loads by 100%. Table 4.3 summarizes the percentage change in DO and BOD along the Klang River main stem due to simulation of scenario III.

It can be noticed from Figures 4.21 and 4.22 that the workshops along Klang River basin have a very light effect on the water quality in term of DO and BOD. As shown in Table 4.3, the exclusion of workshop wastewater caused an increase in DO except at the up and downstream of reach 11, as well as an increase in BOD. The greatest increase of DO was recorded downstream at reach number 13, where it increased by 1.34%, while the greatest increase of BOD was recorded downstream at reach number 11 before the confluence with the Rasau River, where the BOD decreased by 1.06%. On other hand, the increase of workshop wastewater by 100% caused a decrease in DO amount along the main stem of the Klang River except at reach number 11 as well as a decrease in BOD amount along the main stem of the Klang River. The greatest decrease of DO recorded was upstream of reach number 15 after the confluence with the Damansara River, where it decreased by 0.97%, while the greatest decrease was recorded downstream of reach number 11 before the confluence with the Rasau River, where the BOD increased by 1.04%.

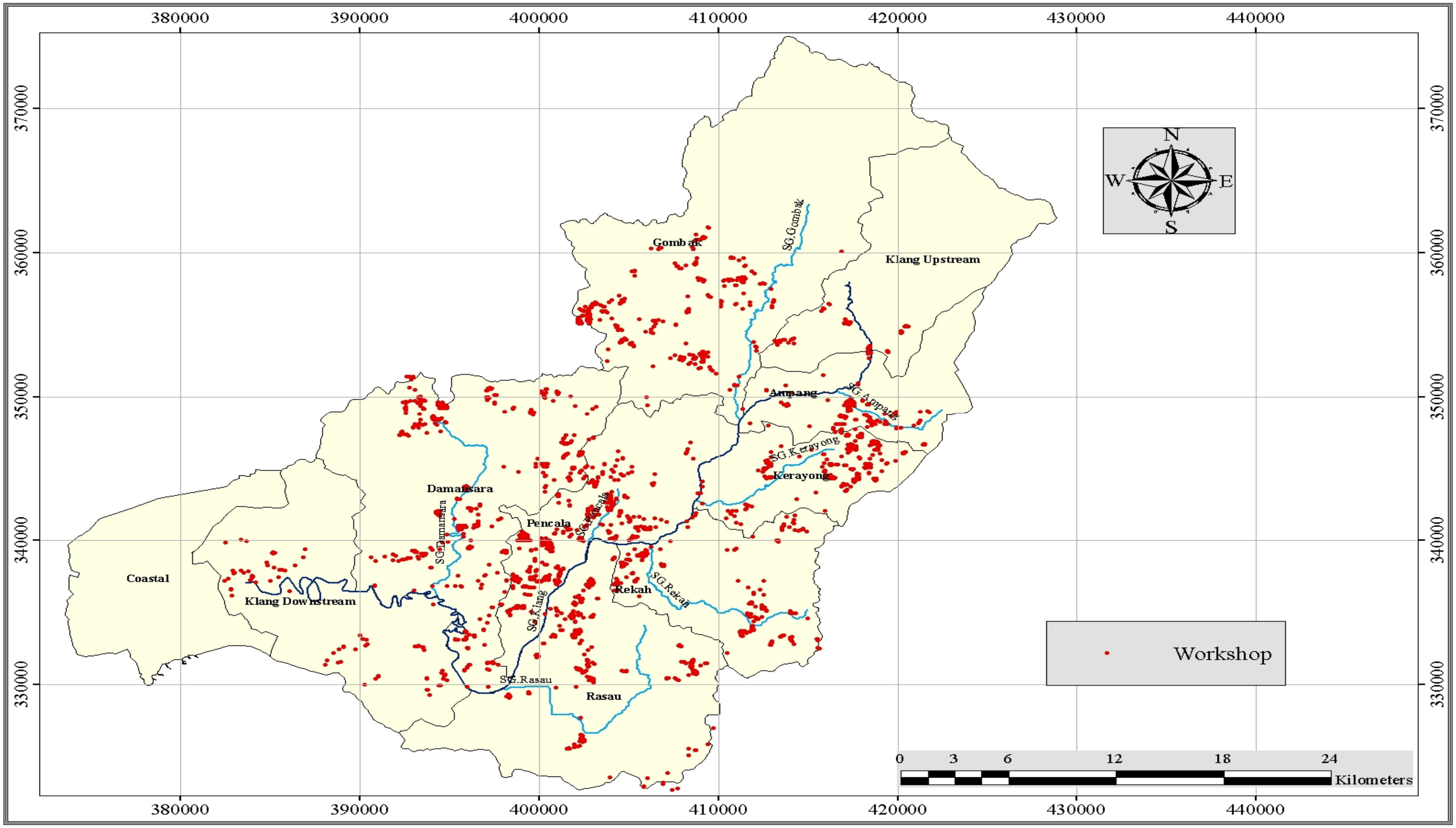
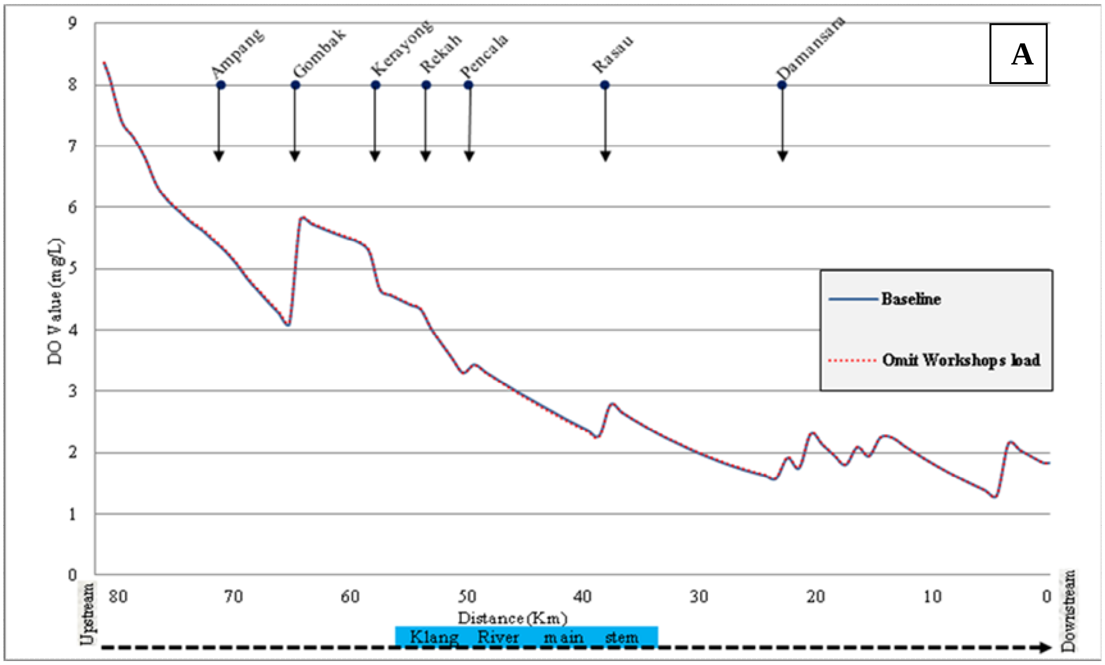


Figure 4.20: The location of the workshops along the Klang River network



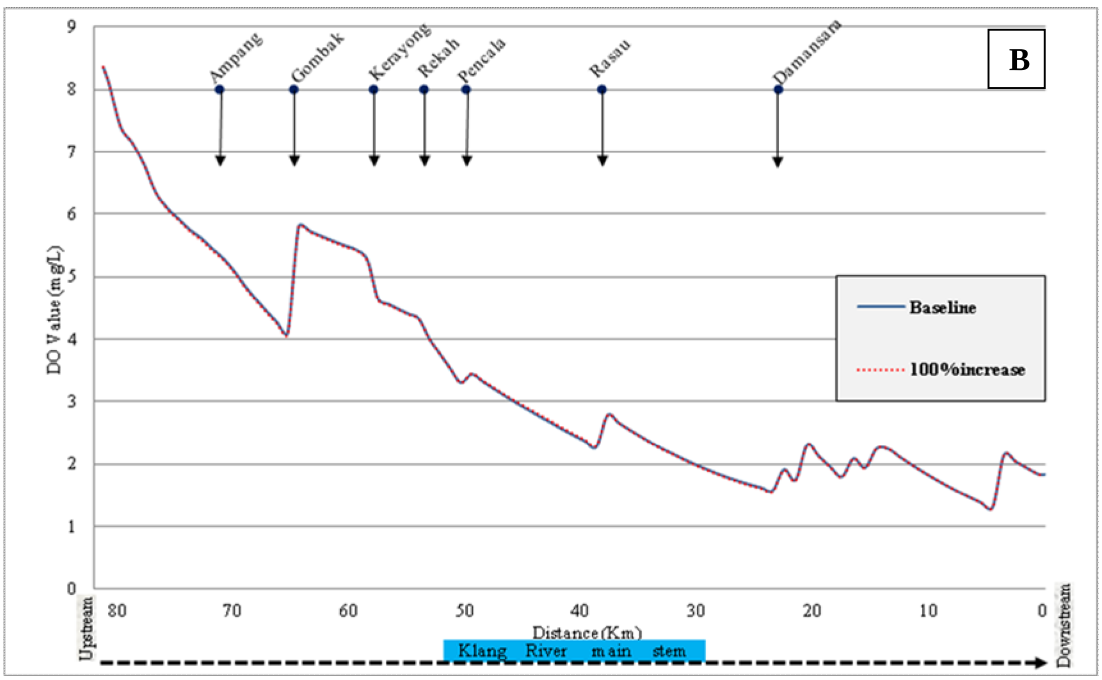
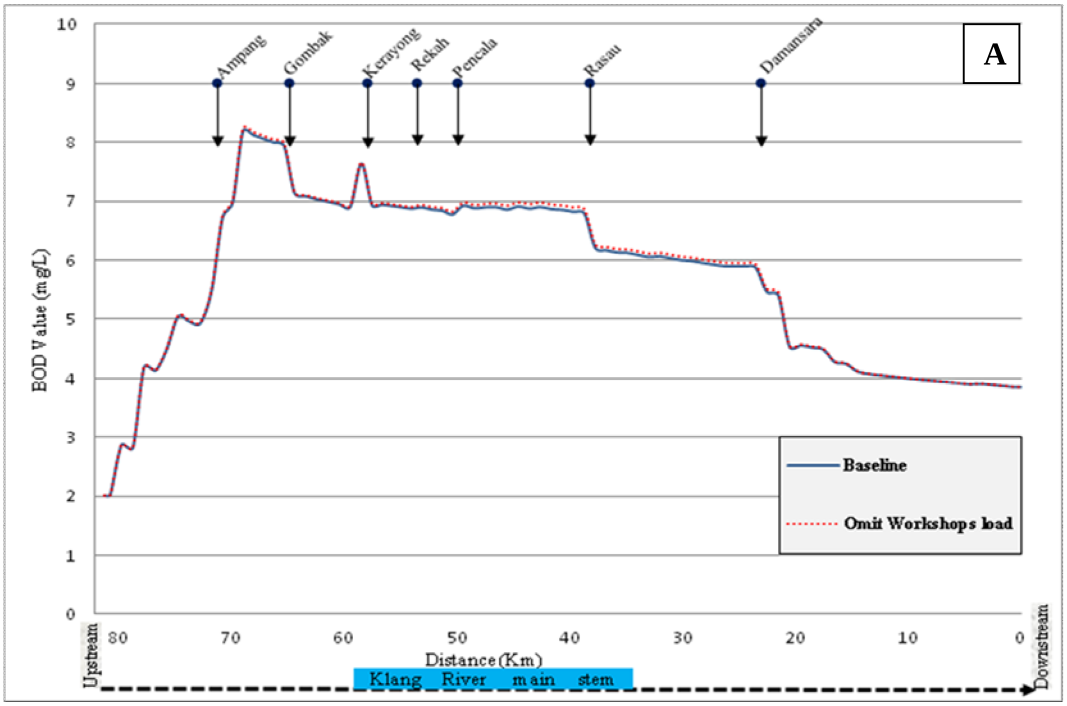


Figure 4.21: The change on DO due to simulation of scenario III



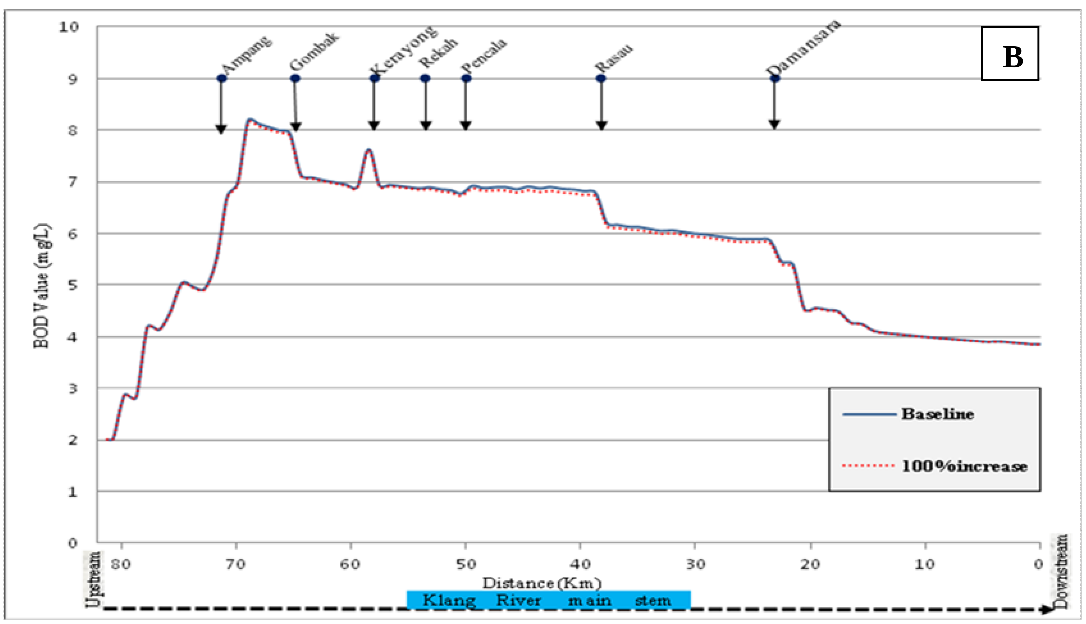


Figure 4.22: The change on BOD due to simulation of scenario III

Table 4.3: Summary of the percentage change in DO and BOD along the Klang River main stem due to simulation of scenario III

Parameter	Scenario Type		Change in percentage							
			Reach Number							
			1	**3**	**5**	**7**	**9**	**11**	**13**	**15**
DO	**Omit Workshops**	**U/S**	0	0.429219	0.269953	0.314205	0.197031	-0.07954	0.17339	1.010543
		D/S	0.645161	0.797641	0.376599	0.30825	0.059182	-0.72745	1.344362	0.232537
	Increase 100%	**U/S**	0	-0.4175	-0.26666	-0.30996	-0.19023	0.081109	-0.16376	-0.97074
		D/S	-0.63596	-0.77442	-0.37214	-0.3037	-0.05455	0.715695	-1.29218	-0.23118
BOD	**Omit Workshops**	**U/S**	0.00	0.43	0.23	0.33	0.56	0.74	0.93	0.93
		D/S	0.40	0.61	0.29	0.37	0.64	1.06	0.94	0.06
	Increase 100%	**U/S**	0	-0.41952	-0.23157	-0.32696	-0.55146	-0.72832	-0.91027	-0.90746
		D/S	-0.39565	-0.59698	-0.28402	-0.36801	-0.63367	-1.03657	-0.91881	-0.05965

4.3.3. Discussions of the Model and Scenarios Simulation

The results of the Qual2K model simulation are presented in several steps for the current condition as a baseline and three model scenarios.

- **The current condition (the baseline)**

Referring to Figures 4.6 and 4.8, the Klang River’s main stem water quality upstream is initially good, but it gradually deteriorates toward downstream. It is clear that the water quality at reach 5 between the confluences with the Gombak and Kerayong Rivers improves after the confluence with the Gombak River and gradually degrades toward the confluence with the Kerayong River. This is attributable to the large amount of the water that discharges from Gombak River at the upstream of reach 5. Likewise, the water quality upstream at reach 13 and 15 improves a little owing to the big amount of the water that discharges at the upstream of each reach. However, the quality of the river water downstream is very low. This is due to the amount of the sources of pollution that may contribute to the river pollution.

- **Scenario I: The Impact of the Sewerage Treatment Plants**

This scenario investigated the effect of excluding the Sewerage Treatment Plants by excluding the sewerages of standard A first and standard B second. The scenario investigated that the sewerage Treatment Plants have an effective role on the water quality of the Klang River’s main stem, where the exclusion of the Treatment Plants caused an improve on the water quality in terms of DO and BOD. The water quality at the upstream of the Klang River’s main stem did not show any improvement after excluding standard A, while it starts to improve after the confluence with Gombak River towards the downstream of the Klang River. This is due to no Treatment Plants with standard A that discharge at the upstream. Subsequently, the excluding of standard B caused an improve on the water quality at the upstream of the Klang River's main stem.

Comparable results were obtained by Das and Acharya (2003) in their research on the Mahanadi River. The study confirmed that domestic sewage causes water quality deterioration in terms of water quality parameters, whereby domestic waste caused a reduction in DO and an increase in BOD. The authors recommended treatment of domestic sewages waste prior to being discharged.

- **Scenario II: The Impact of Industrial Loads**

In scenario II, the effect of excluding and increasing industrial wastewater was simulated assuming that wastewater increased by 100%, while the other point sources were assumed to be at their normal load rates. The scenario investigated that the exclusion of the industrial wastewater caused an increase in both DO and BOD (ranging between 0% to 0.783% for DO, 0% to 1.08% for BOD), while the increasing of the industrial loads by 100% caused a decrease in both DO and BOD (ranging between 0% to 0.76% for DO, 0% to 1.05% for BOD).

- **Scenario III: The Impact of Workshop Loads**

In this scenario, the effect of excluding and increasing workshop wastewater was simulated by assuming 100% increases from the normal rate, while the other point sources were assumed to be at their normal load rates. The scenario investigated that the exclusion of the workshop wastewater caused an increase in both DO and BOD (ranging between 0% to 1.34% for DO, 0% to 1.06% for BOD), while the increasing of the workshop loads by

100% caused a decrease in both DO and BOD (ranging between 0% to 1.29% for DO, 0% to 1.04% for BOD).

4.4. Qual2K Output in the GIS Platform

The GIS techniques and tools were employed to transfer Qual2K output to the GIS platform (the generated digital map). The motive for this process is to connect the water quality model output with the natural phenomena within the river basin; the model shall also be more powerful in analyzing results and making decisions that will help to enhance the river water quality.

First, the model output data from the “WQ output” worksheet was imported and merged to the attribute table of the Klang River network layer. Then, referring to Table 2.1, through GIS techniques the merged data was classified into five groups for all simulated water quality parameters, namely DO and BOD along the main stem of the Klang River. Figure 4.23 depicts the DO classification along the main stem of the Klang River for the current condition. The figure signifies that the water quality of the Klang River main stem in terms of DO is class I upstream, while downstream it is recorded as class IV. Between the river’s upstream and downstream, the DO class varies between I and IV. Table 4.4 tabulates the water classes in terms of DO upstream and downstream of every reach along the Klang River main stem.

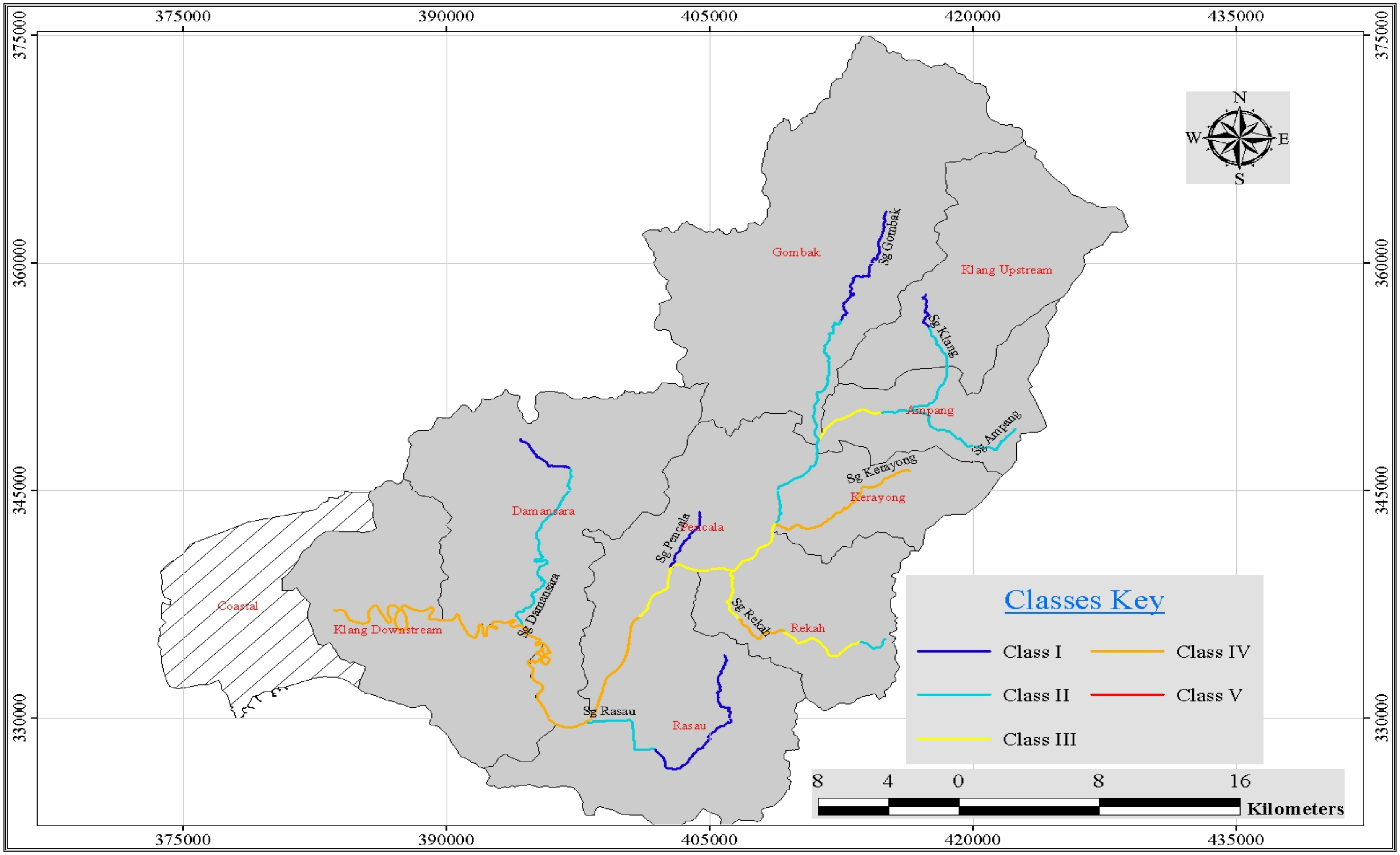


Figure 4.23: The DO classification along the main stem of the Klang River for the current condition

Table 4.4: Summarry of DO classes for every reach along the Klang River's main stem

Reach Number	DO value (mg/L)		DO class	
	Upstream	**Downstream**	**Upstream**	**Downstream**
1 (Headwater)	8.35	5.44	I	II
3	5.27	4.10	II	III
5	5.80	5.27	II	II
7	4.64	4.33	III	III
9	4.01	3.30	III	III
11	3.44	2.28	III	IV
13	2.78	1.58	IV	IV
15 (River mouth)	1.92	1.84	IV	IV

Figure 4.24 contains the BOD classification along the main stem of the Klang River for the present condition. This figure indicates that the water quality of the Klang River's main stem in terms of BOD is categorized as class II upstream, while downstream it is class III and IV. Table 4.5 summarizes the water classes in terms of BOD upstream and downstream of every reach along the Klang River's main stem.

Table 4.6 lists the classes of water qualtiy parameters in the upstream and downstream regions of every reach along the main stem of the Klang River.

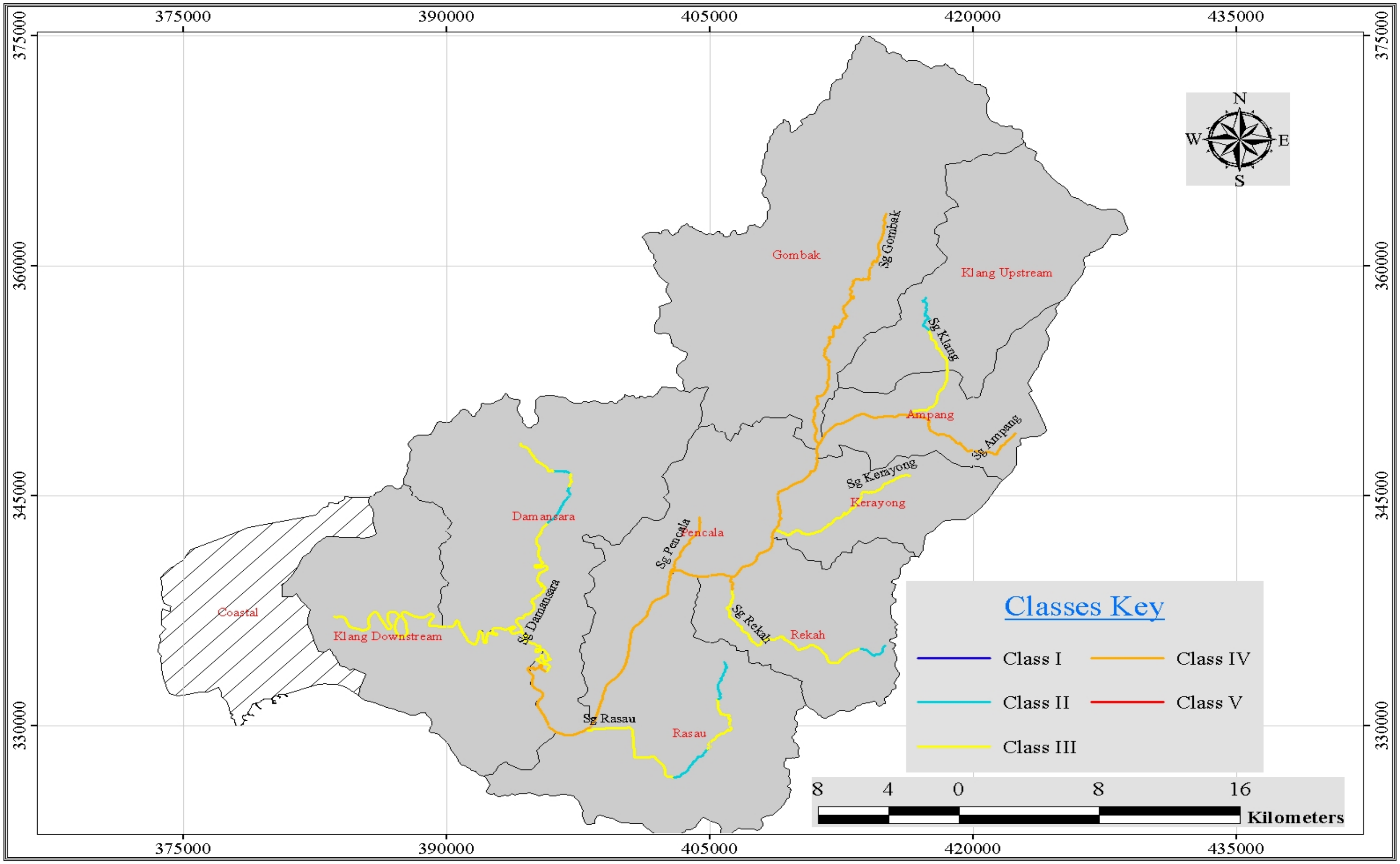


Figure 4.24: The BOD classification along the main stem of the Klang River for the current condition

Table 4.5: Summarry of BOD class for every reach along the Klang River's main stem

Reach Number	BOD value (mg/L)		BOD class	
	Upstream	Downstream	Upstream	Downstream
1 (Headwater)	2.00	5.49	II	III
3	6.71	7.93	IV	IV
5	7.13	7.63	IV	IV
7	6.93	6.87	IV	IV
9	6.89	6.78	IV	IV
11	6.92	6.79	IV	IV
13	6.20	5.86	IV	III
15 (River mouth)	5.45	3.84	III	III

Table 4.6: Summary of all parameters classes for each every along the Klang River's main stem

Reach Number	DO class		BOD class	
	Upstream	Downstream	Upstream	Downstream
1	I	II	II	III
3	II	III	IV	IV
5	II	II	IV	IV
7	III	III	IV	IV
9	III	III	IV	IV
11	III	IV	IV	IV
13	IV	IV	IV	III
15	IV	IV	III	III

Figure 4.25 and 4.26 illustrate the DO and BOD classification respectively due to the simulation of the first scenario comparing with the current condition. Section A in each figure represents the DO and BOD classification respectively due to omit the treatment plants with standard A. Section B in each figure shows the DO and BOD classification respectively due to omit the treatment plants with standard B. While, section C in each figure represents the DO and BOD classification for the current condition (baseline).

The figures signify that the running of scenario I caused an improve of the water quality of the Klang River's main stem in terms of DO and BOD at some points, while the other points remained at the same class as the current condition. Table 4.7 lists the classes of water qualtiy parameters due to the simulation of scenario I in the upstream and downstream regions of every reach along the main stem of the Klang River.

Likewise, Figure 4.27 and 4.28 illustrate the DO and BOD classification respectively due to the simulation of scenario II comparing with the current condition. Section A in each figure represents the DO and BOD classification respectively due to omit the industrial wastewater. Section B in each figure illustrates the DO and BOD classification respectively due to the increase of industrial load by 100%. While, section C in each figure represents the DO and BOD classification for the current condition (baseline).

The figures signify that scenario II did not affect significantly the class of the water along the Klang River's main stem. Table 4.8 lists the classes of water qualtiy parameters due to the simulation of scenario II in the upstream and downstream regions of every reach along the main stem of the Klang River.

Figure 4.29 and 4.30 illustrate the DO and BOD classification respectively due to the simulation of scenario III comparing with the current condition. Section A in each figure represents the DO and BOD classification respectively due to the exclusion of the workshops wastewater. Section B in each figure illustrates the DO and BOD classification respectively due to the increase of workshops load by 100%. While, section C in each figure represents the DO and BOD classification for the current condition (baseline).

The figures signify that scenario III did not affect the class of the water along the Klang River’s main stem. Table 4.9 lists the classes of water qualtiy parameters due to the simulation of scenario III in the upstream and downstream regions of every reach along the main stem of the Klang River.

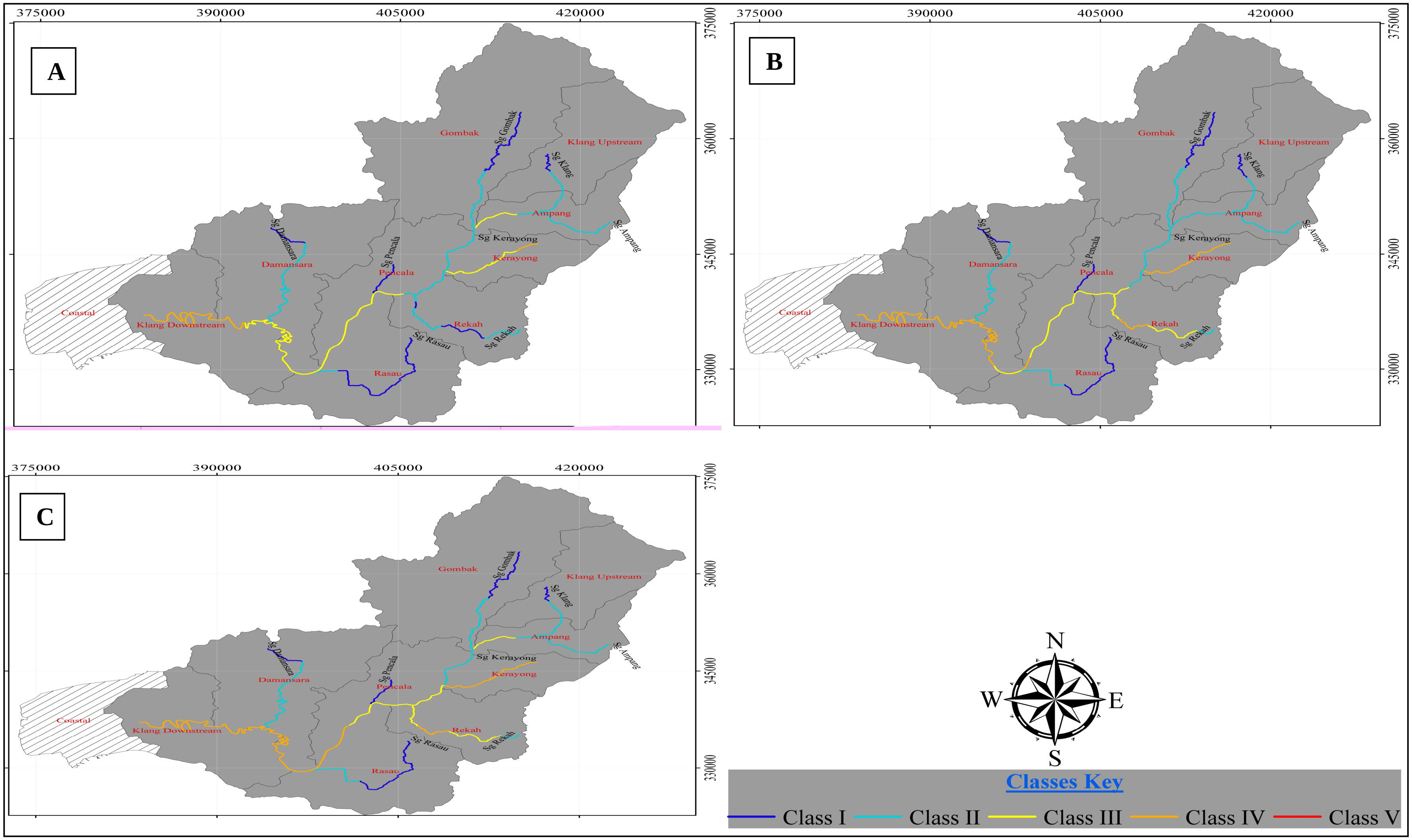


Figure 4.25: Comparison results of scenario I for DO class along the Klang River's main stem

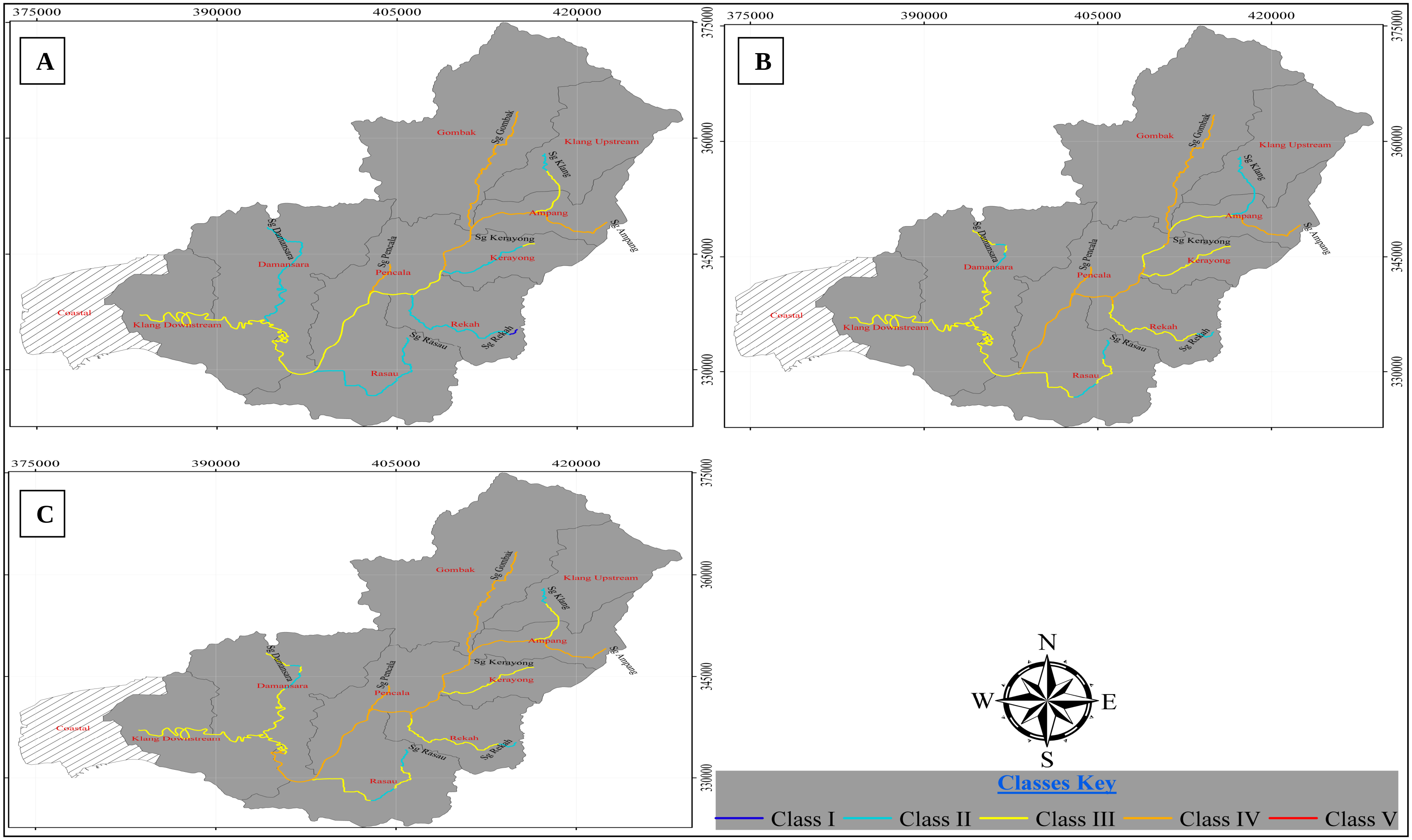


Figure 4.26: Comparison results of scenario I for BOD class along the Klang River's main stem

Table 4.7: Summary of DO and BOD class along the Klang River's main stem due to simulation of scenario I

Parameter	Scenario Type	Up & downstream of each reach along the main river	Water class							
			Reach Number							
			1	3	5	7	9	11	13	15
DO	Current condition (baseline)	U/S	I	II	II	III	III	III	IV	IV
		D/S	II	III	II	III	III	IV	IV	IV
	Scen I (omit Standard A)	U/S	I	II	II	II	II	III	III	III
		D/S	II	III	II	II	III	III	III	IV
	Scen I (omit Standard B)	U/S	I	II	II	II	III	III	III	IV
		D/S	II	II	II	III	III	III	III	IV
BOD	Current condition (baseline)	U/S	II	IV	IV	IV	IV	IV	IV	III
		D/S	III	IV	IV	IV	IV	IV	III	III
	Scen I (omit Standard A)	U/S	II	IV	IV	III	III	III	III	III
		D/S	III	IV	IV	III	III	III	III	III
	Scen I (omit Standard B)	U/S	II	III	IV	IV	IV	IV	III	III
		D/S	II	III	IV	IV	IV	IV	III	III

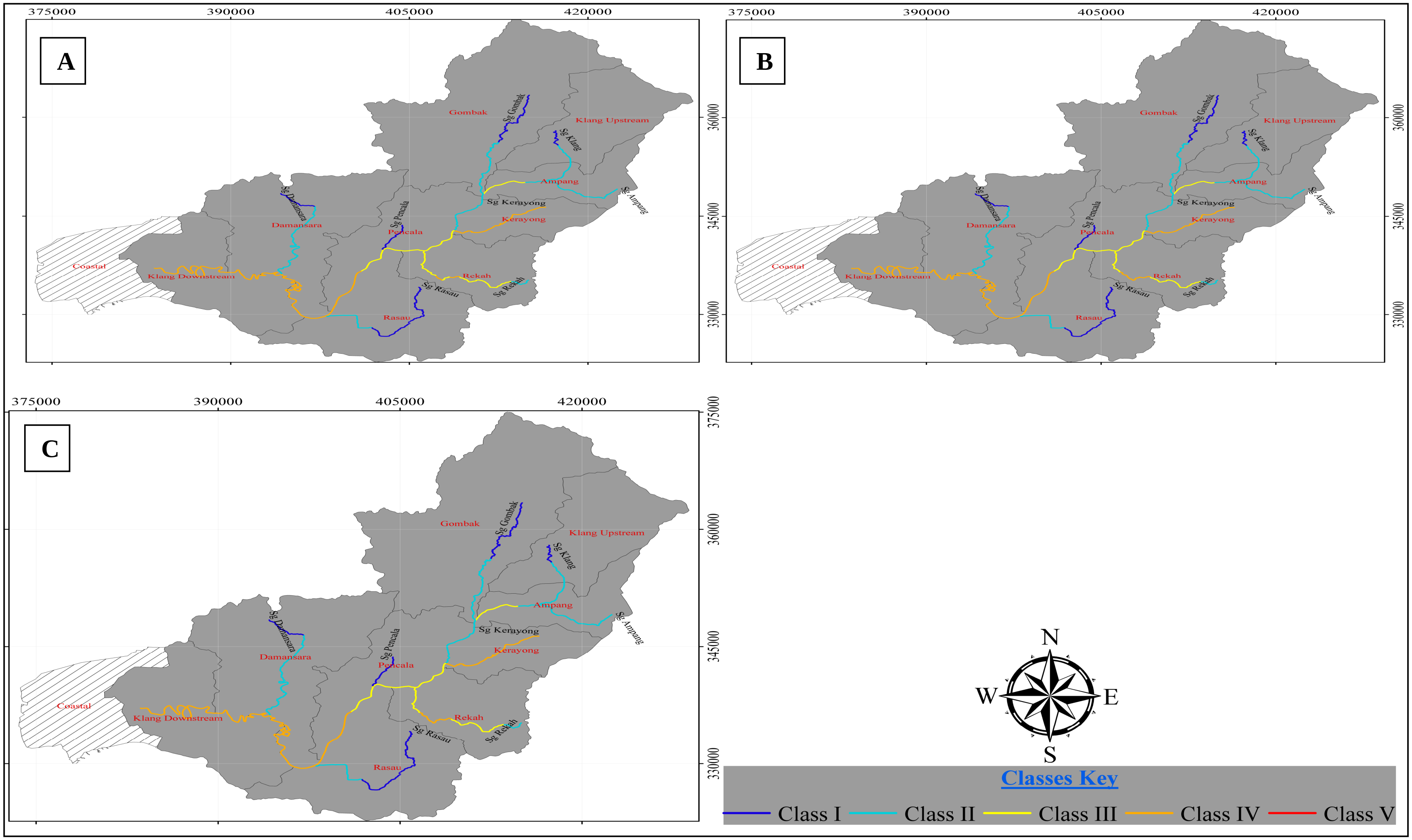


Figure 4.27: Comparison results of scenario II for DO class along the Klang River's main stem

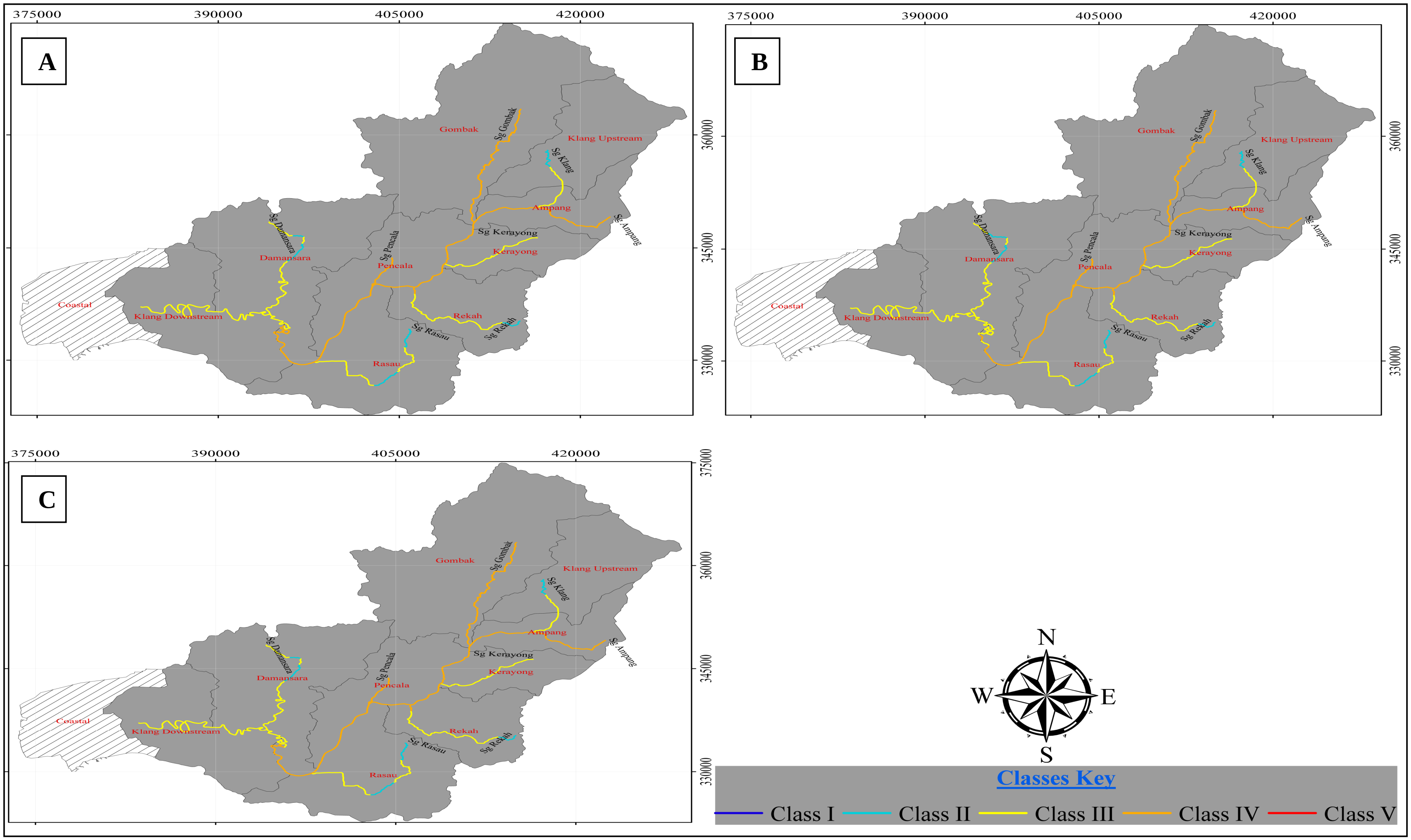


Figure 4.28: Comparison results of scenario II for BOD class along the Klang River's main stem

Table 4.8: Summary of DO and BOD class along the Klang River's main stem due to simulation of scenario II

Parameter	Scenario Type	Up & downstream of each reach along the main river	Water class Reach Number 1	3	5	7	9	11	13	15
DO	Current condition (baseline)	**U/S**	I	II	II	III	III	III	IV	IV
		D/S	II	III	II	III	III	IV	IV	IV
	Scen II (omit Industries)	**U/S**	I	II	II	III	III	III	IV	IV
		D/S	II	III	II	III	III	IV	IV	IV
	Scen II (Increase by 100%)	**U/S**	I	II	II	III	III	III	IV	IV
		D/S	II	III	II	III	III	IV	IV	IV
BOD	Current condition (baseline)	**U/S**	II	IV	IV	IV	IV	IV	IV	III
		D/S	III	IV	IV	IV	IV	IV	III	III
	Scen II (omit Industries)	**U/S**	II	IV	IV	IV	IV	IV	IV	III
		D/S	III	IV	IV	IV	IV	IV	III	III
	Scen II (Increase by 100%)	**U/S**	II	IV	IV	IV	IV	IV	IV	III
		D/S	III	IV	IV	IV	IV	IV	III	III

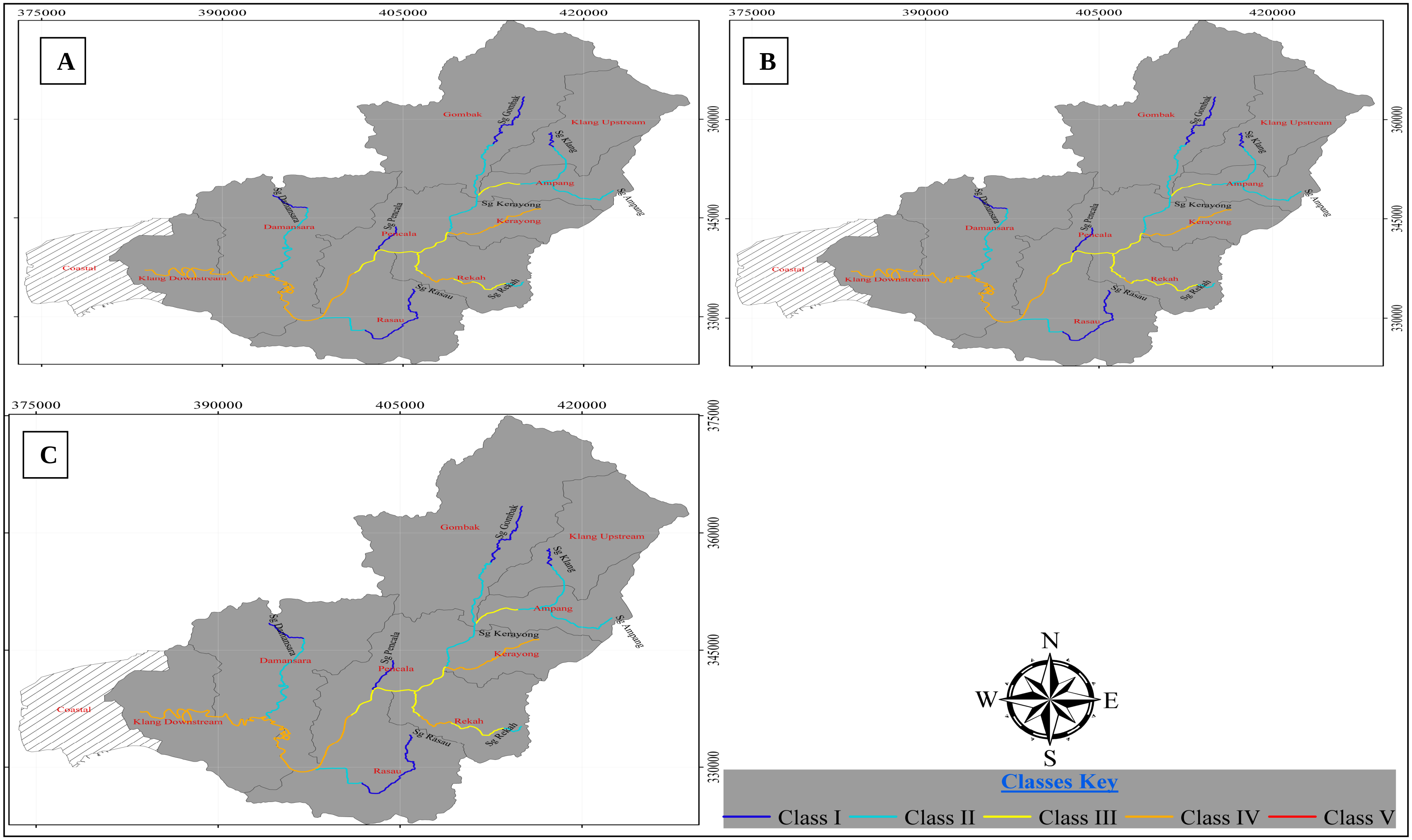


Figure 4.29: Comparison results of scenario III for DO class along the Klang River's main stem

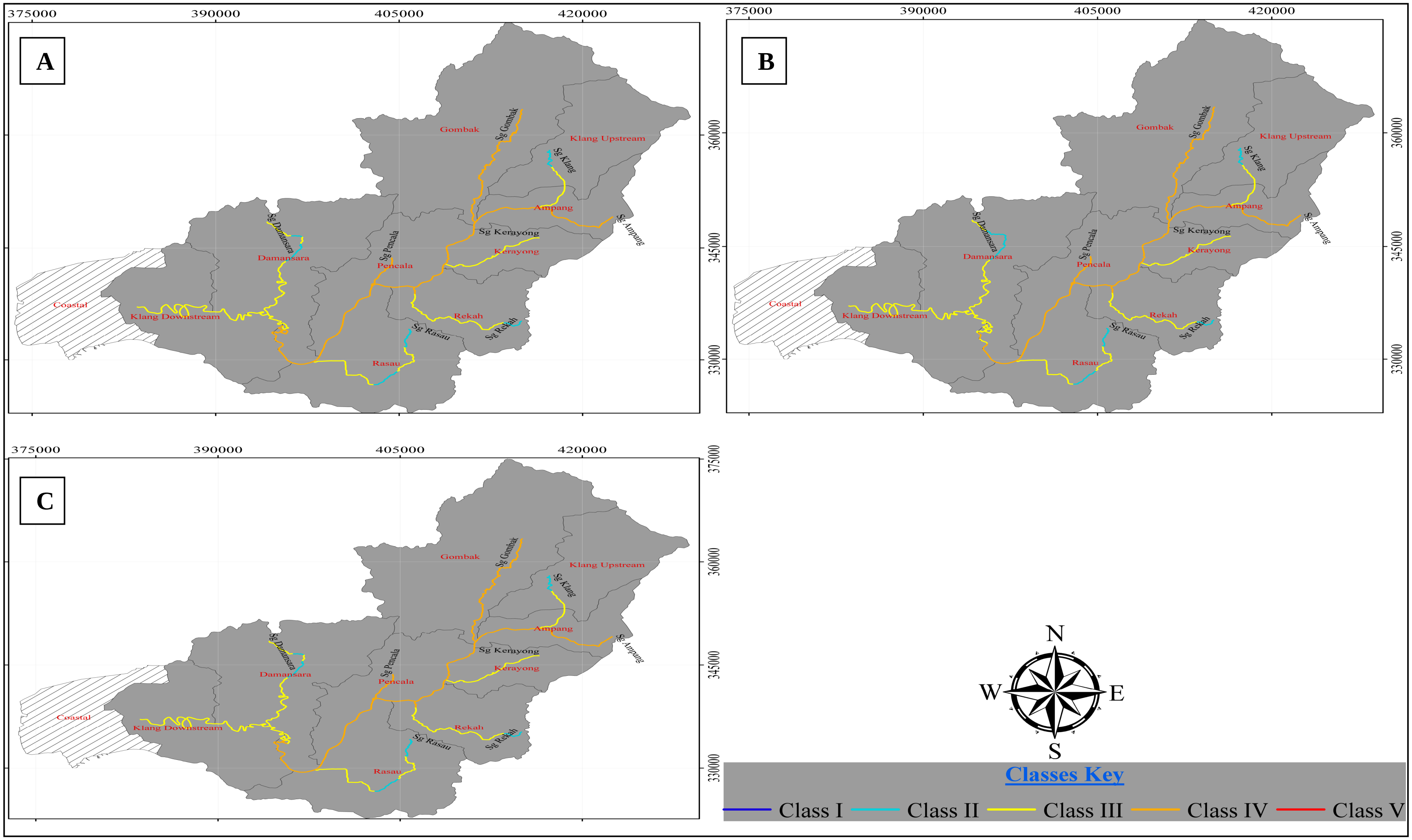


Figure 4.30: Comparison results of scenario III for BOD class along the Klang River’s main stem

Table 4.9: Summary of DO and BOD class along the Klang River's main stem due to simulation of scenario III

Parameter	Scenario Type	Up & downstream of each reach along the main river	Water class Reach Number 1	3	5	7	9	11	13	15
DO	Current condition (baseline)	U/S	I	II	II	III	III	III	IV	IV
		D/S	II	III	II	III	III	IV	IV	IV
	Scen III (omit Workshops)	U/S	I	II	II	III	III	III	IV	IV
		D/S	II	III	II	III	III	IV	IV	IV
	Scen III (Increase by 100%)	U/S	I	II	II	III	III	III	IV	IV
		D/S	II	III	II	III	III	IV	IV	IV
BOD	Current condition (baseline)	U/S	II	IV	IV	IV	IV	IV	IV	III
		D/S	III	IV	IV	IV	IV	IV	III	III
	Scen III (omit Workshops)	U/S	II	IV	IV	IV	IV	IV	IV	III
		D/S	III	IV	IV	IV	IV	IV	III	III
	Scen III (Increase by 100%)	U/S	II	IV	IV	IV	IV	IV	IV	III
		D/S	III	IV	IV	IV	IV	IV	III	III

4.4.1. Discussions of the Transferring the Model Output into GIS Platform

As the third objective as well as one of the main contribution of this study, Qual2K model output has been transformed to the GIS platform. Comparing the maps that shown in Figures 4.23 and 4.24 with the graphical results that shown in Figures 4.6 and 4.8, the output linking with the GIS platform is more detailed and easier to visualize. Furthermore, these maps give a clear indication of the river classes for the whole catchment. Qual2K has been used previously to assess the water quality for many study areas but none of these studies conducted the GIS platform to represent the model output.

4.5. Summary

This chapter represented the output results and the achievement of the current study objectives.

GIS tools were used to modify the spatial data and, thus, to develop the digital spatial map for Klang River Basin. The developed map is more convenient, interactive and efficient than the traditional paper map. It is a physical map that at any time it can easily be edited and modified using the GIS tools. In addition, it is a real-time projected map, where it provides the real location of the features. Furthermore, the developed map connects the spatial data of the features with their tabular databases, which make it easy to analyzing the data for better results that help for decision-making.

Qual2K model was simulated to assess the current status of the Klang River water. The hydraulic parameter, i.e. water discharge, together with the water quality parameters, i.e. DO and BOD, were chosen for model simulation. The model was calibrated using an average data of 2001-2005 and validated using an average data of 2006-2007. The simulation of the current condition indicated that the water quality at upstream of the Klang

River's main stem is initially good, but it gradually deteriorates toward downstream. This is due to the amount of the sources of pollution that may contribute to the river pollution.

Furthermore, three future scenarios were simulated to assess the impact of the point sources on the river water. The first scenario investigated that the Sewerage Treatment Plants (STPs) have an effective role on the water quality of the Klang River's main stem, where the exclusion of the Treatment Plants (standard A and B) caused an improve on the water quality in terms of DO and BOD. The second scenario investigated that the industrial wastewater did not have any effect on the quality of the river. However, the exclusion of the industrial wastewater caused a little increase in both DO and BOD (ranging between 0% to 0.783% for DO, 0% to 1.08% for BOD), while the increasing of the industrial loads by 100% caused a decrease in both DO and BOD (ranging between 0% to 0.76% for DO, 0% to 1.05% for BOD). Likewise, the third scenario investigated that the workshops wastewater did not have any effect on the quality of the river. However, the exclusion of the workshop wastewater caused an increase in both DO and BOD (ranging between 0% to 1.34% for DO, 0% to 1.06% for BOD), while the increasing of the workshop loads by 100% caused a decrease in both DO and BOD (ranging between 0% to 1.29% for DO, 0% to 1.04% for BOD). The simulated scenarios proved that Sewerage Treatment Plants (STPs) are the main point source contributors on the Klang River water.

Finally, the GIS tools were used to link the Qual2K model output to the GIS platform. The output linking with the GIS platform proved that it is more detailed and easier to visualize comparing to the graphical results. Furthermore, these maps give a clear indication of the river classes for the whole catchment.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Introduction

This chapter is divided into two parts. The first section concludes with the current study achievements, while the second part provides some recommendations for future work.

5.2. Conclusions

The aim of this study was to assess the river water quality modeling using GIS and Qual2K model. The Klang River Basin was selected as the study area for this research. The basin is occupied by forests and urban areas and other activities.

5.2.1. The Role of GIS in this Study

GIS techniques and tools were employed through all the stages of this study. They mainly assisted in achieving the first and third objectives, but they were indirectly applied to attaining the second research objective.

5.2.2. The Digital Map of Klang River Basin

As the first objective of this study, the digital map for Klang River basin has been developed. The developed map proved that it is an effective map providing the database including the spatial and non spatial information to achieve the second and the third objectives of the current study. It connects the spatial data of the features with their tabular databases, which make it easy to analyzing the data for better results that help for decision-making. In addition, it proved that it is more powerful, convenient, interactive and efficient than the traditional paper map. This digital map is a physical map that at any time it can easily be edited and modified using the GIS tools, such as the process of adding or removing point sources as well as the process of expanding the river network and the sub-watersheds. Moreover, it is a real-time projected map, where it provides the real location of the features.

5.2.3. Simulation Results of the Water Quality Model

The Qual2K model was employed to simulate and assess the river's quality status. Average water quality data (2001 to 2005) served as observed data during the model calibration process. The model was validated with average data from 2006 and 2007 as observed data. Two water quality parameters (i.e. DO and BOD) were chosen to assess the water status of the Klang River's main stem.

➢ **The current condition (baseline)**

The simulated results for the current condition indicate that DO upstream of the Klang River's main stem varies between classes I and II, while BOD varies between class II and III. The class of DO decreased from mid-stream toward downstream where it recorded a class IV. The BOD was recorded as class IV at mid-stream and improved downstream to class III.

➢ **Water Quality Assessment in terms of DO and BOD through different point source load rates**

Three model scenarios were simulated to assess the impact of the point sources on water quality.

- According to the simulated results for scenario I, excluding Sewerage Treatment

Plants (STP) with standards A and B caused an increase in DO amounts (ranging between 0% and 40.49%), whereas the BOD amounts decreased between by 0% and 49.39%.

- The simulated results for scenario II indicate excluding the industrial wastewater resulted in an increase in DO and BOD amounts (0% to 0.78% for DO, 0% to 1.08% BOD). The results indicate, as well, increasing industrial wastewater by 100% from the normal rate resulted in a decrease in DO and BOD amounts (0% to 0.76% for DO, 0% to 1.05% for BOD).
- The simulation results for scenario III showed that by excluding workshop wastewater DO and BOD amounts increased (0% to 1.34% for DO, 0% to 1.06% for BOD). The results showed, as well, by increasing workshop wastewater by 100% from the normal rate, DO and BOD amounts decreased (0% to 0.97% for DO, 0% to 1.04% BOD).
- The results indicate that the STP is the main contributor to the source of DO and BOD pollution to the river system. Thus, the treatment of this waste is highly recommended before being discharged.

5.2.4. Representing the River Water Quality Model Output into the GIS Platform

After running the water quality model, the GIS tools were utilized to transform and represent the model output into the GIS platform. The output maps show the classes of water quality parameters in terms of DO and BOD along the Klang River catchment as well as they connect the model output with the ambient natural phenomena, which is more powerful for analysis simplicity and enhanced river water management.

5.3. Recommendations

The spatial digital map of the Klang River Basin was developed. It proved that it is more convenient, interactive and efficient than the traditional paper map. Moreover, it helped determining the required spatial data for Qual2K model. However, the layers used to develop this map are for the year 2008 based on the data obtained. Therefore, for future work, an up-to-date data is recommended for developing the map since the natural phenomena changes from time to time.

Qual2K proved that it may be a useful model for simulating and evaluating the quality of the river water. However, only two parameters were examined for a short period (2001-2005) in this study due to the limited data and time, i.e. DO and BOD. Thus, in the future work it is recommended that more parameters have to be tested for long period time for better evaluation of the water quality.

At present, the water quality at mid and downstream of the Klang River's main stem is classified as polluted in terms of DO and BOD comparing with the upstream, meaning that pollution may escalate and become more critical in the future. Several awareness and cleanup campaign programs have been conducted to improve the water quality of the Klang River. However, these programs were failed because they concentrated on beautifying riverbanks rather than cleaning up the rivers. Moreover, the involved people in these programs are government officers and they are not trained as facilitators or campaign workers in the field of mass communication, advertising or education. Therefore, all government agencies and authorities are encouraged to take prompt action toward improving the Klang River water quality through conducting an awareness cleanup campaign programs that involve professional facilitators or campaign workers.

GIS is potentially an effective tool for providing useful information to assist developing water quality models as well as asses and manage river water. Thus, application of GIS is highly recommended for future works involving the river water modeling. The usage and capability of GIS should be explored further.

5.4. Summary

The research achievements were concluded in the first section of this chapter. Thus, the section concluded the role of GIS in this study as well as the importance of the developed digital spatial map, in order to the output results of Qual2K model and the results of linking model output to the GIS platform.

Recommendations for future studies were given in the second part of this chapter. An up-to-date data is recommended for developing the map since the natural phenomena changes from time to time. In addition, more parameters have to be tested for long period time for better evaluation of the water quality. Moreover, all government agencies and authorities are encouraged to take prompt action toward improving the Klang River water quality through conducting an awareness cleanup campaign programs that involve professional facilitators or campaign workers. Finally, application of GIS is highly recommended for future works involving the river water modeling.

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Appendices

Appendix A:

Table A.1: Roughness coefficient values for each channel surface material

MATERIAL	***n***
Man-made channels	
Concrete	0.012
Gravel bottom with sides:	
Concrete	0.020
mortared stone	0.023
Riprap	0.033
Natural stream channels	
Clean, straight	0.025-0.04
Clean, winding and some weeds	0.03-0.05
Weeds and pools, winding	0.05
Mountain streams with boulders	0.04-0.10
Heavy brush, timber	0.05-0.20

Source: (V.T. Chow, Maidment, & Mays, 1988)

Appendix B:

Table B.1: Land use distributions along the sub-watersheds in square kilometers and percentages

Land use type		Upstream	Ampang	Gombak	Kerayong	Rekah	Pencala	Rasau	Damansara	Downstream
Water body	Area (Km^2)	2.56	0.22	8.17	0.39	3.96	2.17	23.85	2.87	0.05
	Percentage (%)	5.79	0.50	18.47	0.88	8.95	4.91	53.91	6.49	0.11
Forest & Shrubs	Area (Km^2)	83.5	24.35	132.23	3.14	6.06	1.66	50.05	25.72	12.06
	Percentage (%)	24.65	7.19	39.03	0.93	1.79	0.49	14.77	7.59	3.56
Urban Land Use	Area (Km^2)	23.27	42.43	90.96	55.78	49.09	81.53	17.54	92.68	51.95
	Percentage (%)	4.61	8.40	18.00	11.04	9.72	16.14	3.47	18.34	10.28
Agricultural & Animal Farming	Area (Km^2)	11.74	1.54	34.84	0.81	23.53	8.43	50.34	49.46	61.42
	Percentage (%)	4.85	0.64	14.39	0.33	9.72	3.48	20.79	20.43	25.37
Open Land and Recreation	Area (Km^2)	1.11	1.88	3.77	0.96	9.85	4.22	13.07	25.4	9.27
	Percentage (%)	1.60	2.70	5.42	1.38	14.17	6.07	18.80	36.53	13.33
Others	Area (Km^2)	0.23	0	0.04	0.09	0.34	0.37	1.02	0.65	3.41
	Percentage (%)	3.74	0.00	0.65	1.46	5.53	6.02	16.59	10.57	55.45

Appendix C:

Table C.1: The final value for the water quality rates

Parameter	***Value***	***Units***	***Symbol***
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	1	gA	gA
Inorganic suspended solids:			
Settling velocity	0.1	m/d	v_i
Oxygen:			
Reaeration model	User specified		
User reaeration coefficient α	2		α
User reaeration coefficient β	0.25		β
User reaeration coefficient γ	0.7		γ
Temp correction	1.024		q_a
Reaeration wind effect	None		
O2 for carbon oxidation	2.69	gO_2/gC	r_{oc}
O2 for NH4 nitrification	4.57	gO_2/gN	r_{on}
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.60	L/mgO2	K_{socf}
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.60	L/mgO2	K_{sona}
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.60	L/mgO2	K_{sodn}
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.60	L/mgO2	K_{sop}
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.60	L/mgO2	K_{sob}
Slow CBOD:			
Hydrolysis rate	0.6	/d	k_{hc}
Temp correction	1.07		q_{hc}
Oxidation rate	0	/d	k_{dcs}
Temp correction	1.047		q_{dcs}
Fast CBOD:			
Oxidation rate	0.9	/d	k_{dc}
Temp correction	1.047		q_{dc}

Table C.1, continued

Parameter	***Value***	***Units***	***Symbol***
Organic N:			
Hydrolysis	0.2	/d	k_{hn}
Temp correction	1.07		q_{hn}
Settling velocity	0.1	m/d	v_{on}
Ammonium:			
Nitrification	2	/d	k_{na}
Temp correction	1.07		q_{na}
Nitrate:			
Denitrification	0	/d	k_{dn}
Temp correction	1.07		q_{dn}
Sed denitrification transfer coeff	0	m/d	v_{di}
Temp correction	1.07		q_{di}
Organic P:			
Hydrolysis	0.2	/d	k_{hp}
Temp correction	1.07		q_{hp}
Settling velocity	0.1	m/d	v_{op}
Inorganic P:			
Settling velocity	2	m/d	v_{ip}
Inorganic P sorption coefficient	0	L/mgD	K_{dpi}
Sed P oxygen attenuation half sat constant	0.05	mgO_2/L	k_{spi}
Phytoplankton:			
Max Growth rate	2.5	/d	k_{gp}
Temp correction	1.07		q_{gp}
Respiration rate	0.2	/d	k_{rp}
Temp correction	1.07		q_{rp}
Death rate	0.2	/d	k_{dp}
Temp correction	1.07		q_{dp}
Nitrogen half sat constant	25	ugN/L	k_{sPp}
Phosphorus half sat constant	5	ugP/L	k_{sNp}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCp}
Light model	Half saturation		
Light constant	100	langleys/d	K_{Lp}
Ammonia preference	25	ugN/L	k_{hnxp}
Settling velocity	0.5	m/d	v_a

Table C.1, continued

Parameter	***Value***	***Units***	***Symbol***
Bottom Algae:			
Growth model	Zero-order		
Max Growth rate	50	$mgA/m^2/d$ or /d	C_{gb}
Temp correction	1.07		q_{gb}
First-order model carrying capacity	1000	mgA/m^2	$a_{b,max}$
Respiration rate	0.1	/d	k_{rb}
Temp correction	1.07		q_{rb}
Excretion rate	0.05	/d	k_{eb}
Temp correction	1.07		q_{db}
Death rate	0.1	/d	k_{db}
Temp correction	1.07		q_{db}
External nitrogen half sat constant	300	ugN/L	k_{sPb}
External phosphorus half sat constant	100	ugP/L	k_{sNb}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCb}
Light model	Half saturation		
Light constant	100	langleys/d	K_{Lb}
Ammonia preference	25	ugN/L	k_{hnxb}
Subsistence quota for nitrogen	0.72	mgN/mgA	q_{0N}
Subsistence quota for phosphorus	0.1	mgP/mgA	q_{0P}
Maximum uptake rate for nitrogen	72	mgN/mgA/d	r_{mN}
Maximum uptake rate for phosphorus	5	mgP/mgA/d	r_{mP}
Internal nitrogen half sat constant	0.9	mgN/mgA	K_{qN}
Internal phosphorus half sat constant	0.13	mgP/mgA	K_{qP}
Detritus (POM):			
Dissolution rate	0.5	/d	k_{dt}
Temp correction	1.07		q_{dt}
Fraction of dissolution to fast CBOD	1.00		F_f
Settling velocity	0.1	m/d	v_{dt}
Pathogens:			
Decay rate	0.8	/d	k_{dx}
Temp correction	1.07		q_{dx}
Settling velocity	1	m/d	v_x
Light efficiency factor	1.00		a_{path}
pH:			
Partial pressure of carbon dioxide	347	ppm	p_{CO2}

Appendix D: List of publications

❖ **Journals:**

1- Othman, Faridah, **Alaa-Eldin, M. E.**, & Mohamed, Ibrahim. (2012). Trend analysis of a tropical urban river water quality in Malaysia. ***Journal of Environmental Monitoring***, *14*(12), 3164-3173. doi: 10.1039/C2EM30676J. **ISI cited**

2- Othman, Faridah, & **M.E, Alaa Eldin**. (2012). Assessment of the Klang river quality using the water quality indices. ***Advanced Materials Research***, *599*, 237-240. doi: 10.4028/www.scientific.net/AMR.599.237. **SCOPUS CITED**

3- Othman, Faridah, **M.E, Alaa Eldin**, & Nor, M.K. Mohd. (2011). Assesment of a tropical urban river using GIS-based modeling. ***Advanced Materials Research***, *250 - 253*, 2949-2952. doi: 10.4028/www.scientific.net/AMR.250-253.2949. **SCOPUS CITED**

❖ **Conferences:**

1. Othman, Faridah, **Alaa Eldin, M. E.**, & Mohamed, Ibrahim. (2012). Assessing the Klang River WQI Trend using Statistical Approach. Paper presented at the The 1st ISM International Statistical Conference (**ISM-1 2012**), **Persada Johor, Johor Bahru, Malaysia**.
2. Othman, Faridah, Elamin, **Alaa Eldin Mohamed**, & Nor, Mustaffa Kamal Mohd. (2010). Application of GIS-based modeling for river system network. Paper presented at the International Conference on Science & Technology **ICSTIE2010**: Applications in Industry & Education, **Pulau Pinang, Malaysia**.

3. Othman, Faridah, & **M.E, Alaa Eldin**. (2009). Digital Elevation Model for Klang River Basin. Paper presented at the International Conference for Technical Postgraduates **TECHPOS2009**, **Kuala Lumpur, Malaysia**.
4. Othman, Faridah, **M.E, Alaa Eldin**, & Nor, M.K. Mohd. (2011). Assesment of a tropical urban river using GIS-based modeling. Paper presented at the International Conference on Civil Engineering, Architecture and Building Materials (**CEABM 2011**), **Haikou, China**.

❖ **Workshops**

1. **UiTM**. (2009, 4-6 May). ***2 1/2 Days Hands on Workshop on: River Water Quality Modeling***, Organised by: Water Resources Technical Division, Faculty of Chemical Engineering, Universiti Teknologi Mara (UiTM), Shah Alam, Selangor, Malaysia.