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ASSESSMENT OF INDUSTRIAL POLLUTION AND WATER QUALITY INDEX OF TUNGGAK RIVER AT GEBENG PAHANG, MALAYSIA

MOHAMMED AMJED HOSSAIN

Thesis submitted in fulfilment of the requirements
For the award of the degree of
Doctor of Philosophy (Environmental Management)

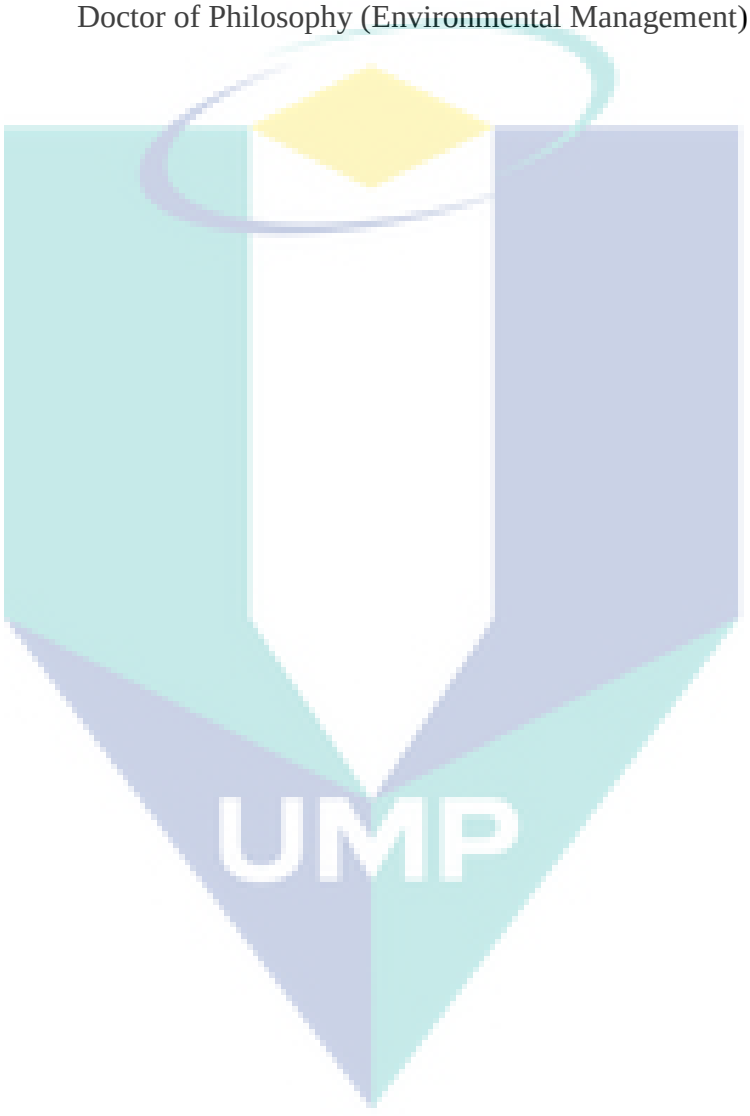
Faculty of Civil Engineering and Earth Resources
UNIVERITI MALAYSIA PAHANG

September 2014

STATEMENT OF AWARD FOR DEGREE

Thesis submitted in fulfilment of the requirements for the award of the degree of

Doctor of Philosophy (Environmental Management)



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I hereby declare that the work in this thesis is my own except for quotations and summaries, which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Dedicated to my Parents and my Family

ACKNOWLEDGMENTS

Syukur Alhamdulillah, all praise upon Allah s.w.t. the Almighty and Merciful, for His will this dissertation be successfully completed. I would like to express my deep gratitude to Datin, Dr. Nasly Binti Mohamed Ali, Professor, Faculty of Civil Engineering and Earth Resources, UMP as my honourable supervisor, for her indispensable guidance, invaluable advice and suggestions, consistent help right from the start and final stage of my research and spending long hours reading the manuscript and making critical comments. All her motivation encouragement and patient during the entire research are greatly appreciated. I would like to extend my gratitude to Dr. Mir Sujaul Islam, Senior lecturer, Faculty of Civil Engineering and Earth Resources, UMP as my co-supervisor for his advice and suggestions, motivation and continuous help in laboratory analysis and in all part of the research. Thank him for providing me with the financial support to the research from his project RDU 110354: Development of impact assessment model for industrial pollution in Gebeng area, Kuantan, Malaysia; without which it would not have been possible to conduct this research.

Special thanks to Professor Emeritus Dato Dr Abu Azam Md Yassin for his presence and valuable comments in my colloquium. Thank must goes to Kamariah Binti Mat Peah and Norazimah Binti Abdul Aziz, penolong pegawal latihan vokasional, Makmal Alam Sekitar, FKASA for their cooperation and help during sampling and laboratory work. Heartiest thanks to Md Najmul Kabir Chaudhury and Urmi Binti Salam for their help and support from the beginning to end of my research. Thanks to my dear Vabi Mrs Zulkha Islam for her guidance as my elder sister and local guardian. Thanks to Faisal Nadeem Saher my nearest friend for his outstanding cooperation. I would like to thank to all of my community, my foreign friends and my neighbours who helped me, support me, guided me with their good thinking, suggestions, and advises. During the study, I lost my mother-in-law. I would like to pray to Allah to keep her in Zannah who prayed for me to complete the degree successfully.

During the study, my family totally missed me due to my absence. I would like to express my gratitude and obeisance to my mother for her great sacrifice during the days. My heartiest thanks and endearment goes to my wife Mrs Kamrun Nahar, who managed everything of my family in my absence. My affections and caress to my two sons Mahmud Al Hossain and Mahdi Al Hossain, and my dearest daughter Noor Areeba Hossain, who missed me for a long time and sacrificed their lots of dearest moments.

Thanks and gratitude goes to the IPS UMP for sanctioning Doctoral Scholarship Scheme (DSS) in favour of me; without which my study could not be precede. Finally, I would like to express my gratitude to the honourable Secretary of Ministry of Public Administration, Bangladesh for his permission to obtain the degree in abroad.

ABSTRACT

Gebeng is an industrial estate that contained multifarious industries, which generate industrial effluents and consequently pollute the adjacent river water as well as surface water quality of the area. With the objectives to assess the water quality of the area with spatial and temporal variations, to classify the water based on water quality index, to assess the heavy metal contamination of soil due to the industrial pollution and to perform a water quality model to simulate the water quality parameters of Tunggak River, this study has been conducted. To fulfil the objectives, water and soil samples were collected and analysed. Water samples were collected for a period of one year from February 2012 to January 2013 from ten preselected sampling stations, and soil samples were collected from thirty sampling points according to the standard method of sample collection. Twenty-four water quality parameters including ten heavy metals and heavy metals in soil samples were analysed. The water quality model was calibrated and validated with the collected data. All testing and analyses were done in accordance with the standard method procedures. Data analysis was conducted using SPSS 16.0 statistical software. The results of water quality analyses showed that the concentrations of DO observed were very low (less than 4.0 mg/L) over the whole area, accordingly BOD (6.8 – 27.1 mg/L) and COD (14.0- 59.6 mg/L) were observed very high. Ammoniacal nitrogen and phosphorus were also recorded in higher concentrations. Compared to all areas the water qualities at the industrial zone were more deteriorated. According to the INWQS Malaysia recommended threshold levels, fifteen parameters were found to be beyond this level. The results from the calculation of the DOE-WQI revealed that the water of the Tunggak River was under class III and class IV and the swampy area was class III. According to the INWQS Malaysia, class IV water cannot be used for any purpose except irrigation. Soil heavy metal contamination investigation showed that five heavy metals were found contaminating the area that led to soil pollution. Soils of the industrial zone were polluted with arsenic, mercury, lead, cobalt and zinc. Arsenic and mercury contamination was observed all over the study area. Source apportionment study revealed that the major sources of pollution in both cases of water and soil were due to anthropogenic activities. The sources of physicochemical parameters were primarily of the industrial effluents associated with domestic wastewater, and agricultural and urban runoffs. Some parameters with heavy metals contamination were due to natural sources. The water quality model calibration and validation result showed that the model has represented the field data quite well. RMSE showed good match between the observed and simulated data. The model suggested that the lower concentration of DO could not be revived without taking proper management, including water quality control strategy. Several water quality control strategies were tested with the model to propose the best one for use to revive the water quality of the Tunggak River. It is proposed that the pollution load modification with 20.0 mg/L BOD + flow augmentation and imposing three weirs in critical locations- strategy would be able to control the minimum level of DO and maximum level of nitrogen and phosphorus of the Tunggak River. At the same time, it also recommended that the industries should be compelled to adhere strictly the Environmental Quality (Industrial Effluent) Regulations 2009, Malaysia before discharging BOD more than 20.0 mg/L and 6.0 kg/day into the Tunggak River.

ABSTRAK

Gebeng adalah estet perindustrian yang terdiri daripada pelbagai jenis industri, yang menjana bahan buangan industri dan seterusnya mencemarkan air sungai yang berdekatan dan juga kualiti permukaan air di kawasan ini. Kajian ini telah dijalankan dengan objektif untuk menilai kualiti air kawasan tersebut secara spatial dan temporal, mengklasifikasikan air berdasarkan Indeks Kualiti Air, menilai pencemaran logam berat terhadap tanah akibat pencemaran perindustrian dan untuk melaksanakan model kualiti air untuk mensimulasikan parameter kualiti air Sungai Tunggak. Untuk memenuhi objektif , sampel air dan tanah telah dikumpulkan dan dianalisis. Sampel air telah diambil untuk tempoh satu tahun dari Februari 2012 hingga Januari 2013 daripada sepuluh stesen persampelan yang diprapilih , dan sampel tanah telah diambil dari tiga puluh titik persampelan mengikut kaedah perkumpulan sampel yang berpiawai. Sebanyak dua puluh empat parameter kualiti air termasuk sepuluh logam berat dan logam berat dalam sampel tanah telah dianalisis. Model kualiti air telah ditentukur dan disahkan dengan data yang dikumpul . Semua ujian dan analisis telah dilakukan mengikut prosedur kaedah berpiawai. Analisis data dijalankan dengan menggunakan perisian statistik SPSS 16.0. Keputusan analisis air yang berkualiti menunjukkan bahawa kepekatan DO diperhatikan sangat rendah (kurang daripada 4.0 mg / L) di seluruh kawasan tersebut, seterusnya nilai BOD (6.8-27.1 mg / L) dan COD (14.0-59.6 mg / L) diperhatikan sangat tinggi. Nitrogen ammoniacal dan fosforus juga dicatatkan berkepekatan lebih tinggi. Berbanding dengan semua kawasan, kualiti air di zon perindustrian adalah yang paling merosot. Menurut INWQS piawaian Interim Kualiti Air Kebangsaan, lima belas parameter didapati melebihi peringkat kepiawaian tersebut. Hasil daripada pengiraan DOE- WQI mendedahkan bahawa air Sungai Tunggak adalah di bawah kelas III dan kelas IV dan kawasan paya ialah kelas III. Menurut INWQS Malaysia, air kelas IV tidak boleh digunakan untuk sebarang tujuan kecuali pengairan. Penyiasatan tanah pencemaran logam berat menunjukkan bahawa lima logam berat didapati mencemarkan kawasan yang membawa kepada pencemaran tanah. Tanah zon perindustrian telah tercemar dengan arsenik , merkuri, plumbum , kobalt dan zink. Pencemaran arsenik dan merkuri dikenalpasti di seluruh kawasan kajian. Kajian sumber pembahagian mendedahkan bahawa sumber utama pencemaran di kedua-dua kes air dan tanah adalah disebabkan oleh aktiviti antropogenik. Sumber-sumber parameter fizikokimia adalah terutamanya daripada bahan buangan industri yang berkaitan dengan air sisa domestik, dan air larian pertanian dan bandar. Beberapa parameter pencemaran logam berat adalah disebabkan oleh sumber semula jadi. Model penentukuran kualiti air dan pengesahan hasil menunjukkan bahawa model telah mewakili data lapangan dengan baik. RMSE menunjukkan perlawanan yang baik antara data yang diperhatikan dan simulasi. Model ini mencadangkan bahawa kepekatan yang lebih rendah daripada DO tidak boleh dipulihkan semula tanpa pengurusan yang betul, termasuk strategi kawalan kualiti air. Beberapa strategi kawalan kualiti air telah diuji dengan model untuk mencadangkan teknik yang terbaik untuk digunakan bagi memulihkan kualiti air Sungai Tunggak . Adalah dicadangkan bahawa pengubahsuaian beban pencemaran dengan 20.0 mg / L BOD + pembesaran aliran dan mengenakan tiga empang dasar dalam kritikal lokasi strategi akan dapat mengawal tahap minimum DO dan tahap maksimum nitrogen dan fosforus di Sungai Tunggak . Pada masa yang sama, ia juga dicadangkan bahawa industri perlu mematuhi sepenuhnya Peraturan-Peraturan Kualiti Alam Sekeliling (Efluen Perindustrian) 2009, Malaysia sebelum dilepaskan BOD melebihi 20.0 mg / L dan 6.0 kg / hari ke dalam Sungai Tunggak.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
APHA	American Public Health Association
As	Arsenic
BCWQI	British Columbia Water Quality Index
CBOD	Carbonaceous Biochemical Oxygen Demand
CCMEWQI	Canadian Council of Ministers of the Environment Water Quality Index
DID	Department of Irrigation and Drainage
DOE	Department of Environment
EIA	Environmental Impact Assessment
FAO	Food and Agricultural Organization
GA	Genetic Algorithm
GEMS	Global Environment Monitoring System
GIE	Gebeng Industrial Estate
GPS	Global Positioning System
Hg	Mercury
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
INQWS	Inland National Water Quality Standards
MARDI	Malaysian Agricultural Research and Development Institute
NH3-N	Ammoniacal Nitrogen
NIC	Newly Industrialized Country
NO3-N	Nitrate nitrogen
NSFWQI	National Sanitation Foundation Water Quality Index
OWQI	Oregon Water Quality Index

Pb	Lead
ppb	parts per billion
ppm	parts per million
RMSE	Root-mean square error
TDS	Total Dissolved solids
TSS	Total Suspended solids
UNEP	United Nations Environment Programme
USEPA	United State Environment Protection Agency
WEPA	Water Environment Partnership in Asia
WHO	World Health Organization
WQCindex	Chemical Water Qaulity Index
WQI	Water Quality Index

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Water is the most delicate part of the environment, which is essential for all living beings, and a crucial portion of any industrial, agricultural, or other development. It is expected to be the main issue in the 21st century as this vital resource becomes increasingly polluted and scarce. In the worse scenario, countries are expected to go to war over water (Burke et al., 2009; Watkins and Berntell, 2006). Among all water sources, surface water is the major source that represents 97 percent of the total available water (FAO, 2012). The demand is due to the population growth, urbanization and rapid development in commercial and industrial sectors. In the last few decades the demand of fresh water rises tremendously due to increasing population and rapid industrialization (Yisa and Jimoh, 2010). At the same time the pace of fresh water deterioration by anthropogenic activities is coupled with the ever-growing demands on water resources (Charkhabi and Sakizadeh, 2006). Because of its indispensability, surface water pollution is a major concern all over the world. Several natural and anthropogenic factors govern the surface water chemistry or total hydrochemistry (Ahearn et al., 2005; Bahar et al., 2008) which come from two types of sources namely, point and non-point sources of pollution. Point sources include sewage treatment plants, Agro-based, manufacturing and other industries and animal farms whereas, the non-point sources are the diffused sources such as agricultural activities and surface runoff (Li et al. 2009; Ling, 2010). Untreated wastes from old houses, old hotels, small towns and farms (both animals and crops) are also threatening to further pollute our waters. Rivers which are the main reservoir of surface water, serves as the recipients of excessive amount of wastes generated and discharged from anthropogenic activities all over the world (Milovanovic, 2007). Due to the addition of effluents from industries,

municipalities, agricultural farms and homesteads containing heavy metals, organic and inorganic pollutant into the river, the quality of water deteriorates terribly. The natural and anthropogenic metal contamination in aquatic ecosystem leads to the need of characterising their impact on the environment (Tercier-Waeber and Taillefert, 2008).

Malaysia is blessed with a bounty of natural water resources that contributes significantly to the socioeconomic development of the country (Moorthy and Jeyabalan, 2012). Though the country seems to have no shortage of water, it had faced two big water crises in 1991 at Melaka and in 1998 at Kuala Lumpur and Selangor (Hashim et al., 2010). However, the situation is not constant; it is shifting every day due to uncontrolled loggings and deforestations that result in the reduction of water catchment and increasing pollution. It is further worsened by the rapid industrialisation, urbanisation and population growth (Hashim et al. 2010; Hossain et al. 2012). River catchments, the major source of the water are polluted continuously due to anthropogenic activities especially industrial effluents. Department of Environment in their Environmental Quality Report showed that in 2009, 46% of rivers were polluted and in 2010 recorded 50%, a value higher than the previous couple of years (DOE, 2009; DOE, 2010).

Malaysia is fast becoming an industrial country and a proud member of Newly Industrialized Country (NIC) of the world (Norzatulakma, 2010). It has a number of industrial estates all over the country, including the Gebeng Industrial Estate (GIE), one of the main industrial areas in Kuantan, Pahang. GIE is located near Kuantan Port. The major industries of the area include petrochemical, chemical, food, manufacturing and other multifarious industries. Due to the discharge of industrial effluents and wastewater generated by those industries, the water resources of the area are being polluted. Untreated or partially treated wastewater of the industries containing high concentrations of conventional and non-conventional pollutants are merging with the river water thus deteriorating the water body. Two rivers Tunggak and Balok are carrying the wastes from GIE, of which Tunggak flows through the middle and eastern catchment covering maximum part of the GIE (Hossain et al., 2012; Nasly et al., 2013; Sujaul et al., 2013). The water environment of the area is becoming more vulnerable due to the new establishment of some mining and rare earth plants (Bell, 2012). In spite

of its importance, the water qualities of Gebeng area including Tunggak River have never been studied and no report of environmental degradation is available except for a few environmental impact assessments (EIA) conducted by several industrial companies. Therefore, for better management, water quality assessment including water quality modelling would be the most important tool to the water agencies, stakeholders and policy makers.

1.2 PROBLEM STATEMENT

Water quality deterioration is one of the major concerns of the world. Rapid industrial and commercial developments are causing tremendous pressure on the water resources. According to records of DOE in 2008, 17,633 water pollution point sources in Malaysia comprised of 54.01% from sewage treatment plants (inclusive of 668 Network Pump Stations), 38.73% from manufacturing industries, 4.48% from animal farms and 2.78% from agro-based industries (DOE, 2009). This data showed that almost all of the point sources are due to the development of industry. Speedy developments in the industrial sector at Gebeng threaten the water quality of its two rivers and deteriorating the environmental conditions of the areas. The random discharge of wastewater and effluents from industries, sewerage treatment plants along the river catchments are impairing the water quality (Sujaul et al., 2013).

The Gebeng area is situated in the neck of the South China Sea, and the adjacent two river flows fall to the sea. The typical tides of the sea cause intrusion of seawater into these two rivers and the water levels usually rise from 0.5 m to 2.5 m and it is likely to be tidal up to 10 km upstream (Sujaul et al. 2013: CAP-SAM 2011). As a result the industrial effluents that are dumped from the industrial estate can go upward and cause environmental pollution all over the area. Environmental degradation has started here since the inception of the industrialisation in early 1970's; when the deforestation and reclaiming was started using fill, quarried from the nearby hilly areas (CAP-SAM, 2011). Due to deforestation and reclamation, the soil of the area has also been contaminated. The process of contamination has been accelerated with the discharge of industrial effluents. Moreover, contamination of soil is a common problem in the surrounding area of any industrial estate like Gebeng (Krishna and Govil, 2007;

Shukurov et al., 2006). The water pollution and contaminated soil can hamper the regular livelihood of the residential area. By using the polluted water may create variuous water born disease and other disasters. Therefore, it is essential to asses the water quality, find out the sources of pollution and the water quality trend that can generate important information for the authority concerned or policy makers to take proper action for better management.

1.3 SIGNIFICANCE OF THE STUDY

Rapid development in industrial sector in Malaysia has caused serious environmental problems including water pollution in the country. The Gebeng industrial area is one of the largest industrial estates in Malaysia. Wastewater from this estate is usually pumped out into two rivers, namely Sungai Tunggak and Sungai Balok. Water quality is seriously deteriorated here. Despite the declining process, any in-depth study on industrial pollution at Gebeng as well as in east-coast of peninsular Malaysia was never been done; neither the study of water quality nor on the soil contamination. Prior to this study, a very limited effort and information have been produced regarding treatment of the wastewater of the area. At present the department of environment (DOE) is monitoring the Tunggak river water in the downstream region (DOE, 2009). Those efforts have produced some information but could not indicate the real scenario.

This study gives emphasis on the present status of industrial pollution especially the river water quality of Sungai Tunggak and contamination of the soil of the catchment area using several methods of water quality assessment. On the basis of the result of the research work river water of Sungai Tunggak is classified according to Interim National Water Quality Standard (INWQS), Malaysia (DOE, 2008). It also proposed a modified water quality index for the calculation of water quality index and classification of Tunggak River water. The water quality model used in this research suggested one strategy to control the water quality of Tunggak River. The findings of the study will help to adopt adequate measures by the policy makers as well as the environmentalists to prevent further deterioration of the water quality and improve the land use pattern in the Gebeng Industrial Areas. The result of this study can be used as

baseline information on river water quality of Sungai Tunggak and can also be used as reference for further research.

The major contribution of the research is to propose the strategy to control and revive the water quality of the Tunggak river by performing QUAL2Kw water quality model and propose a new approach of determining the water quality index by adopting an existing water quality index through combining the DOE-WQI and Canadian Council of Ministers water quality index (CCMEWQI) after comparing the advantages and limitations of several water quality indices of the world.

1.4 OBJECTIVES OF THE STUDY

The critical situation of the environment in the study area demands a detailed and inclusive study that can provide conclusive information about the environment, water resources and soil contamination in Gebeng. Apprehending the problems, the following objectives are fixed out:

I. To evaluate the spatial and temporal variation of surface water quality in Gebeng industrial areas
II. To classify the river water by assessing the Department of Environment-Water Quality Index (DOE-WQI) and adopt an existing water quality index for Tunggak river by comparing several water quality indices of the world
III. To determine the contamination level of heavy metals in soils in and around the industrial areas
IV. To model for the prediction of river water quality trends of Tunggak River using QUAL2Kw river and stream water quality modelling software and investigate a water quality control strategy to control the water pollution of Tunggak River

1.5 SCOPE OF THE STUDY

In this study, the tests and experiments will be held in the field level for *in-situ* data and in the Environmental Laboratory, and Central Laboratory of Universiti Malaysia Pahang. The water and soil samples are collected from the study area and those will be analysed to collect the water quality data. Physicochemical parameters are

analysed in Environmental laboratory and heavy metals are determined in the Central laboratory. The collected and measured data will be analysed using statistical softwaere to fulfil the abovementioned objectives. The study will create a database of water quality and soil of the study area, it will identify the correlation among the physical and chemical parameters responsible for pollution, pollution sources and the relation between river water flow and water quality/pollution to fulfil the objectives.

1.6 ORGANIZATION OF THE THESIS

The thesis comprises eight (8) chapters. Chapter 1 is Introduction that includes objectives, problem statements and the significance of the research. Chapter 2 describes the literature review on water quality studies, water quality index, soil contamination and water quality modelling. Third chapter focuses on the materials and methods of execution of this thesis that include a description of the study area, selection of monitoring stations, parameters measured, sampling frequency, sampling methodology, analysis methods, statistical analysis, water quality index and water quality modelling.

Chapters 4 to 7 present the results and discussion. Chapter 4 highlights on water quality assessment and statistical analysis, while Chapter 5 presents the water quality index and river water classification. Chapter 6 describes the soil contamination, Chapter 7 focuses on water quality modelling, and the final chapter provides an overall conclusion of the study and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Water is a crucial part of the environment that is common in nature and essential for all forms of lives. No life can survive without water. It plays an important role in the human body system by dissolving and transporting essential ingredients for our lifecycle. Although, the earth is like a water planet, fresh water that is essential for the environment as well as all living beings is becoming scarce. This scarce resource is under tremendous threat of pollution, as water quality degradation is now a universal problem partly due to uncontrolled natural and anthropogenic activities. Thus, water quality degradation has now become a major concern all over the world.

Although more than 72% of the earth is covered by water (Beard, 2013; Rao, 2004), the available water is only about 2%, a rather small amount. The major source of available water is the surface water that comes mostly from the river basins. River plays a vital role in the surrounding environment of any locality exclusively for the hydrology and natural balance. It protects the aquatic community from several environmental problems and provides energy and nutrients (Losco et al., 2012). It also provides a wide range of services to the society by giving facilities of transportation and several terms of usages like water supply for drinking and irrigation, industrial uses, and recreational and spiritual activities (Losco et al., 2012). Moreover, rivers contribute substantially to industrial, agricultural and economic development along with potable water supply and provide opportunities for recreation and aesthetic. Besides the water pollution, soil contamination is one of the most important events for environmental degradation. Contaminated soil also contributes to the water quality degradation. In most cases, plant uptake the metals from the soil and thus they are accessing into human

intestine through the food chain (Peralta-Videa et al., 2009; Monachese et al., 2012).

Industrialisation is the key indicator of economic development nowadays. Water plays a vital role in industrial development. Prompt economic and industrial development demands drastic change in land use pattern, as a result water sources are squeezed and both the events cause water quality deterioration. Hwang et al. (2007) stated in their research that there are strong links between water quality characteristics and land-use, which support the deterioration of water quality due to land use change. Industrial development can be an incremental source of toxic pollutants including physical, biochemical and chemical parameters that threaten river health as well as the ecosystem of the locality. Water quality deterioration and water management are major concerns in sustainable development. To ensure sustainable development, it is essential to understand the behaviour of the environment in response to stresses induced by new development.

2.2 SURFACE WATER QUALITY STUDIES

A water quality study in Malaysia is not a new event. It was first initiated in 1962 by Norris and Charlton (Yusuf, 2001; Ainon and Sukiman, 1987). Water quality of Tunggak River, which is adjacent to the Gebeng industrial areas are being monitored by DOE in two monitoring stations at the downstream region for the last several years. Since the start of monitoring the river was clean until 2004 when it becomes polluted (DOE, 2004). Industrial pollution is the major cause of water pollution here. This section reviews the previous literature on water quality and its deterioration.

2.2.1 Temperature

The surface water temperature usually ranges between 0 ºC and 30 ºC (RAMP, 2013). Water temperature effects on oxygen solubility as increased water temperature causes the depletion of the solubility of dissolved oxygen (DO) (Yusuf, 2001). A water temperature above 27 °C is considered "unsuitable" for public use and above 32 °C it would be considered "unfit" for public use (Chapman, 2002; Yusuf, 2001).

The aquatic ecosystems largely depend on water temperature, especially the metabolic rate of aquatic organisms that varies with fluctuation of temperature. Higher water temperature enhances respiration rates of aquatic organisms that lead to increased oxygen consumption. This results in more decomposition of organic matter followed by increase in water turbidity (Dallas, 2008; Khan and Khan, 2008; Jackson and Jackson, 2000 ;Yusuf, 2001). Moreover, higher temperature (more than 26 ℃) can make the toxic chemical more soluble and may cause more harm to the aquatic life including fish (Chapman, 2002). Higher surface-water temperature can affect the biological productivity and can accelerate the growth of bacteria and fungi in the water and encourages algal blooms (Kundzewicz et al., 2007). This may create toxic contaminants that cause serious threats to human and aquatic ecosystem health (UNEP, 2010a).

The water temperature recorded from Malaysian rivers generally range from 24 °C to 31.3 °C (Hossain et al., 2012; Sujaul et al., 2013; UKM-DOE, 2000) and normal temperatures in Malaysian river water is 27 °C -31 °C (Saad et al., 2008). The Interim National Water Quality Standard (INWQS) Malaysia recommended river water temperature is Normal + 2 °C (Appendix A) and the highest limit of final discharge temperature of wastewater is 40 °C according to the Malaysia Environmental Quality (Sewage and Industrial Effluents) Regulations 2009 (MNRE, 2009). Wider river water temperature range 17 °C - 29 °C was observed in Sungai Liwagu, Sabah and 21 °C - 31 °C for Linggi River, Negeri Sembilan (UKM-DOE, 2000; Yusuf, 2001). High fluctuation was due to the location of sampling point and change of sampling time.

River water temperatures usually increases due to the ambient air temperature and other natural/climatic variables along with anthropogenic activities like discharge of industrial effluents and domestic wastes into the water (Bonacci et al., 2008; Nedeau et al. 2003). Although, no in-depth study on the surface water temperature of the Tunggak River and surrounding area of the Gebeng industrial estate have been conducted, a few studies and other investigations recorded the water temperature that ranged from 26.16 °C to 35.24 °C (Hossain et al., 2012; Sujaul et al., 2012). The differences of water temperatures were due to the timing variation of sampling and the location of the sampling stations. Ambient air temperature and industrial effluents also contributed to

the higher temperature in the river water (Hossain et al., 2012; Sujaul et al., 2012). Ambient air temperature increases water temperature naturally because of surface warming (Austin and Colman, 2007; Morrill et al., 2001) and industrial effluents containing organic matter that decomposes by various reactions, which cause the increase in water temperature (Chaurasia et al., 2011).

2.2.2 pH ($pH = - \log [H^+]$)

The pH is one of the most important water quality parameters for all forms of water in the environment. It is a measure of hydrogen ion concentration that expresses the acidity or alkalinity of a solution. It plays a critical role in the chemistry of river water quality. Fluctuation of pH from natural level may affect many chemical and biological processes in the water. The pH range of 6.5 - 8.0 is favoured by the largest species of aquatic animals (Malallah and Daifullah, 2008; Nolte and Loose, 2004). Toxic elements and compounds become more available and mobile in low pH. Declining in pH would increase availability of toxic metal that enhances the aquatic plant and animals to uptake more metals which can cause physiological damage to them (Gasim et al., 2007; Greaney, 2005; Rosli et al., 2010; Weis and Weis, 2004; Yusuf, 2001). Low pH in aquatic ecosystem constrains microbial activity, reduces decomposition and nutrient cycling which may lead to a reduction in invertebrate and plankton populations that are a vital part of the food chain (Liu et al., 2010; STAC, 2008; NYSERDA, 2008; Yusuf, 2001). Acidification of surface water leads to disbanding of toxic metals from the sediment that can result in killing of fish and other aquatic organisms (Bjerknes et al., 2003)

Level of pH is influenced by several conditions, such as, presence and amount of organic matters, soil on which the water is moving, sources of water and so on. Higher organic matter leads to higher decomposition, which can affect the pH level. Similarly, soil pH also effect on water pH level. Generally, peat soil and the water peat soil can cause decline in water pH level largely (Euro-limpacs, 2009; Shrestha and Kazama, 2007; Wang et al., 2007). The pH level can also fluctuate due to the industrial effluents. It may be low due to the industrial effluents from metallic and some chemical industries, while the effluents from detergent and beverage industries cause high pH

level (Khan et al., 2002; Tariq et al., 2006). Biological decomposition of vegetation associated with humic acid also causes low pH in surface water (Yusuf, 2001).

The level of pH recorded from Malaysian river has a range between 3.8 to 9.1 (Gasim et al., 2007; Hossain et al., 2013; UKM-DOE, 2000; Yusuf, 2001). The INWQS Malaysia recommended threshold range of pH is 6.5 - 8.5 (DOE, 2008) and the acceptable level of pH during final discharge of wastewater is 6.0-9.0 (MNRE, 2009). Therefore, pH in Malaysian river was both higher and lower than the threshold range. The highest pH was due to organic matter containing basic matter and the lower pH value in the industrial areas was due to the acid rain and wastewater from industries that contain acidic substances(Nor et al., 2013).

2.2.3 Conductivity, Salinity and Total Dissolved Solids

The ability of water to conduct electricity or electrical conductivity (EC) of water is directly related with salinity and total dissolved solids (TDS). The salts that dissolve in water is the measure of salinity and due to the dissolution of the salts in positive and negative ions, it can conduct an electrical current proportionately to their concentration. Dissolved salt or solids increase conductivity as well as salinity; hence, these three parameter measurements are closely related. The EC of a water sample (mS/cm) can be converted into the approximate concentration of TDS (ppm) by multiplying the mS/cm with a conversion factor of between 0.54 – 0.96 ((TDS) ppm = Conductivity µS/cm x 0.67). The value of this factor depends upon the chemical composition of TDS. A widely accepted value of this factor is 0.67 when the actual factor is not known (Allan and Castillo, 2007; Ali et al., 2012). Similarly, the conductivity can be converted into salinity which is influenced by the ambient temperature and pressure (Fofonoff and Millard, 1983).

2.2.3.1 Conductivity

Conductivity of water is one of the most important parameters for water quality analysis. It is largely affected by the presence of inorganic dissolved salts, such as, the anions of chloride, nitrate, sulphate, and phosphate or the cations of sodium, magnesium, calcium, iron, and aluminium. EC is the measurement of the total ions in

the water. It is temperature sensitive and usually increases with temperature (Appelo and Postma, 2010; Balandin, 2011; Gandaseca et al., 2011). Conductivity of water is an indirect measure of the TDS and can cause the corrosiveness of water, eye irritations, reduced portability, increase toxicity and reduce habitat suitability (Ali et al., 2012).

Conductivity recorded in Malaysian river water ranged between 5 - 30,000 µs/cm (UKM-DOE, 2000; Yusuf, 2001). The saltwater intrusion to the water bodies and anthropogenic activities, such as, industrial effluents can result in high level EC in water (Karikari et al., 2009; Muwanga and Barifaijo, 2006; Paul, 2011). However, the INWQS Malaysia recommended threshold level of conductivity is 1000 µs/cm (Appendix A).

2.2.3.2 Salinity

Salinity is the measure of saltiness or dissolved salt (such as sodium chloride, magnesium and calcium sulphates, and bicarbonates) in the water. In 1978, oceanographers defined salinity in the Practical Salinity Scale (PSS) as the conductivity ratio of a seawater sample to a standard KCl solution (Fofonoff and Millard, 1983). It is a major constraint for crops (Munns and Tester, 2008; Peleg et al., 2011; Witcombe et al., 2008). Generally, salinity results from the natural causes although deforestation or excess irrigation and fertilisation can contribute to the salinisation process (Peleg et al., 2011). There have been evidences of increasing water salinity in the dry season or drought compared to the wet season due to more evaporation (Phillips et al., 2003). In the river water salinity may be increased due to tidal water intrusion (Karikari et al., 2009; Muwanga and Barifaijo, 2006; Paul, 2011).

Saline aquatic systems naturally increased dryness and salinisation in arid region (Rahel and Olden, 2008; Seager et al., 2007). Increasing salinity in aquatic ecosystems has a strong influence on the pathways of species introductions. it can even alter the pathway, native species can be demolished and non-native species may become established (Leif-Matthias Herborg et al., 2007; Moyle and Marchetti, 2006; Rahel and Olden, 2008). In Australia, salinity has devastated ecologies that resulted in massive loss of habitat, biodiversity, native vegetation and water resource value and an estimated 48 000 hectares of land in Queensland is seriously affected by induced salinity (Dunlop

et al., 2005). There is no previous record of salinity in the Tunggak River and the surrounding water bodies of Gebeng industrial areas. However, the INWQS Malaysia recommended threshold level of salinity for Malaysian river is 0.5% Appendix A).

2.2.3.3 Total Dissolved solids (TDS)

A total dissolved solid (TDS) is the measure of all organic and inorganic substances that are dissolved in water. It is the dissolved or soluble fraction of water which includes total loads of solids into the water (Das et al., 2005). The inorganic sources of TDS include dissolved anion of carbonates, chlorides, sulphates and nitrates, and cations of sodium, potassium, calcium and magnesium. On the other hand, organic sources include leaves, silt, and plankton, and industrial, domestic and sewage wastes. TDS can also increase due to runoff from agricultural areas where fertilisers and pesticides are used on lawns and farms. Atmospheric deposition also contributes to the TDS concentration in water. Soil and rocks also release ion when water moves over them to consequently causing increase TDS level in surface water (Das et al., 2005; Ideriah et al. 2010; Lawson, 2011; Ogedengbe and Akinbile, 2010; Ruark et al., 2009; Wilson et al., 2013).

A certain level of ion (cause of TDS) is essential for aquatic life. Nevertheless, changes in TDS concentration can be harmful to aquatic organisms. Too high or too low a TDS concentration can limit the growth of aquatic life and can result in death of aquatic organisms (Murphy, 2007). Higher TDS concentrations can results in a decrease of water clarity, increase in water temperature, and can combine and transport toxic elements and heavy metals. It can also contribute to a decrease in photosynthesis of the aquatic plants (Ivan et al., 2011; Palanna, 2009; Stihi et al., 2005). Water with a TDS concentration above 1000 mg/L is usually considered unsuitable for human consumption as high TDS indicates the hardness of water. It can change the taste of water from normal taste to bitter, salty or metallic. High TDS also indicates the presence of toxic minerals such as, nitrates, sodium, sulfates, barium, cadmium, copper, and fluoride in water (Lawson, 2011; Weber-scannell and Duffy, 2007).

Rivers water in Malaysia has different concentrations of TDS. TDS range was recorded at 57-120 mg/L in Bebar river (M. Gasim et al., 2007); Semenyih River recorded 17.66-80 mg/L (Al-Badaii et al., 2013). Wide range of TDS was due to the anthropogenic activities as hill cutting associated with natural causes like heavy shower followed by strong runoff and tidal interference (Hossain et al., 2012) . However, the INWQS Malaysia recommended threshold level of TDS is 500 mg/L (DOE, 2008).

2.2.4 Turbidity and Total Suspended Solids (TSS)

Turbidity is the cloudiness or haziness of water caused by the suspended particles that are invisible to the naked eyes. On the other hand, total suspended solids (TSS) include all suspended particles in water, which cannot pass through a glass fibre filter (47 mm or 1.5 µm). These two parameters are closely correlated and very important for water quality analysis. High level of TSS causes higher TDS in river and lake water (Batt, 2012; Murphy, 2007; Yu et al., 2012). Presence of these parameters in water has a significant impact on aquatic life.

2.2.4.1 Turbidity

Turbidity is a visual quality of water, which indicates the deficiency of clearness of water and the degree of interfering of the straight-line transmission of light into it (Chen et al., 2007; Allen et al., 2008). Turbid water is unfit for industrial as well as homestead or recreational uses (Lopez and Dates, 2009; Sinha et al., 2011). Turbidity lessens the amount of light entering the water column that results in a decrease of photosynthesis of aquatic plants (Batt, 2012; Wilson, 2013). It can affect the water suitability by reducing clarity, contributing microorganisms (bacteria, viruses, and protozoans) that may cause an outbreak of waterborne diseases (Wilson, 2013). It can also affect the overall productivity of phytoplankton and zooplankton (Wellington et al., 2010). Anthropogenic activities increases turbidity and may lead to concerns about the impact on various fisheries species (Meager and Batty, 2007).

The growth of phytoplankton may cause turbidity in open water associated with human activities that can disrupt land profile leading to high sediment transport in water bodies, especially during rainstorms due to storm water runoff (Domingues et al., 2011;

Wilson, 2013). On the contrary, the source of turbidity of the river or lakeshore may be due to particles of clays and silts from the bank erosion. Urbanisation and residential areas contribute a lot to turbidity to the nearby water bodies through storm water pollution from paved surfaces such as, roads, bridges and parking lots. Forestry activities including timber harvesting, deforestation for Industrialisation and road construction cause huge soil erosions and runoffs that contribute to increased stream sediment followed by turbidity (Webb and Haywood, 2005). Higher TSS in water also causes high level of turbidity (Rügner et al., 2013). Dredging of water bodies also contributes to turbidity by re-suspending the fine particulates (Wilson, 2013).

Turbidity recorded from the Malaysian rivers ranged from 4 to 750 NTU (Yusuf, 2001; 2007; UKM-DOE 2000). Suspended solids and suspended organic matter contributed to high turbidity values. Previous studies recorded turbidity from Langat Basin river ranging from 17 to 500 NTU. The INWQS Malaysia recommended threshold level of turbidity for river water is 5.0 NTU (DOE, 2008). Higher turbidity in river water adjacent to industrial area was due to the industrial effluents and sewage treatment plants as well as high precipitation causing strong runoff (Nasly et al., 2013; Wilson, 2013).

2.2.4.2 Total Suspended Solids (TSS)

A TSS is a conventional pollutant that is present in many types of industrial wastewater. A water body loses its capability to support a diversified aquatic life when TSS level increases in that water (Akan et al., 2012; Iqbal et al., 2010). High level of TSS results in an increase in water temperature by absorbing heat from sunlight, which consequently decreases the DO level in the water. It also hampers photosynthesis in aquatic plants since light penetration is drastically reduced due to its presence in surface water. This again lessens the DO in water as the aquatic plant can only produce less oxygen with lesser photosynthesis. A variety of cold water species like trout and stoneflies are sensitive to change in DO level (Akan et al., 2012; Iqbal et al., 2010; Suhag et al., 2011; Xu and Shen, 2011). Fish habitat can also be destroyed due to high level of TSS in water, as suspended solids blanket the riverbed through settling to the bottom of the river. It can smother the fish and aquatic insects' offspring and restrict

newly hatched insect larvae (Sipelgas et al., 2006; Wei, 2007). Besides these, suspended solids can harm fish species directly as it can clog gills, reduces the growth rate of fish and can diminish disease resistance capacity (Hazim, 2012; Iqbal et al., 2010; Lawson, 2011). Thus, it can change the aquatic environment that may result in shrinking food sources of aquatic organisms, and migration or natural movement may be disrupted. It also lessens the suitability of water for aesthetic entertainment and recreational use.

Suspended solids usually occur naturally in river and lake water. However, the anthropogenic activities can significantly contribute to the higher concentration of suspended solids in water (Dahlgren et al., 2004). Including soil particles, phytoplankton and zooplankton, and small fragments of dead plants contribute a lot to the suspended solids. Moreover, discharge of industrial wastes, urban and domestic wastes, runoff from agricultural sites, and riverbank erosion along with soil erosion from newly construction sites are the potential sources of suspended solids in water. Excessive algal growths also contribute to the higher concentration of TSS in water (Akan et al., 2012; Lawson, 2011; Susfalk et al., 2008).

TSS in Malaysian rivers was varied from river to river. In Perai industrial park the highest TSS was recorded 390 mg/L(Ayub et al., 2004), while in Selangor river it was recorded 11.7- 58.1 mg/L (Al-Badaii et al., 2013) and in Bebar, TSS was recorded at 0.75-15.75 mg/L (Gasim et al., 2007). There were no specific studies on TSS done in the Tunggak River previously. However, the INWQS Malaysia recommended threshold level of TSS for Malaysian river water is 25 mg/L (DOE, 2008) and the maximum limit of SS for the final discharge of wastewater is 50 mg/L (MNRE, 2009). Al-Badaii et al. (2013) stated that the maximum level of TSS in Malaysian rivers permitted to the aquatic life is 150 mg/L.

2.2.5 Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

Oxygen is a very crucial element for living creatures including animals and human beings. A well-mixed water can dissolve as much as approximately 10 mg oxygen in 15 °C temperature and it is controlled by temperature to a great extent

(Andrew, 2005; Chapman 2000). The lack of dissolved oxygen (DO) can cause death to fish and other aquatic animals. Fish and other aquatic organisms begin to suffer when DO level falls below 4 - 5 mg/l (Howitt et al. 2007; Jackson and Jackson, 2000; Gehrke, 1988; Klein 1959). Generally, DO level lower than 3 mg/L is stressful and 1-2 mg/L will not support aquatic vertebrates and other aquatic life (Ibrahim et al., 2012; Indiana University, 2013; USEPA 1986).

Deficiency of oxygen in water happens due to the addition of organic matter that is oxidised to be decomposed by several microorganisms. A lesser amount of organic matter is enough to diminish the oxygen content in water. Chapman (2000) and Klein (1959) stated that usually microorganisms consume about 3 mg/l oxygen for the oxidation of one milligram of organic matter. Major sources of organic matter in the river and lake water can comprise of unfiltered or partially filtered industrial wastewater, domestic wastes with sewage treatment plant, wastewater and wastes from animal and pig farms and also agricultural wastes (DOE, 2010; DOE, 2009; Yusof et al., 2007). Increased organic matter cause the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) to increase as a result of oxidizing the organic matter and for the decomposition of certain chemicals in the river water. Both BOD and COD have been used as overall indicators of water pollution in the field of water quality monitoring science (Krisanab 2001; USEPA 1986). The increasing demand of oxygen indicates the increased trend of organic matter in water.

2.2.5.1 Dissolved Oxygen (DO)

DO is an important indicator of water quality. It is the barometer for the river ecosystem and a key factor for the aquatic life (Kannel et al., 2007). It indicates whether the water is polluted or not (Ibanez et al., 2008). Biological and biochemical reaction in water depend on DO availability. It regulates the capacity of water to receive organic matter without causing trouble (Wetzel, 2001). The source of DO in river water is mostly natural. Oxygen can dissolve in river water freely from atmosphere by inducing air into water flow. DO concentration in water also depends on temperature largely. Besides atmosphere, photosynthesis of aquatic plants also contributes a considerable amount of DO in water (Moss, 2013; Wetzel, 2001). The DO concentration in water is

directly related to the biological and biochemical process i.e. decomposition of organic matter and thus the amount of organic matter in water is a big factor for DO concentration (Moss, 2009; Arnell, 2002). Effluents from industrial, residential and urban areas that contain a lot of organic matter ultimately cause depletion of DO in the adjacent water bodies. Therefore, the main causes of low DO levels in river water are the discharge of organic matter in the form of effluents or wastewater into rivers. The sources of these effluents or wastewater can be from treatment plants, multifarious industries, domestic and urban wastewater (Ahmed et al., 2012; Dai et al., 2006; Emongor et al., 2005; Hudson and Reynolds, 2007; Qadir et al., 2008; Sánchez et al., 2007; Shah and Pant, 2013; Shuhaimi-Othman et al., 2007; Singare et al., 2010). Agricultural activities also contribute to the depletion of DO concentration in surface water (Decker et al., 2013; Girija et al., 2007; Mallin et al., 2009; Mallin and McIver, 2012; Qadir et al., 2008).

DO levels in water regulate the metabolism rate of fish and other aquatic organisms as the decrease in DO level results in the decrease of respiration and feeding of fish. Consequently, the growth rate is reduced and the potential diseases attack increases, which ultimately results in low productivity of fish (Mallya, 2007; Brungs, 2011). Due to rapid development, Asian rivers are experiencing rapid changes regarding DO level as well as the pollution level, especially with industrial development DO level fluctuate rapidly (Dai et al., 2006). European rivers are also polluted with organic pollutant that caused depletion of DO in river water although most of those rivers are well aerated (Hajslová et al., 2007; Dai et al., 2006; Loos et al., 2009; Reemtsma et al., 2006).

Previous recorded DO from Malaysian rivers varied based on the location and the source of pollutions. In upper tropical river Dong, DO was recorded at 8.22 - 8.8 mg/L; which was better than the minimum required level and indicated that the river received low input of pollutants (Ekhwan et al., 2012). In Johor, the DO of Melana river ranged between 3.16 to 4.07 mg/L in (Hazim, 2012); while Bebar river in Pahang, the DO ranged 0.54 - 1.76 mg/L (Gasim et al., 2007). In Selangor, the DO was recorded 5.58 - 7.07 mg/L in the Semenyih River (Al-Badaii et al., 2013), and several oxbow lakes in Sabah contained 3.9 - 12.4 mg/L DO in surface water (Heng et al., 2006).

Lower DO concentrations were due to the industrial activities and urban wastewater (Al-Badaii et al., 2013; Saad et al., 2008). However, the INWQS Malaysia Recommended threshold level of DO at minimum 7 mg/L for class I water that has been shown in Appendix A (DOE, 2008).

2.2.5.2 Biochemical Oxygen Demand (BOD

BOD is the amount of DO needed by aerobic biological organisms in a body of water to break down organic material present in water. It is an approximate measure of the biochemically degradable organic matter present in a water sample (Annalakshmi and Amsath, 2012). Higher BOD results in the decrease of DO level that may cause the reduction of metabolism in aquatic organisms, less tolerance to potential disease of fish and other aquatic life and it may lead to low productivity of fish and other organisms (Pörtner, 2010).

In surface water, BOD level usually increases due to the enrichment of organic matter, decay of plant and animal matter into the river or lakes (Annalakshmi and Amsath, 2012). Discharge of industrial effluents that contain a considerable amount of organic materials and nutrients significantly contribute to the BOD level (Ansari et al., 2012; Gyawali et al., 2012; Islam et al., 2012; Pawar, 2013; Sujaul et al., 2013; Vishwakarma et al., 2013; Yadav et al., 2012). In addition, effluents or wastewater from agricultural farms, urban and domestic wastewater are also responsible for high level of BOD in surface water (Al-Badaii et al., 2013)

Previous studies showed that BOD concentrations in Malaysia ranged between 0.46 to 676 mg/L (Al-Badaii et al., 2013; Cleophas et al., 2013; Gandaseca et al., 2011; Hazim, 2012; Sujaul et al., 2013; UKM-DOE, 2000; Yusuf, 2001). The concentration in Semenyih River was 0.63 to 19.8 mg/L, while in the Langat Basin river the range was 0.40 to 55.08 mg/L (Al-Badaii et al., 2013; Yusuf, 2001). Higher concentration in Malaysian river water was due to the effluents from industries, especially from the palm oil and food processing industries (Sujaul et al., 2013; Yusuf, 2001). However, the INWQS Malaysia threshold level of BOD for class I water is 1.0 mg/L that is shown in

Appendix A (DOE, 2008) and the standard limit for final discharging of wastewater into river flow is 20 mg/L (MNRE, 2009).

2.2.5.3 Chemical Oxygen Demand (COD)

The COD is a measurement of the amount of material that can be oxidised in the presence of a strong chemical oxidising agent. It is usually used to determine the amount of organic pollutants found in surface water (Reddy et al., 2011). High COD levels may cause reduction in DO level due to the decomposition by microbes and consequently hamper the aquatic life (Annalakshmi and Amsath, 2012). The causes of higher COD values are primarily industrial, domestic and urban wastewater. Industries that produce and discharge their effluents containing significant amount of organic compound may be the major sources of COD in adjacent water bodies (Kanu and Achi, 2011; Naddeo et al., 2013; Walakira and Okot-Okumu, 2011; Zhao et al., 2011). Besides industrial and urban wastewater, agricultural runoff also contributes to the higher amount of COD (Zhao et al., 2011). Seasonal variation was also noticed that in the wet season due to increased water flow COD was recorded comparatively lower than the dry season (Varol et al., 2012; Garg et al., 2010).

According to the previous literatures, the level of COD recorded from Malaysian rivers ranged from 2.1 to 2418.0 mg/L (Bishop, 1971; Environmental Protection Society Selangor, 1975; Law and Mohsin, 1980; Lai, 1983; Lai and Norajiki, 1988; Law and Yeo, 1997; Nasly et al., 2013; UKM-DOE, 2000 ; Yusuf, 2001). However, the threshold level of class I water based on the INWQS Malaysia is 10 mg/L, while for class II that is considered good water is 25 mg/L (DOE, 2008) and the final discharge limit for the industrial wastewater is 80 mg/L (MNRE, 2009).

2.2.6 Inorganic nutrients

Nutrients are essential elements in normal amount for the growth and reproduction of all plants and animals whether in terrestrial or aquatic. Aquatic plant and animal species depend on their surrounding water bodies for inorganic and organic nutrients (Chapman, 2002; EPA, 2012; RIDEM, 2007). Nutrients are essential but in normal amount, excessive nutrient can be detrimental to aquatic flora and fauna. It can

cause faster growing of aquatic plants, potentially harmful algae blooms, choking waterways and may create a low oxygen condition that can detriment fish species and other aquatic organisms (CEES, 2013; EPA, 2012). Inorganic nutrients include nitrogen (ammoniacal-nitrogen, nitrate-nitrogen, and nitrite-nitrogen), phosphorus, sulphur etc. The major sources of inorganic nutrients are fertiliser, domestic, urban and animal wastes and industrial wastewater (Haese et al., 2009; Howarth et al., 2000). Natural sources along with atmospheric deposition of nutrient also contribute a significant amount in surface water through soil erosion and plant materials (Klapprath and Johnston, 2000). However, the major sources of nutrient in surface water nowadays are the anthropogenic activities, such as, fertilisation on crop and lawn, sewage and industrial wastes that discharge into the surface water (Dinnes, 2004; Haese et al., 2009; Howarth et al., 2000). This section discusses the inorganic nutrients namely, nitrate (ammoniacal nitrogen and nitrate nitrogen) phosphate phosphorus and sulphate.

2.2.6.1 Nitrogen

Nitrogen is one of the limiting nutrients in water bodies for eutrophication that control the primary productivity (Howarth and Marino, 2006). Nitrogen pollution has increased unusually and considered as the greatest consequence of human augmented comprehensive alterations in the water resources (Galloway et al., 2004; Howarth and Marino, 2006).

- ***Ammonical-Nitrogen***

In a water body, ammonia exists in two forms, ionised ammonium (NH_4^+) and un-ionised ammonia (NH_3). The NH_4^+ and NH_3 form in water by series of reaction, such as, $H^+ + NH_3 \rightarrow NH_4^+$ and $NH_4^+ + B^- \rightarrow HB + NH_3$ (B for base). The sum of these two forms of ammonia is referred to ammoniacal nitrogen (Ebeling et al., 2006). The un-ionised form of ammonia is usually toxic to aquatic organisms even in low concentration that can be stable at water column below the water-air interface (Dinnes, 2004; Camargo and Alonso, 2006; Francis-floyd et al., 2012). The toxicity of unionised ammonia is critically dependent on pH and temperature. At a given concentration of total ammonia, pH has a greater influence compared to the temperature (Eddy, 2005; Hegazi, 2011; Neil et al., 2005). Free toxic ammonia may rapidly convert to non-toxic

ammonium (NH_4^+) ion [2 NH_3 (aq) ≈ NH_4^+ (aq) + NH_2^- (aq)] in acidic condition and if that toxic ammonia containing effluent can enter into a well buffering system. It also depends on the pH, if the pH level is high it may cause buffering system poorer than the conversion may be slower. Consequently, most of the biota of the system will be adversely affected (Abbas, 2006; Hegazi, 2011; Neil et al., 2005). The concentration more than of between 0.15 - 0.30 mg/L are associated with sub lethal toxic effects on many fish species (Eddy, 2005). Unpolluted fresh water generally contains small amount of ammonia and ammonia compound, normally < 0.1 mg/L and rarely contains >0.05 mg/L (Chapman and Kimstach, 1996; EQMD, 2005).

The concentration of ammoniacal-nitrogen in Malaysian river was recorded from various rivers and water bodies in several previous researches. From those researches the range of ammoniacal nitrogen in peninsular Malaysia was recorded 0.003 - 45.75 mg/L (Al-Badaii et al., 2013; Aweng et al., 2011; Gasim et al., 2006; Hazim, 2012; Khalik et al., 2013; UKM-DOE, 2000 ; Yusuf, 2001). In Sabah and Sarawak the range was 0.05 - 8.0 mg/L (Cleophas et al., 2013; Gandaseca et al., 2011; Said et al., 2009). Higher concentration of ammoniacal nitrogen was due to the discharge of effluents from industries, especially palm oil, rubber, fertiliser and food processing industries (Hossain et al., 2012; Kanu and Achi, 2011; Varol et al., 2012; Yusuf, 2001; Walakira and Okot-Okumu, 2011). However, the INWQS Malaysia recommends level of ammoniacal nitrogen for Malaysian river water at 0.1 mg/L for class I water (Appendix A).

- ***Nitrate-Nitrogen***

The nitrate ion (NO_3^-) is the common form of combined nitrogen found in natural water. Nitrite (NO_2^-) ion rapidly oxidises to nitrate (WHO, 2011). This conversion process is Ammonia + Oxygen + Alkalinity + Nitrosomonas = Nitrite and Nitrite + Oxygen + Alkalinity + Nitrobacter = Nitrate. It is an essential element for aquatic plant and its fluctuation can cause limiting effect on plant growth (Piwpuan et al., 2013). It is the stable form of combined nitrogen for oxygenated systems (Sutka et al., 2004; WHO, 2011). Higher level of nitrate in surface water can affect phytoplankton growth (Hutchins, 2012). Excessive amount of nitrate can cause extreme growth of

algae (Wang et al., 2008). The major source of nitrate concentration in surface water is the agricultural runoff (Cleophas et al., 2013; Gasim et al., 2006; Islam et al., 2012). The concentration of nitrate in surface water may exceed more than 5 mg/L if it is induced by the human activities (Chapman and Kimstach, 1996).

Previous record of nitrate in Malaysian river ranged between 0.0 - 8.53 mg/L (Al-Badaii et al., 2013; Aweng et al., 2011; Cleophas et al. 2013; Gandaseca et al., 2011; Gasim et al., 2006; Hazim, 2012; Khalik et al., 2013; UKM-DOE, 2000 ; Yusuf, 2001). The nitrate concentration at Semenyih river was ranged 4.23 to 15.4 mg/L, while in Langat basin river the concentration was 0.2 to 6.3 mg/L (Al-Badaii et al., 2013; Yusof, 2002). There is no previous record of nitrate concentration in the Tunggak River.

- ***Phosphate-Phosphorous***

Alike nitrogen, phosphate (PO_4^{3-}) is one of the limiting factors of aquatic environment that controls the productivity of aquatic organisms (Howarth and Marino, 2006). It is an essential element for plants and aquatic organisms. In an aquatic environment, it exists in both dissolved and particulate phases (Murphy, 2007; Paytan and McLaughlin, 2007). Higher level of phosphate greatly stimulates the growth and production of algae that can cause eutrophication in water bodies. Potential effect of eutrophication to river water may be the incremental rate of biomass, shifting of the bloom-forming algae to toxic or inedible species, reduce fish productivity, reduction in aquatic species, development of scum and odours as well as reducing the DO concentration (Liu et al., 2012; Smith and Schindler, 2009; Wu et al., 2012).

In surface water, phosphorus initiates from a variety of sources; with anthropogenic activities as the major sources of phosphorus. Anthropogenic sources include soil erosion due to human activities and runoff from farmland or lawns, runoff from urban areas and construction sites, use of detergents and septic systems, municipal sewage treatment plants and human and animal wastes (Ahlgren et al., 2012; CCES, 2012; Comber et al., 2013; Donnert et al., 2002; Hubbard et al., 2004; Tyler et al., 2012; UWSP, 2005; Yuan et al., 2012; Yusuf, 2001). Phosphate is a common water quality parameter in agricultural areas because a substantial amount of phosphate fertilisers is

usually used in agriculture and the animal waste contains a high amount of excess phosphorus, which may seep into the adjacent water bodies through spills, leaks and runoff during storms (Hubbard et al., 2004; Tirado and Allsopp, 2012). A significant amount of phosphate in water comes from various natural sources, which include the weathering of phosphorus bearing rocks, decomposition of organic matter that contain phosphate compounds, atmospheric deposition, the soluble nonreactive P pool in water or soil and sediment flux into the water bodies (Amist, 2010; Paytan and McLaughlin, 2007; Smith and Schindler, 2009).

The INWQS Malaysia recommended level of phosphate for Malaysian river water is 0.2 mg/L-0.1 mg/L (WEPA, 2008) (Appendix A). Previous studies have concluded that, phosphate concentration on Malaysian river water ranged between 0.00 - 26.55 mg/L (Al-Badaii et al., 2013; Aweng et al., 2011; Gasim et al., 2006; Heng et al., 2006; UKM-DOE 2000 ; Yusuf 2001). The main causes of the higher phosphate were the anthropogenic activities including industrial and urban wastewater, fertiliser runoff and domestic effluents.

- ***Sulphate***

Sulphate (SO_4^{2-}) is a naturally occurring substance that contains sulphur and oxygen. It is generally considered to be a non-toxic nutrient (Saskatchewan, 2003). Usually, it is the stable oxidised form of sulphur and is readily soluble in water. Drinking water containing a high concentration (more than the standard) of magnesium or sodium sulphate can cause intestinal discomfort, diarrhoea lead to dehydration. Diarrhoeal dehydration is often observed when an individual drinks high amounts of sulphate-containing water although one is accustomed to drinking water with low concentrations of sulphate (Saskatchewan, 2003; Patterson et al., 2004) . High level of sulphate concentration may affect the chlorination efficiency of water supplies and it can increase the corrosive properties of water (Sharmila and Rebecca, 2013; Yiasoumi et al., 2005). Excess amount (1000 mg/L) of sulphate in water can reduce the productivity of a variety of aquatic organisms including fish species (Davies, 2007; Lasier and Hardin, 2010; Meays and Nordin, 2013).

There is a variety of sources of sulphate in surface water including natural sources. The natural sources of sulphate include the atmospheric deposition, the leaching of sulphur compounds (either sulphate minerals or sulphide minerals) from the weathering of sedimentary rocks (Meays and Nordin, 2013; Sievert et al., 2007) . Dissolved sulphur can arise in water naturally from mineral weathering, decomposition and combustion of organic matters, input from volcanoes and sea salts (Meays and Nordin, 2013) . Besides the natural sources, anthropogenic activities contribute a significant amount of sulphate in surface water. Anthropogenic activities like, industrial discharges, burning of coal and fossil fuel, animal and plant matter decomposition and use of substantial amounts of sulphate fertiliser in agricultural activities produce and release sulphur compounds into the environment and water bodies (Lewicka-Szczebak and Trojanowska, 2008; Meays and Nordin, 2013) .

In natural water, the concentrations of sulphate are usually between 2 - 80 mg/L and sometimes it may exceed even 1000 mg/L (Chapman, 2002). The INWQS Malaysia recommended threshold level of sulphate for the Malaysian river water is 250 mg/L (WEPA, 2008). Nonetheless, from the previous record it is concluded that the range of sulphate in Malaysian river is 0.00 - 900 mg/L (Al-Badaii et al., 2013; Barzani et al., 2007; Hossain et al., 2012; Gasim et al., 2006; Gasim et al., 2008). The concentration at Semenyih River was recorded 1.67 to 61.0 mg/L but no specific study on sulphate determination was done in Tunggak River previously.

2.2.7 Heavy metals

"Heavy metals" are chemical elements with more than five (5) times the specific gravity of water at 1 to 4 °C water temperature, such as Arsenic, Cadmium, Iron, Lead and Mercury (Ada et al., 2012; Egwaikhide et al., 2013; Prasher, 2009; Ramola, 2013). Their occurrence in water indicates the natural and anthropogenic sources of water pollution (Jayaprakash et al., 2012). There are two types of heavy metals, some of which are essential while the others are non-essential for life and the environment (Theron et al., 2012). Some heavy metals such as manganese, iron, copper and zinc are nutritionally essential in a very small quantity for a healthier life; which are generally trace metals. These essential trace elements (in several forms) are usually available

naturally in foodstuffs, various fruits and vegetables, and in multivitamin products that are commercially available (Abolude et al., 2013; Haroun, 2009; Idris et al., 2013; Jarup, 2003). Common problematic heavy metals are arsenic (As), cadmium (Cd), mercury (Hg) and lead (Pb), which are widely dispersed in the environment (Jarup, 2003; Llobet et al., 2003; Prasher, 2009). Usually the excess amount of trace elements and all other heavy metals remain un-metabolised in the body system and accumulate in the bones or soft tissues causing toxic effect. This toxicity may result in damage or reduction of mental and central nervous activities, energy level may lessen, can damage blood composition, liver, lungs, kidney and other important organs of the body (Jarup, 2003; Prasher, 2009; Ramola, 2013).

Nonessential heavy metals are normally toxic in even very low amount. Arsenic, mercury, cadmium and lead are the non-essential heavy metals (Johri et al., 2010; Theron et al., 2012). Toxic amounts of arsenic can coagulate the protein in the human body and forms complexes with coenzymes that prevents the ATP production during respiration (Duruibe et al., 2007). It can result in skin cancer as well as lesions in the skin, such as, hyperkeratosis and alteration of pigmentation (Jarup, 2003). Liquid heavy metal mercury is toxic to both human and aquatic life and is not required for any organisms even in trace amounts (Ada et al., 2012). Inorganic mercury microbiologically transformed into lipophilic organic compound methylmercury. Consume of contaminated fish or a particular species increase the risk of methylmercury poisoning (Zahir et al., 2005). Its presence in the environment can cause serious pollution (Egwaikhide et al., 2013). Another non-essential heavy metal cadmium, may cause occupational lung cancer, kidney and skeletal damage and hearing dysfunction in the human body (Prasher, 2009). Eventually it is toxic to aquatic organisms even at low concentration (USEPA, 2001). Non-essential heavy metal lead (Pb) is toxic in even lower concentration than any other heavy metals (Fontenele et al., 2009; Pescim et al., 2012). In the human body, it can cause neurobehavioural and endocrine alteration; increase blood pressure and effect on behaviour and development (Kosnett, 2009; Prasher 2009).

Cobalt is an essential element of vitamin B12 (Env.Canada, 2013) and is required in very small amount, as excess amount is toxic to all living organisms

including aquatic life (Renge et al., 2012). Similarly, copper is needed in very small quantity and excess amount is harmful for aquatic as well as all organisms including human health (Stern et al., 2007). Another heavy metal nickel is nutritionally essential for some plant species, microorganisms and animal species, and its deficiency or toxicity can hamper their lifespan (Cempel and Nikel, 2006). Zinc is also an essential element that is important to many enzymes (Dhawan and Chadha, 2010; Nriagu, 2010; Plum et al., 2010). It is usually non-toxic at lower doses but excess intake may cause acute toxicity (Dhawan and Chadha, 2010; Stefanidou and Maravelias, 2006). It can cause cell death in the brain, and ischemia or trauma (Plum et al., 2010).

The common pathway of heavy metals in the human body is the food and drinking water. Air and skin may also be the pathway of metals in some cases when metals remain in gaseous form or come in contact with the human body (Jarup, 2003; Njar et al., 2012; Prasher, 2009; Ramola, 2013; Renge et al., 2012; Sardar et al., 2013). In the current era, heavy metals are common contaminants of surface water and are of concern due to their toxicity (Cheng et al., 2012). It is often attributed in most developing countries due to the negative effect of technological development. Rapid Industrialisation and urbanisation with poor planning of waste management causes the deterioration of water quality of the adjacent water bodies (Haribhau, 2012; Jayaprakash et al., 2012; Rajaganapathy et al., 2011). Occurrence of trace metal in waters indicates the presence of natural and anthropogenic sources of pollution. Water heavy metal contamination may come from broadly two types of sources, namely natural and human induced (anthropogenic) sources. Volcanism, atmospheric transport, bedrock erosion and release from plants are the possible potential natural sources of trace metals in water (Krishna et al., 2009a; Prasanna et al. 2012; Pekey et al., 2004).

On the contrary, anthropogenic sources including mining and mineral processing activities have strong influences on bio-geochemical cycles of heavy metals (Krishna et al., 2009; Prasanna et al., 2012) and industrial activities, especially electroplating, metal coating, tyre, tractor, power plant, etc. (Pathak et al., 2013). Significant amount of heavy metals especially Cr. Cd, Ni and Pb can come in surface water from effluents of electroplating industries (Varalakshmi and Ganeshamurthy, 2010). The existence of heavy metals in a river ecosystem may lead to serious concerns about their harmful

effect on plant and animal life (Mohiuddin et al., 2010; Sheikh et al., 2007; Zvinowanda and Okonkwo, 2009). At the same time, the behaviour of trace metals including the fate and transportation, in a polluted river basin depends on the interaction of hydrologic and geochemical processes (Yacoub et al., 2013).

Heavy metal concentration in the rivers of the world has been studied and is being studied by several researchers. Previous studies showed a significant variation based on the location and contamination sources. In the Asian rivers, the concentration of arsenic was ranged 0.00 - 12.00 mg/L (Govil et al., 2011; Jayaprakash et al., 2012) and the mercury range was recorded at 0.00 - 3.70 mg/L (Jayaprakash et al., 2012). The cadmium was ranged 0.05 - 1.89 (Amin et al., 2009; Rajaganapathy et al., 2011; Raju et al., 2013; Ramola, 2013) and the lead (Pb) range was recorded at 0 - 142.7 mg/L (Amin et al., 2009; Govil et al., 2011; Jayaprakash et al., 2012; Rajaganapathy et al., 2011; Raju et al., 2013; Ramola, 2013). The contamination of the heavy metals was due to the electroplating, pharmaceuticals, metal industries and mining activities associated with some natural sources (Amin et al., 2009; Govil et al., 2011; Jayaprakash et al., 2012; Rajaganapathy et al., 2011; Ramola, 2013).

In Peru, the concentration of cadmium and lead was recorded at 0.01 - 0.13 mg/L and 0.025 - 0.266 mg/L respectively. The cause of the contamination was the mining activities (Yacoub et al., 2013). African rivers were characterised with mercury, cadmium and lead contaminations. Mercury concentration was ranged 0.010 - 0.074 mg/L (Oduro et al., 2012); cadmium was recorded at 0.024 - 0.204 mg/L (Idris et al., 2013; Oduro et al., 2012; Oguzie and Okhagbuzo, 2010) and lead concentration ranged at 0 - 0.125 mg/L (Idris et al., 2013; Oguzie and Okhagbuzo, 2010). The source of mercury concentration was the effluents from gold mining activities (Oduro et al., 2012); while the Pb and Cd contamination were due to the urban run-off and effluents from rubber industries (Oguzie and Okhagbuzo, 2010) and pharmaceutical industries (Idris et al., 2013). Natural sources, such as, the weathering of minerals and soils associated with urban storm-water runoff and discharge of domestic effluents that contain Cd-laden materials also contributed to the contamination of heavy metals (Oduro et al., 2012).

In Malaysian river water, heavy metal contaminations were identified and the causes of those contaminations were the industrial effluents especially the effluents from palm oil, petrochemical industries and metal industries that use metal alloys associated with the natural sources. Rapid development in the industrial sector and urbanisation also contributed to the contamination (Prasanna et al., 2012). The INWQS Malaysia recommended threshold levels of different heavy metals are given in Appendix A. Malaysia also fixed the maximum discharge limit of different heavy metals during final discharge of wastewater that are shown in Appendix B.

2.3 WATER QUALITY INDEX

Water quality index (WQI) is a dimensionless numeric figure that combines several water quality parameters into a single number by standardising values to individual rating curves (Hossain et al., 2013; Jena et al., 2013; Khwakaram et al., 2012; Yogendra and Puttaiah, 2008). It is a 100-point scale, which summarises the results from different water quality measurements. Parameters or factors considered in the WQI vary based on several issues; which are related to the designated water uses of the water body concerned and country or local preferences (Rikta et al., 2013). A good number of scientist/researchers worked on the WQI concept and developed new indices, and they published their findings and examples with case scenarios in the literature (Bhargava, 1983; Bolton et al., 1978; Brown et al., 1972; Cude, 2001; House, 1989; Liou et al., 2004; Said et al., 2004; Nasiri and Maqsood, 2007).

Brown et al. (1972) developed National Sanitation Foundation water quality index (NSFWQI) with great attention in parameter selection, developing a common scale and assigning weights of the parameters. They exercised the Delphic method for developing the index (Bharti and Katyal, 2012). US National Sanitation Foundation coordinated the development of the NSFWQI. Chemical water quality index (WQC_{index}) was developed by Tsegaye et al. (2006) to assess a number of water quality parameters of Lake Basin. Development of Oregon water quality index (OWQI) was the significant step of improvement in the water quality sciences (Dunnette, 1979). British Columbia water quality index (BCWQI) was developed by the Canadian Ministry of Environment (Rocchini and Swain, 1995); which as later replaced by the widely acceptable water

quality index namely the Canadian Council of Environment Ministers water quality index (CCMEWQI) (Anon, 2001). This index was a modification of the BCWQI. It compared water quality parameters with their standard limit or background concentrations instead of normalization and development of rating curves. It was based on BCWQI (Bharti and Katyal, 2012.; CCME, 2001; Khan et al., 2004; Lumb et al., 2006) and utilised as more as 400 water quality parameters in its consideration.

Department of environment, Malaysia developed a water quality index (DOE-WQI) in 1985 based on the opinion poll of a panel of experts. They were consulted on the choice and weightage of water quality parameters (Zainudin, 2010). Six physicochemical parameters DO, BOD, COD, SS, ammoniacal-nitrogen and pH were considered for the calculation of the index (Haque et al., 2010; Norhayati, 1989). DOE-WQI consists of sub-index values assigned to each pre-identified water quality parameter by comparing its observed value with a parameter-specific rating curve, which are optionally weighted and combined into the final index (Zainudin et al., 2010). Sub-index values of six (6) physicochemical water quality parameters are obtained from a series of best-fit equations (Appendix C). However, the water quality does not only depend on those six parameters but the number of parameters including physico-chemical, heavy metals and coliform. Based on the DOE-WQI value, the river water can be categorised into five classes (WEPA, 2008). The DOE Water Quality Index Classification is shown in Appendix C. According to the INWQS Malaysia, the water of class III can be used for water supply after extensive treatment and for livestock drinking, and irrigation (DOE, 2008). It may not be wise to recommend the water for the above-mentioned purposes without considering the heavy metal content. But, in DOE-WQI, there is no option of taking the heavy metals in consideration; as this index has a lot of limitation, such as consideration of less and only physicochemical parameters (Zainudin, 2010). With this issue in mind and to fulfil the objective of adopting an existing water quality index for Tunggak River, world's famous and widely used water quality indices along with DOE-WQI has been critically reviewed and discussed in the following sub-section (2.3.1). Consequently, an existing water quality index has been adopted for the calculation of water quality index of Tunggak River after comparing it with DOE-WQI and discussed in Chapter 5.

2.3.1 DOE-WQI and other widely used indices of the world: A Critical review

Revision or analysis of WQI is essential to adopt an existing WQI or to develop a new one because several studies have come out with new approaches and tools for developing other indices (Bharti and Katyal, 2012). To adopt an existing WQI for Tunggak river (as it is quite impossible to develop a new one with only one year limited data), a detailed literature review has been conducted and after the review, a few WQIs which are most commonly used and recognised as important all over the world are being critically discussed here.

2.3.1.1 National Sanitation Foundation (NSFWQI)

US National Sanitation Foundation (NSF) has developed a water quality index (NSFWQI) based on Brown et al. (1972). For the development of the WQI, Brown et al. (1972) and co-workers paid great attention in parameters selection, developing a common scale, assigning weights of the parameters and also performing Delphic exercises for this purpose (Bharti and Katyal, 2012). NSFWQI provides an identical way to compare the relative quality of various water bodies (Said et al., 2004). About 35 water quality tests were surveyed by more than 140 water quality scientists. A rating curve was developed by asking the scientists to attribute the standard for deviation in the level of water quality caused by each of the selected variables (Mitchell and Stapp, 1994). Establishing the rating curves and assigning weights, water quality index can be calculated as follows,

$$WQI = \sum_{i=1}^{n} W_i Q_i \qquad \text{---------- (2.1)}$$

Where, Wi = Weighting factor, n = Number of parameters, $Q\ i$= Q value of ith parameter obtained from the rating curve.

The limitations of the NSFWQI are noted, such as, it does not consider the consumption of water, lack of dealing with uncertainty and subjectivity present in complex environmental issues (Mnisi, 2010; Tyagi et al., 2013) and only nine parameters was considered where there was no heavy metal included (Bharti and Katyal, 2012 ; Said et al., 2004).

2.3.1.2 Chemical Water Quality Index

Tsegaye et al. (2006) has developed a Chemical water quality index (WQC_{index}) for Lake Basin to assess a number of water quality parameters by standardising each observation to the maximum concentration for each parameter (Bharti and Katyal, 2012). The WQC_{index} was calculated by normalising and summing the measured water quality parameters (Tsegaye et al., 2006). It was developed based on only six (6) water quality parameters.

2.3.1.3 Oregon (OWQI)

Oregon water quality index (OWQI) is calculated by integrating measurements of eight water quality parameters, namely, DO, BOD, Ammoniacal + nitrate nitrogen, pH, total P, total solids and faecal coliform. After developing the OWQI, significant improvement of the science of water quality had occurred (Dunnette, 1979). After the introduction of NSFWQI, the original OWQI was modelled for better use (McClelland, 1974). Both indices, NSFWQI and OWQI used logarithm transfer for converting water qualities into sub-index values. The original OWQI used a weighted arithmetic mean function:

$$WQI = \sum_{i=1}^{n} SI_i W_i \quad \text{---------- (2.2)}$$

Where, *SI*= sub-indices, *n*= number of sub-indices, *i*= *i*th parameter and *W*= weightage of the parameter.

Despite some advantages, it has a number of limitations. Such as, it does not consider toxicity concentrations changes, it cannot define the water quality for particular uses, it cannot provide definitive information about water quality without considering the other parameters, as it considers less number of parameters and it does not consider any heavy metals (Cude, 2001;Hubler et al., 2009; Tyagi et al., 2013).

2.3.1.4 British Columbia (BCWQI)

Canadian Ministry of Environment developed British Columbia water quality index (BCWQI) in 1995 for water quality assessment (Rocchini and Swain, 1995). The index was based on the achievement of water quality objective (Zandbergen and Hall,

1998). For calculating the index, the measured water quality parameters were compared with their predefined limit (objective value) to determine their violation (Bharti and Katyal, 2012). The BCWQI is stated as in equation 5.3

$$BCWQI = \sqrt{\left(F_1^{\,2} + F_2^{\,2} + \left(F_3/3\right)^2\right)}/1.453 \qquad \text{---------- (2.3)}$$

Where, *F1* is the number of objectives not met, *F2* is the number of times objectives were not met and *F3* is a measure of the maximum amount by which objectives are not being met in a given year. The factor 1.453 had been introduced for scaling from 0 - 100.

The great advantage of this index is that it provides option for considering all possible water quality parameters to make classification of water. But, the problem is that it does not point out the trend of water quality until it deviates from standard limit (Bharti and Katyal, 2012). However, this Water Quality Index has been replaced by the new federal Water Quality Index, developed by the Canadian Council of Environment Ministers (CCME) (Anon, 2001).

2.3.1.5 Canadian Council of Ministers of Environment (CCMEWQI)

The CCMEWQI was developed based on the BCWQI. Instead of normalisation and development of rating curve, it compares water quality parameters with their standard limit or background concentrations (Bharti and Katyal, 2012.; CCME, 2001; Khan et al., 2004; Lumb et al., 2006). Similar to the BCWQI, it has wide flexibility in the selection of variables and consider up to 400 water quality parameters, including physico-chemical, coliform and heavy metals (Abbasi and Abbasi, 2012; Terrado et al., 2010). For calculation of this index, at least four (4) water quality parameters with their threshold/standard (objective) values are needed. It is considered the most sensible water quality index used for surface water vulnerability assessment method in a data set with low values, as it takes more weight than those with high values (Bharti and Katyal, 2012). By this indexing model, it is possible to identify the exact problematic parameters that may possibly contribute to dropping the CCME WQI values. It would illustrate the specific change in the water environment, which would be great information for water users, suppliers, planners, policy makers, and environmentalist (Lumb et al., 2006).

By considering the wide range of variables, identifying the exact problematic parameters and easy calculation system had made the CCMEWQI well accepted and universally applicable. Hence, it is being applied by many scientists and water agencies all over the world, with minor or no modification (Bharti and Katyal, 2012; Khan et al., 2004; Lumb et al., 2006). Other researchers such as, Abhishek and Khambete (2013); Boyacioglu (2010); Damodhar and Vikram Reddy (2013); Magesh et al. (2012); Selvakumar and Ch (2012); Sharma and Kansal (2011) used this index in their research for assessing water quality and classification of water.

From the above review, it is clear that among all water quality indices CCMEWQI is more acceptable to the water scientist, agencies and most stakeholders. If it were to be used for water quality of Tunggak River, the details about the CCMEWQI would need to be considered.

The CCMEWQI comprises of three factors, F_1 (scope), F_2 (frequency) and F_3 (amplitude). These factors are defined as follows (CCME, 2001):

F_1 (scope): F_1 assesses the extent of water quality guideline non-compliance over the time of interest, which means the number of parameters whose objective limits is not met

$$F_{1(scope)} = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}} \right) \times 100 \qquad \text{---------- (2.4)}$$

Where, the "variables" indicate those water quality parameters whose objective values (threshold limits) are specified and observed values at the sampling sites are available for the index calculation.

F_2 (frequency): F_2 assesses the number of occasions the observed or the tested value is off the acceptable limit with which the objectives are not met. It represents the percentage of individual test that do not meet the objective (failed test)

$$F_{2(frequency)} = \left(\frac{\text{Number of failed test}}{\text{Total number of variables}} \right) \times 100 \qquad \text{---------- (2.5)}$$

F_3 (amplitude): F_3 denotes the number of failed test values that do not meet their objectives.

It can be calculated in three steps-

Step 1 *(Excursion):* The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective, is termed an "excursion" and is expressed as follows;

When the test value must not exceed the objective:

$$excursion_i = \left(\frac{Failed\ Test\ Value_i}{Objective_j} \right) - 1 \text{---------- (2.6)}$$

For the cases in which the test value must not fall below the objective:

$$excursion_i = \left(\frac{Objective_j}{Failed\ Test\ Value_i} \right) - 1 \text{---------- (2.7)}$$

Step 2 *(normalised sum of excursions):* The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalised sum of excursions, or nse, is calculated as follows;

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{No.\ of\ Test} \text{---------- (2.8)}$$

Step 3 (calculation of F_3): F_3 is then calculated by an asymptotic function that scales the normalised sum of the excursions from objectives (nse) to yield a range between 0 and 100.

$$F_{3(amplitude)} = \left(\frac{nse}{0.01nse + 0.01} \right) \text{---------- (2.9)}$$

With these three factors, CCMEWQI is calculated as:

$$CCMEWQI = 100 - \left(\frac{\sqrt{F_1^{\,2} + F_2^{\,2} + F_3^{\,2}}}{1.732} \right) \text{---------- (2.10)}$$

The factor of 1.732 arises because each of the three individual index factors can range as high as 100. This means that the vector length can reach

$$\sqrt{100^2 + 100^2 + 100^2} = \sqrt{30000} = 173.2 \text{---------- (2.11)}$$

as a maximum. Division by 1.732 brings the vector length down to 100 as a maximum.

Based on the CCMEWQI values the water quality is ranked in five categories. They are;

Excellent (Grade/class I): (CCME WQI Value 95-100) – Water quality is protected and no threat or impairment of pollution is prevails. The condition of water is very close to natural or pristine level. Water can be used for all purposes including drinking, recreation, irrigation and livestock watering. It is similar to 'Class I' of INWQS, Malaysia.

Good (Grade/class II): (CCME WQI Value 80-94) – Water quality is protected but a minor degree of threat or impairment prevail; water conditions rarely depart from natural or desirable levels. This water can be used for all-purpose including aquatic life and wildlife and also drinking after disinfection. It is similar to 'Class II' as categorised by INWQS, Malaysia.

Fair (Grade/class III): (CCME WQI Value 65-79) – Water quality is generally safe but threatened or impairment has prevailed occasionally. Water conditions sometimes depart from natural or desirable levels.

Marginal (Grade/class IV): (CCME WQI Value 45-64) – Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.

Poor (Grade/class V): (CCME WQI Value 0-44) – Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

This Water Quality Indexing system is developed based on the threshold or standard values of parameters which can be used for everywhere in the world with their own standardisation system. It can be used for the present research as Malaysia has fixed-up their standard/threshold limit of more than 72 water quality parameters (Zainudin, 2010).

2.4 HEAVY METAL CONTAMINATION OF SOIL

Heavy metals are the components of natural soil (Besada et al., 2011). The background concentrations are the natural amount of heavy metals in soil. The fluctuations in heavy metal concentration largely depend on complex bio-geochemical cycles. This complex cycle may be influenced by the anthropogenic activities like dumping of industrial effluents, treatment of wastes, vehicles trafficking and

agricultural practices (D'Emilio et al., 2013; Ramos-Miras et al., 2011; Smith, 2009). However, in this study, both soil heavy metal contamination and source identification were investigated. Soil physical properties such as, soil pH, soil organic matter and EC were also studied as these are closely related to the heavy metal contamination (Deka and Sarma, 2012).

2.4.1 Soil Physicochemical Properties

2.4.1.1 Soil pH

Soil pH indicates the acidic or basic properties of soil. It is the measure of acidity or the alkalinity that is also known as soil reaction (Camargo et al., 2007; McCauley, 2003). Soil chemistry and fertility are indicated by soil pH. It affects the chemical properties of the elements in the soil, as well as many of the soil properties (McCauley, 2003; 2005). It also affects the pH of adjacent water bodies (Addy et al., 2004; Brady and Well, 2007). Solubility of nutrients and activities of micro-organisms that are responsible for breaking down organic matter and chemical compounds are largely influenced by the soil pH (Garcia et al., 2002; Liu and Hanlon, 2012; Shen et al., 2011). It also affects the enzyme activities in the soil (Das et al., 2011; Khan et al., 2003). The pH influences the inhibitors or the activators of concentration in the soil solution and thus affects the enzyme activities (Bilen, 2010; Myburgh, 2013).

The most favourable soil pH range for plant growth and uptake maximum plant nutrients is between 6.0 - 7.0 as in this range most of the plant nutrients remain readily available (Bååth and Anderson, 2003; Liu and Hanlon, 2012). Fluctuation of soil pH from the allowable range may affect the pesticide activities in the soil as it may change the pesticides into undesirable forms or pesticides may not degrade as expected (Arias-Estévez et al., 2008; Spadotto and Hornsby, 2003). Soil pH largely affects the solubility of metals in soil solutions. A good number of heavy metals become more soluble under acid conditions and can percolate downwards with water through the soil, and in some cases, they can move to aquifers, surface stream or lakes (Antoniadis et al., 2008). However, the majority of the upland soils in Malaysia is weathered and are developed from a series of parent materials and the pH of that highly weathered soil are usually < 5.0 (Shamshuddin and Anda, 2008). Peat soil is a dominating soil category in the

country, which are characterised by having low pH (Grealish and Fitzpatrick, 2013; Huat et al., 2011; MARDI, 2009).

2.4.1.2 Soil Electrical conductivity

The ability of soil to conduct the electricity is termed as soil electrical conductivity. It has been used to measure the salinity of soil (Al-Busaidi et al., 2006; Davis et al., 1997; Motavalli et al., 2013). To estimate variation in some of the soil physical properties EC measurements are an important tool (Corwin and Lesch, 2005). However, the EC measurement also has some potential where salinity is not a problem. EC is correlated with a variety of soil properties including soil texture, soil organic matter, salinity, cation exchange capacity (CEC), drainage conditions, and subsoil characteristics that affect crop productivity. It is also correlated with topsoil depth, soil pH and available water holding capacity (Chan et al., 2006; Corwin and Lesch, 2003; Doerge, 2001).

2.4.1.3 Soil organic matter

Soil organic matter (SOM) includes all organic matter components within the soil. It consists of dead plant without leaving the roots and animal residues at various stages of decomposition, soil organisms including their cells, tissues and synthesized substances in soil. Soil microbial activities on these fresh inputs alter them to microbial biomass that ultimately convert into the soil organic matter (Bilek, 2007); Kögel-Knabner, 2002; Perminova and Kulikova, 2008). The structure of fresh organic inputs and soil organic matter is completely different from each other; where the organic matter is characterised by a much more complex chemical nature (Brookes et al., 2008). In addition to the above stated inputs, soil organic matter also consists of some complex compounds, which are relatively more resistant to decay (Huang et al., 2009; Schmidt et al., 2011). These complex materials are synthesised by the soil microorganisms that are collectively known as humus. The organic matter content of a typical well-drained mineral soil usually varying from 1.0 to 6.0% by weight in the topsoil and it is normally less in the subsoil (Magdoff and Es, 1993; Johnston and Poulton, 2005).

Soil organic matter is an important contributing factor to soil fertility and productivity, and is a key factor in the global carbon cycle (Manlay et al., 2007). Indeed, soil OM is an important source of nutrients as it promotes soil structure and water retention capacity and is a substrate for soil heterotrophs (Barthèsa et al., 2008; Sohi et al., 2010; Trejo et al., 2012). It plays a vital role in conserving the soil physical condition, nourishing soil microbial activity and ensuring high and sustainable crop production (Johnston and Poulton, 2005; Lal, 2007). SOM act also as a buffer in the soil solution that protects the rapid change in soil pH as it also fixes organic contaminants, keeping them beyond the soil solution so that plant cannot uptake the pollutants and they cannot leach into the ground water (Cooperband, 2002). Declining or removal of organic matter is an important factor of deteriorating soil productivity and increasing soil erosion (Jahiruddin and Satter, 2010). However, SOM has many positive effects on soil physical and chemical properties and it enhances the soil's capability to provide regulatory ecosystem services (McCauley, 2005).

2.4.2 Soil Heavy Metals

Soil is an important part of environmental condition that can influence human health (Chabukdhara and Nema, 2013). With the rapid development in the industrial and urban sectors, heavy metal contamination of soil is also increasing. Because of their extended persistence and toxicity, metal contaminations are nowadays a great concern all over the world. It can threaten the human health, ecosystems, food safety and water resources (Dheeba and Sampathkumar, 2012; Jan et al., 2011; Solgi et al., 2012). Soil is the major source of plant nutrients. Normally plants uptake the nutrients and water from soil, for their growth and reproduction. With these nutrients and water, they also uptake contaminated metals. This way metal enter into the food cycle and thus create health hazard (Dheeba and Sampathkumar, 2012; Oyedele et al., 2006). Again, contaminated heavy metal can move from soil to the adjacent water body and may percolate to the ground water and consequently pollute it. Through the drinking water metal can enter easily to human and animal body and accordingly cause the health hazard as drinking water is a major pathway of entering metals into human and animal body (Njar et al., 2012; Muralidharan, 2013; Qu et al., 2012).

A number of researchers have proved that heavy metals were among the contaminants that degrade the environments or decrease the qualities of soils (Sponzaa and Karaoğlub, 2002; Tangahu et al.,2011; Tripathi and Misra, 2012). Soil can act as a sink for metals contaminate, which usually come from a variety of sources like industrial activities, agricultural practices and deposition of emitted particles from vehicle exhaust (D'Emilio et al., 2013; Guo et al., 2012; Solgi et al., 2012; Xu et al., 2013). Various soil parameters especially soil organic matter and pH have significant influence on the availability of heavy metal in sludge treated soils (Antoniadis et al., 2008). Moreover, previous researches reported that the concentrations of heavy metals were positively correlated with the type of clay and content in soil (Finžgar et al., 2007; Szabó and Czellér, 2009). The rapid Industrialisation with inadequate waste management would generate increased amount of inputs that led to large-scale contamination of soil as well as the surrounding environment (Srinivasa Gowd et al., 2010). Several metal industries used a good number of metals either in raw or furnished condition to produce alloys and steels (Li et al., 2008). These industries also generated solid wastes, wastewater, and waste air. These wastes normally come to soil directly by dumping of wastes or indirectly by dust falling, deposition, precipitation and other ways (Abechi et al., 2010; Jarup, 2003). In addition to anthropogenic activities, natural sources also contribute a lot to soil heavy metal contamination (Adamu, 2010; Hu et al., 2013; Moor et al., 2001).

2.5 WATER QUALITY MODELLING

A water quality model is a tool that can predict the fate of water pollution using mathematical simulation procedures (Benedini, 2011; Wang et al., 2013). Mathematical models of water quality are a means to obtain the best resolutions of water problems and play identical role in comprehensive watershed management (Alexander et al., 2007; Tufail, 2006). It can simulate the effect of different scenarios on water quality as well as choosing specific solution and assess the water quality parameters (Tsvetkova, 2007; Wang et al., 2013). Water quality model is often used to predict the behaviour of a complicated, poorly understood entity of a river basin from the behaviour of its well-understood parts, generate hypothesis, and test the validity of field measurements and assumptions derived from observed data. Simulation techniques are generally used in

predictive modelling for the prediction of some system property that is actually measured to see whether computer projections and field data agree or otherwise. Predictive models are frequently used in resource management situations to assess environmental impact or change (Jantz et al., 2004; Jones et al., 2013).

Water quality models can provide data assistance for environmental management and technical supports for water environmental protection and thus nowadays it is an important tool for taming environmental management decisions (Bai et al., 2012; Wang et al., 2013). Development of theory of models and updated computer techniques enhanced the development of new water quality model for the last couple of years. A good number of water quality models have been introduced in the recent years with various model algorithms considering the topographical differences of water bodies, and time and space of pollutants (Wang et al., 2013; Wang et al., 2009).

Stochastic and deterministic models are the two types of water quality model that are used for water quality modelling; these two types of models can be empirical or theoretical or both (Mohamed, 2008). Deterministic model attempts to simulate natural processes of self-purification in river system and the stochastic model randomizes the error in the water quality model. However, the water quality model was first introduced by Streeter and Phelps (1925) to control river pollution in Ohio state of the US. After that introduction, significant progresses in water quality modelling have been made by several scientists all over the world. Progress in the development in this field was remarkable. The single factor model has been upgraded to multi factors of water quality, steady-state model were promoted to dynamic model, the point source model was enhanced to the coupling model, and zero-dimensional model were improved to three-dimensional models (Wang et al., 2011; Zu-xin and Shi-qiang, 2003). The real development and recognition of water quality model had taken place in between 1980 and 2000. Several scientists developed a number of water quality models during that period (Ambrose et al., 1993; Brown and Barnwell, 1987; Cole and Wells, 2000; DHI, 2008; Ivanov et al., 1996; Runkel, 1998; Shanahan et al., 2001; UKEA, 2001 ; Whitehead et al., 1997).

Among the water quality models, QUAL2E was the widely used mathematical model for river and stream water quality to evaluate the conventional pollutant impact(Brown and Barnwell, 1987; Drolc and Končan, 1996; Kannel et al., 2007). It was developed by USEPA to evaluate the waste load allocation (WLA), discharge-permit allocation, and other water quality pollution (Mohamed, 2008). Although the model is numerically accurate and include updated kinetic structure for most conventional pollutant (Park and Lee 2002); it still had some limitations which were later modified by Park and Lee (2002) and they developed QUAL2K, 2000. It included the addition of new water quality interactions. It was further improved by Chapra and Pelletier (2003) with the name QUAL2K, 2003. By modifying the QUAL2K, 2003, Pelletier et al. (2006) developed QUAL2Kw, which is the modernised version of QUAL2E (Kannel et al., 2007).

QUAL2Kw has many new features, including Software Environment and Interface, Model segmentation, Carbonaceous BOD speciation and others (Pelletier and Chapra, 2008). Similar to QUAL2K, it is a one-dimensional, steady flow stream water quality model and useful even in data limited condition (Kannel et al., 2007). The software of QUAL2Kw is freely available and can be used for both small and big rivers (Bottino et al., 2010). It can simulate a number of constituents including temperature, pH, carbonaceous biochemical demand, sediment oxygen demand, dissolved oxygen, organic nitrogen, ammonia nitrogen, nitrite and nitrate nitrogen, organic phosphorus, inorganic phosphorus, total nitrogen, total phosphorus, phytoplankton and bottom algae. Kannel et al. (2007) applied the model for Bagmati River, Nepal and the model represented the field data quite well. Gardner et al. (2007) also used the model for better understanding of the water quality status in Rio Blanco watershed in Jalisco, Mexico. As a tool for water quality management of small river basin, Oliveira et al. (2012) used this QUAL2Kw in Portugal. In Malaysia, QUAL2K model was used by Zainudin et al. (2010) for Sungai Tebrau and found as an outstanding tool in managing the river basin. It is common nowadays in the management of surface water quality that includes mathematical models for evaluating the impact of pollutants. Water quality models are being used for water management as an important tool; which are able to predict long and short term variation of water quality parameters (Bottino et al., 2010; Sardinha and Conceição, 2008).

2.6 CONCLUSION

The water quality studies in local, national and global contexts have been reviewed in this chapter. The reviewed studies suggest that the surface water deterioration was primarily due to the organic substances and inorganic nutrients, suspended solids, dissolved solids and heavy metals. They were largely induced by the anthropogenic activities. The major sources of river water pollutions were effluents and wastewater discharges from multifarious industries, sewage treatment plants, agricultural-farms, dumpsites of solid wastes, domestic and urban areas. High levels of organic constituent have increased the biological and chemical oxygen demands in river water and lessened the DO level. High organic content has pulled down the pH of river water to acidic condition in which most of the species in tropical streams could not survive. The reviewed studies indicated that high levels of inorganic nutrients such as nitrogen and phosphorous in the river can lead to unexpected extreme growth of aquatic plants, this causing less aeration, restrict water flow and consequently reduced the DO that result in water quality deterioration. Solids including suspended and dissolved solids are common pollutants in any surface water. They degrade the river water by reducing the light penetration into the water column; silting and blanketing the riverbed to ultimate destroy the aquatic life. Heavy metals in water can cause serious problems for aquatic life as well as for everyday water use. Elevated levels of trace metals may cause sub-lethal effects on living organisms, such as, changes to their physiology, reproduction and behaviour. Excess or toxic amount of heavy metal presence can make the water less potable for water supply and other uses.

Water quality studies reported that the presence of a variety of pollutants in the river and lake water could deteriorate its quality, and water become unsuitable for the support of aquatic life as well as water supply for drinking, recreational, industrial and irrigation purposes. The presence of toxic level of pollutants in surface water has exposed adverse effect on fish species and other aquatic organisms. The reviewed studies confirmed that the sources of pollutants were mainly the anthropogenic activities associated with the natural sources and climatic reasons. The previous study on the water quality index (WQI) stated that it is an important tool for assessing the water quality and classifying the river water. A good number of water quality indices have

been developed and in use all over the world. The DOE-WQI that considered six water quality parameters are being used for water quality assessment and river water classification of the Malaysian river. The WQI that can consider more parameters might be the better option, as water quality deterioration involved numerous pollutants.

Soil heavy metals contamination studies suggest that contamination of heavy metal affects the human health as the nutrients enter into human body though the food cycle. It can cause water quality deterioration when leached or percolated to the adjacent water body and thus hamper the aquatic organisms. The source of soil heavy metal contamination can be natural, as well as, anthropogenic causes like dumpsites of effluents from the industries that use heavy metals and metals alloys, vehicle exhausts, use of fertilisers and so on. The studies reported that although some heavy metals were essential for plant and animal lives, the toxic amount of those metals and the non-essential heavy metals were destructive for the environment as well as, living beings.

Previous studies on water quality modelling support that water quality modelling can be an important tool for water quality management. With the advancement of computer techniques and mathematical theories, development and improvement of water quality model, is also more rapid. Among the models, QUAL2Kw was more widely used river and stream water quality model.

In Tunggak River, there had been no in-depth, long-term and comprehensive water quality study covering most of the important water quality parameters and other important aspects. A limited number of parameters from two monitoring stations have been monitored by the department of environment (DOE) for the last couple of years. However, no study was performed on water quality assessment in the aspect of supporting aquatic life and other water uses. This monitoring program did not integrate physicochemical assessment results with heavy metal contaminations. DOE-WQI was used in the monitoring program to classify the river stress according to the DOE river water classification scheme. Nonetheless, the information obtained from only two stations and limited water quality parameters did not focus on the real scenarios of the river water. Regarding the water quality index the DOE-WQI cannot able to provide the real condition of water quality, as it consider only six physic-chemical parameters.

Therefore, it is essential to develop a new water quality index or to adopt an existing water quality index that is widely used, globally accepted and better comparing with DOE-WQI. As per the literature reviewed, no study was ever done in the area to investigate the soil heavy metal contamination. Similarly, any in-depth study of water quality of the river had never been assessed or simulated using any water quality-modelling tool, although the water as well as the environment of the area was heavily polluted by the industrial activities from the beginning of the development of the Gebeng industrial estate (GIE).

It is essential to consider the above-mentioned components during water quality assessment, water classification and assessment of heavy metal contamination of soil to obtain the status of the Tunggak River and the surrounding surface water, as well as, the soil of the Gebeng industrial area. The Tunggak River that is situated adjacent to the GIE plays a substantial role in the discharging of the industrial effluents and wastewater, which affect the ecology of the catchment, and aquatic and marine environment as it falls into the South China Sea. Rapid developments in the GIE had threatened the river water quality and soil of the area. The present study conducts on the assessment of water quality, classification of river water using DOE-WQI, physicochemical characteristics and heavy metals contamination of soil, sources of pollution, and simulation of water quality parameters using QUAL2Kw water quality modelling software. Furthermore, a WQI model has been proposed to adopt for the Tunggak river water assessment, combining the DOE-WQI and Canadian Council of Ministers of Environment water quality index (CCMEWQI). Finally, water quality control strategy has been discussed using the water quality modelling software to manage the water quality of the Tunggak River.

CHAPTER 3

METHODOLGY

3.1 INTRODUCTION

Chapter 3 describes about the study area, the methodologies and procedures used to establish the monitoring stations for water quality assessment, calculation of water quality index, soil sampling and analysis and water quality modelling of Tunggak River. The chapter also includes the monitoring stations selection techniques, procedures for measurement of parameters, plan for sampling frequency, sampling approach, methods of laboratory analyses and data analysis with statistical software.

3.2 DESCRIPTION OF THE STUDY AREA

3.2.1 Location

Gebeng is a small town in Kuantan in the state of Pahang, in peninsular Malaysia. It is the main industrial area of Kuantan, which is located in the neck of Kuantan Port. The geographical location of the town is 3° 58' 0" North and 103° 26' 0" East, about 20 km north of Kuantan town. The surface water of the area including adjacent river Tunggak is the focus of the study. Gebeng Industrial Estate (GIE) is one of the leading industrial areas in Malaysia. It has been established since 1970. Subsequently, the two main phases of the industrial area were developed, where phase one consists of small and medium scale industries, such as, wood processing industries, metal works factories and concrete ducting company located near the main Kuantan-Gebeng trunk road by-pass. In the early 90s the second industrial phase (Phase II) is developed. It consists of mainly petrochemical companies, such as, Petronas MTBE-Polypropylene, BP Chemicals, WR Grace, Eastman chemical, Kaneka and Cryovac.

Currently the third phase is being developed and would be occupied by Poly-plastics Asia Pacific, BASF-Petronas, Petronas CUF, Petronas Centralized Emergency Facilities and PDH Plant (CAP-SAM 2011; Hossain et al. 2013).

3.2.2 Hydrology

Gebeng is located within the Sungai Balok and Sungai Tunggak catchment area, adjacent to the South China Sea. The tidal range in this area is between 2 m - 3.5 m with a difference of 1.5 m between high and low tides. At the mouth of Sungai Balok and Sungai Tunggak, the typical tidal levels usually rise from 0.5 m to 2.5 m., and it is likely propagate 10 km upstream. The groundwater level in this area is very shallow and it is only 0.95 - 3.5 m below ground surface. It is quite difficult to augur any well in case of pollution, spills, leaks etc. (Sujaul et al. 2013: CAP-SAM 2011). Map of the Gebeng area indicating its location on Pahang map is shown in Figure 3.1.

Figure 3.1: Map of the study area indicating the water sampling stations at Gebeng

Gebeng Industrial Estate was formerly part of the Paya Tanah Merah peat swamp forest. From the inception of the GIE, the area was reclaimed using fill quarried from the nearby hilly areas. The process of cleaning and filling is still ongoing and it is still surrounded by peat swamp vegetation. Industrial wastewater or effluents from GIE are drained through two main water streams; Sungai Tunggak and Sungai Balok. Sungai Balok which generally serves the western catchment of the GIE originates as Sungai Batang Panjang from the hills to the north west of GIE and flows into the sea (CAP-SAM, 2011). The second main flow Sungai Tunggak originates from the Tanah Merah peat swamp forest and flows through the middle and eastern boundary of the GIE. This river drains the industrial wastewater from the most part of the GIE including the eastern sector. Thus, it serves the middle and eastern catchment of GIE and flows in a southerly direction towards the sea. After its confluence at Sungai Balok near the 'Angler marine centre', it falls into the South China Sea (Sujaul et al., 2013).

3.2.3 Climate of Gebeng

The climate of entire Malaysia is tropical in nature, characterised by high but approximately uniform temperature, high humidity and copious rainfall throughout the year. The rainfall pattern of the east coast is affected by wind direction and topography. The North East monsoon that causes heavy rain in the areas is usually between October-March. Thus, Gebeng experiences two seasons per year, one is the Dry (dry and hot) season (from March to August) and another is the Wet (rainy) season or monsoon (from September to February). During monsoons, there are high precipitations with an average rainfall of 2,958 mm/annum. Sometimes, the heavy rain may cause an overflow of the retention ponds and other stored wastes into groundwater and/or river. It may also result in runoffs of wastes from the storage shed, residual storage facility (RSF) and segregated water leach purification (WLP) ponds into the drain and groundwater, and into the river water and eventually the south china sea (CAP-SAM, 2011). The average temperature at Gebeng usually lies between 22-32 °C and it may raise up to 40 °C in hot season (Wikimedia, 2013). The average temperature and precipitation of the study area are presented in Appendix E.

3.2.4 Geology of the study area

Gebeng area is geologically underlain by the alluvium of Quaternary age with a thickness of approximately up to 38 meters. The alluvial layer is formed with peat, humid clay and silt of Beruas and Simpang formation. Underlying the Quaternary alluvium layer, the Granite of Cretaceous age is formed. Generally, the area is swampy and had been deposited with the debris of soil brought down by river flow. The soil of the area is characterised by alluvial peat soil (CAP-SAM, 2011).

3.3 SELECTION OF SAMPLING STATIONS

3.3.1 Water sampling stations

The possible locations in the study areas were surveyed for monitoring stations prior to initiation of water and soil sampling. The survey was done with the help of GPS. The point and non-point sources of pollution, human activities and possible natural sources that could impair water quality of the area especially of the respective station were identified. During the survey, five conditions were examined:

1. Accessibility to the stations and ability to sample in all meteorological conditions;
2. Uniformity of the water column;
3. Location of streams;
4. Location of the industrial sites; and
5. Distance from point sources of pollution.

After examining all the above conditions, ten sampling stations were established along the Tunggak River and the surrounding area of Gebeng Industrial Estate (Figure 3.1).

Eight stations were selected from Tunggak River and two stations were picked from swampy areas. With those ten stations, the whole area of surface water of the Gebeng (except west catchment) was covered. The stations were named and numbered from downstream of the Tunggak River. The middle stations were adjacent to the industrial estates that represented the river water quality at industrial zones. The last two stations represented the status of swampy area that was adjacent to the new phase of

industrialisation and to the peat swamp forest. The geographical coordinates and locations of the sampling stations are shown in Table 3.1.

3.3.2 Soil sampling stations

Soil sampling stations were selected on the land use pattern of the area that could also hamper the water quality. The emphasis was given to identify the locations, where the industries dumped their effluents and the domestic wastewater discharged areas. Based on the land use pattern and identified possible pollution sources, 10 stations were selected. The total study area was divided into three zones, namely residential cum semi-industrial zone (with 3 stations), industrial zone (with 4 stations) and swampy area (with 3 stations). The map of the study area indicating soil-sampling points is presented in Chapter 6 (Heavy Metal Contamination of Soil). The geographical coordinates and locations of all sampling points are shown in Appendix F.

Table 3.1: Location of the water sampling stations with their geographical coordinates

Station number	Name of stations	Geographical coordinates	Location
1.	Downstream Station (DS)	03°56'35"N 103°22'32"E	Adjacent to the mangrove vegetation and near estuary
2.	Seberang Balok 1 (SB1)	03°57'19"N 103°22'60"E	Adjacent to the Kampung Seberang Balok (at south part)
3.	Seberang Balok 2 (SB2)	03°57'40"N 103°23'15"E	Adjacent to the Kampung Seberang Balok (at north part); near Kampung Berahi
4.	Industrial zone 1 (IZ1)	03°57'54"N 103°23'23"E	Adjacent to the road and starting point of Gebeng industrial estate (GIE)
5.	Industrial zone 2 (IZ2)	03°58'13"N 103°23'23"E	Located besides Asturi Metal builders (M) Sdn. Bhd
6.	Industrial zone 3 (IZ3)	03°58'34"N 103°23'14"E	Located at the southern part of British Petroleum Sdn Bhd
7.	Industrial zone 4 (IZ4)	03°59'14"N 103°23'17"E	Adjacent to the road and near to the Eastman chemical industries
8.	Upstream Station 1 (US1)	03°59'16"N 103°23'17"E	The last station of Tunggak river at the upper part near peat swamp forest
9.	Swampy area 1 (SA1)	03°59'27"N 103°24'12"	Located near peat swamp forest
10.	Swampy area 2 (SA2)	03°59'38"N 103°24'45"E	Located near the new phase of industrial expansion and peat swamp forest

3.4 PARAMETERS MEASURED

Physicochemical parameters and heavy metals were measured from the water and soil samples of the study area. A total of twenty-four (24) parameters were studied from the water samples consisting of seven physical parameters, seven chemicals and ten (10) heavy metals as seen in Table 3.2. Rainfall and temperature data were collected from the Malaysian Meteorological Department in Kuantan. Soil samples were studied for determination of ten (10) heavy metals and three (3) physicochemical parameters.

Table 3.2: List of measured water quality parameters

Physical parameters	Chemical parameters	Heavy metals
Temperature	Dissolved oxygen	Arsenic
pH	Biochemical oxygen demand	Barium
Conductivity	Chemical oxygen demand	Cadmium
Salinity	Ammoniacal nitrogen	Chromium
Total dissolved solids	Nitrate nitrogen	Cobalt
Turbidity	Phosphate phosphorus	Copper
Total suspended solids	Sulphate	Lead
		Mercury
		Nickel
		zinc

3.5 SAMPLING FREQUENCIES

3.5.1 Water sampling

Sampling frequencies for water samples were determined based on the weather condition of the study area. Grab samples were collected for a period of one year from February 2012 to January 2013. Water sampling was done in accordance to the global environment monitoring system (GEMS)/water operation guide (WHO, 1992). Sampling of water was carried out for eight times; 4 times in the dry season and 4 times in the wet season. Sampling began from downstream sampling sites and proceeded upstream. During water sampling, two types of bottles were used. Surface water was collected with a 1000 ml HDPE bottle from about 10 cm below the water surface for laboratory analysis. With those ex-situ samples physicochemical parameters; such as,

ammoniacal-nitrogen (NH_3-N), nitrate-nitrogen (NO_3^-), phosphate (PO_4^{3-}), sulphate (SO_4), chemical oxygen demand (COD), total suspended solids (TSS) and total dissolved solids (TDS) were measured. Water samples for bio-chemical oxygen demand (BOD) were collected using dark 300 ml BOD bottles. All samples were collected and kept in dark cool boxes while maintaining 4 - 6 °C temperature until transported to the laboratory. In the laboratory, the collected samples were stored in the cold room on the same day. All analyses were done within 7 days of sampling. All chemical testing and analyses were carried out in the Environment Laboratory of the Universiti Malaysia Pahang (UMP).

3.5.2 Soil sampling

Soil samples were collected for one time on August 2012 from preselected 10 sampling stations. Three samples were collected from each station to get better and more reliable results. A total of 30 soil samples (10 x 3) were collected with Dutch auger from 30 sampling points. Samples were transported to the laboratory and air-dried. The details of sampling methods have been discussed in section 3.6.2 of this chapter.

3.6 SAMPLING METHODOLOGY

3.6.1 Water sampling methods

Water sample were collected manually from each sampling station. The methods for water sampling were adopted from the "Standard methods for the examination of water and wastewater" (APHA, 2005); Water analysis guide (HACH, 2005) and GEMS/Water operation guide (WHO, 1992). All containment and preservation methods were adopted based on the recommendations of above three guidelines including sampling techniques. The following procedures were maintained during water sampling:

i. Water samples were collected close to or in the middle of the river, wherever possible;
ii. Samples were taken approximately 10 centimetres from below the surface of the water;

iii. Sampling bottles were pre-cleaned with chromic acid and rinsed with distilled water prior to sample collection, and all bottles were again rinsed with river water before sampling was carried out.

3.6.2 Soil sampling methods

Soil samples were collected from in and around of the Gebeng industrial estate. The topsoil was collected randomly with a Dutch auger. Samples were collected with five replications of topsoil (0 - 20 cm) from each sampling point. About 500 gram of soil samples were collected from each sampling point. Soil sampling were done following the recommendation of Soil Survey Manual (Soil Survey Division staff., 1993). These samples were kept in a tight plastic bag and transported to the laboratory. In the laboratory, the samples were air dried, broken into smaller sizes using wooden mortar and sieved to pass through at 2 mm sieve. Sieved soil samples were used for determination of physicochemical properties and heavy metals content.

3.7 ANALYTICAL METHODS

The environmental methods have been employed in order to formulate a study based on sequences of event, such as, environmental degradation, type of pollution, methods of analysis, identification of pollution sources and solution to the problems. The methods used are discussed in the preceding paragraphs.

3.7.1 Water Quality Assessment

The aim of water quality assessment was to obtain quantitative information on the physical and chemical characteristics including heavy metal contamination of surface water mainly due to industrial activities. Water quality assessment was done based on the method approved by the APHA (2005) and proposed by Ward et al. (1990) that consist of three main components:

a) Sample collection;
b) Laboratory analysis; and
c) Data handling

Other components such as data analysis, reporting, and information utilization are considered as the information generation. In this study, the procedure in Figure 3.2 was followed for water quality assessment.

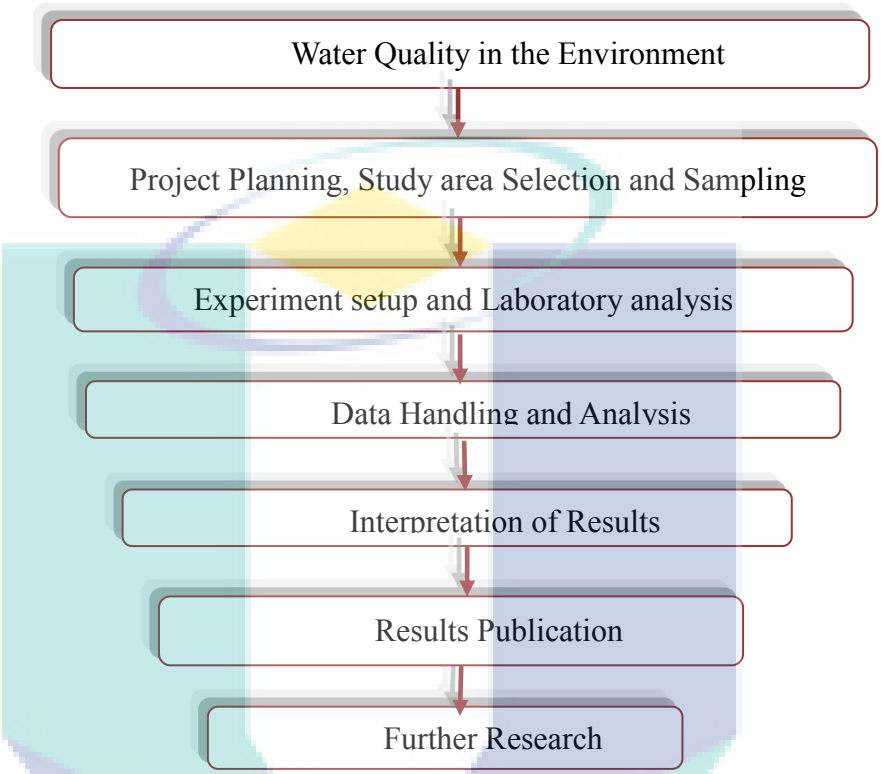


Figure 3.2: Flowchart of the water quality assessment procedure (Source: Ward et al., 1990)

3.7.2 Water Quality Analysis

Six physical water quality parameters (temperature, pH, DO, EC, salinity and turbidity) were measured *in-situ* during sampling using portable instruments (Table 3.3). Two other physical parameters (TSS and TDS) were determined in the laboratory along with chemical parameters and heavy metals.

3.7.2.1 In-Situ Measurements

In-situ measurement of water quality parameters: temperature, pH, DO, EC, salinity, turbidity and hydrological data were collected using portable instruments (Table 3.3). Application of the portable instruments was almost similar. Glass electrodes were plunged under the water and measurements were taken. To avoid errors and to get

Table 3.3: Instruments used for *in-situ* measurement of water quality and hydrological parameters

Parameters	Instruments	Unit
Temperature	YSI 650 MDS (Multi-parameter Display System)	°C
pH	YSI 650 MDS (Multi-parameter Display System)	
Dissolved oxygen (DO)	YSI 5100 (DO meter)	mg/L
Electrical conductivity (EC)	YSI 650 MDS (Multi-parameter Display System)	µS/cm
Salinity	YSI 650 MDS (Multi-parameter Display System)	%
Turbidity	HACH 2100P, Turbidimeter	NTU
River width	Measuring Tape	m
Water velocity	SWOFFER 300, Current meter	m/s
Depth of the river	CMI 5m measuring staff	m

a stable result, measurement was repeated at least twice or three times. Hydrological measurements (water velocity, depth and the width of the river) were done in a systematic way. Stream velocity and discharge measurements were determined using current meter. Measured width, depth and velocity were plotted on the square graphing paper and the thus the cross section of the river has done. From the cross section water flow (m^3/s) was calculated using the measured.

3.7.2.2 Laboratory Analysis

Collected water samples were preserved with ice in the iceboxes during transportation to the laboratory and those were preserved in the laboratory at a temperature below 4 °C until analysis to control all the activities and metabolism of the organisms in the water. For BOD_5, initial DO analysis was done as early as reach to the laboratory and the samples were kept in incubator for 5 days. Phosphate analysis was done within 48 hours of sample collection to avoid interference of other parameters. All laboratory analyses were done within 7 days of sample collection. Laboratory analysis of *ex situ* parameters was conducted in accordance with the standard method (APHA, 2005; HACH, 2005). The lists of physical and chemical parameters that was analysed in

the laboratory are shown in Tables 3.4 and 3.5 along with the methods adopted for analysis. The methods that used in this study were selected based on the recommendation of APHA (2005) and HACH (2005). The heavy metal content of surface water was analysed using ICP-MS spectrometry that can detect heavy metals at concentration as low as part per trillion (Anonymous, 2001) and is validated by US EPA Method 6020. Mercury was detected using direct mercury analyser, which can analyse the mercury directly without using any chemical or digestion step and is validated by US EPA method 7473 (EPA, 2007c; Colnaghi, 2011).

a) Physical parameters

Two physical parameters, TSS and TDS were analysed in the laboratory. The methods that were used to measure these two parameters are shown in Table 3.4.

b) Chemical parameters

Laboratory analyses were carried out to measure sixteen (16) chemical parameters (four inorganic nutrients, two organic parameters and ten (10) heavy metals) in the water samples collected from the study area. Methods of analysis and required equipment that were used to analyse the chemical parameters (except heavy metals) are given in Table 3.5.

c) Heavy metals

A total of ten heavy metals were analysed in the laboratory from the collected water samples. The methods and equipment used in the analysis are shown in Table 3.6.

Table 3.4: Methods used for analysing the TSS and TDS in water

Parameters	Method of analysis	Unit of
TSS	Method 2540 D (APHA, 2005), Gravimetric method	**mg/L**
TDS	Method 2540 C (APHA, 2005), Gravimetric method	**mg/L**

Table 3.5: Methods and equipment used in analysing the chemical parameters in water

Parameters	Methods	Equipment/Instrum
Ammoniacal-Nitrogen (NH_3-N)	Nessler method (HACH Method 8038; wave length 380)	HACH Direct Reading Spectrophotometer Model DR 5000
Nitrate-Nitrogen (NO_3- N)	Cadmium Reduction Method (HACH Method 8192; wave length 351)	HACH Direct Reading Spectrophotometer Model DR 5000
Phosphate- Phosphorous (PO_4^{3-})	Ascorbic Acid Method (HACH Method 8048; wave length 490)	HACH Direct Reading Spectrophotometer Model DR 5000
Sulphate (SO_4^{2-})	Sulfaver 4 Method (HACH Method 8051; wave length 680)	HACH Direct Reading Spectrophotometer Model DR 5000
Biochemical Oxygen Demand (BOD5)	Method 5210B (APHA, 2005)	YSI 5100 Dissolved Oxygen Meter
Chemical Oxygen Demand (COD)	COD Reactor Digestion Method (HACH Method 8000; wave length 430 & 431)	HACH Direct Reading Spectrophotometer Model DR 5000

Table 3.6: Methods and equipment used in analysing the heavy metals in water

Heavy metals	Methods of analysis	Equipment/Instrument
Arsenic (As); Barium (Ba); Cadmium (Cd); Chromium (Cr); Cobalt (Co); Copper (Cu); Lead (Pb) Nickel (Ni); Zinc (Zn)	EPA Method 6020A (EPA, 2007a)	Agilent 7500cx ICP-MS (Inductively coupled plasma mass spectrometry)
Mercury (Hg)	Method 7473 (EPA, 2007c)	DMA-80 Direct Mercury Analyser

3.7.3 Soil analysis

All collected soil samples were analysed in the laboratory to measure the physicochemical properties of soil and to detect 10 selected heavy metals contamination. Sieved soil samples were used for analysis. The list of parameters along with the methods of analysis and required equipment are shown in Table 3.7.

Table 3.7: Methods and equipment used in analysing the physic-chemical parameters and heavy metals contamination in soil

Parameters	Methods of analysis	Equipment/Instrument
Soil pH	Soil survey standard test method (Rayment and Higginson, 1992)	Seven Easy pH meter (Toledo)
Electrical Conductivity (EC)	Soil survey standard test method (Piper, 1942; Rayment and Higginson, 1992)	HACH 2100P Conductivity meter and cell
Soil organic matter (OM)	Weight Loss-on-Ignition method (Schulte and Hopkins, 1996; Combs and Nathan, 2011)	Muffle furnace- Carbolite ELF 11/23, Drying oven (105°C)
Arsenic (As); Barium (Ba); Cadmium (Cd); Chromium (Cr); Cobalt (Co); Copper (Cu); Lead (Pb) Nickel (Ni); Zinc (Zn)	EPA Method 6020A (EPA, 2007a)	Agilent 7500cx ICP-MS (Inductively coupled plasma mass spectrometry)
Mercury (Hg)	Method 7471B (EPA, 2007b)	DMA-80 Direct Mercury Analyser

3.8 STATISTICAL ANALYSIS

SPSS 16.0 statistical software was used for statistical analysis of data. Multivariate statistical analyses were executed in this study. To test the significant correlation amongst the water quality parameters Pearson correlation coefficient analysis was done. Significant levels used for the statistical analysis were 5% and 1% level of significance.

Significant level was interpreted as:

i. $P > 0.05$, insignificant;

ii. $P < 0.05$, significant at the 5% level of significance (*);

iii. $P < 0.01$, significant at the 1% level of significance (**)

Hierarchical cluster analysis (HCA) was done to group (cluster) the monitoring stations based on the pollution loading. Principal component analysis (PCA) was performed to identify the sources of pollution. Multiple linear regression (MLR) models were conducted to investigate the contribution of water quality parameters to water quality of the study area.

3.9 WATER QUALITY INDEX (WQI) AND WATER CLASSIFICATION

The water quality index (WQI) was calculated to classify the surface water of the Tunggak River and the surrounding areas of the Gebeng industrial estate. For the calculation of the WQI the DOE-WQI index was used according to the system adopted by the DOE (DOE, 1994; Zainudin, 2010). DOE-WQI was calculated based on the six water quality parameters, namely, DO, pH, BOD, COD, SS and ammoniacal-nitrogen (Norhayati, 1989; Zainudin, 2010). For the formulation of the DOE-WQI, an opinion poll was conducted where a panel of experts was consulted on the choice and weightage of the water quality parameters. Based on their opinions, a formula was established to calculate the DOE-WQI (DOE, 1994; Zainudin, 2010). The calculation of the WQI was done with the sub-indices values of the parameters that were obtained from a series of best-fit equations. These best fit equations were formulated from rating curves (Norhayati, 1989). The sub-indices for the particular water quality parameters were SIDO for DO, SIBOD for BOD, SICOD for COD, SIAN for ammoniacal-nitrogen, SISS for suspended solids and SIPH for pH. With those sub-indices, equation 3.1 was used to calculate the WQI, as follows:

$$DOE\_WQI = 0.22 \times SIDO + 0.19 \times SIBOD + 0.16 \times SICOD + 0.15 \times SIAN + 0.16 \times SISS + 0.12 \times SIPH \quad \text{--------- (3.1)}$$

Where, the SI indicates the sub-index function and the coefficients are the weightages for the corresponding parameters with a total value of unity. The best-fit equations used to calculate sub-indices are given in Appendix C.

With the calculated WQI values, the surface water of the study area was classified based on the recommendation of INWQS Malaysia. The DOE-WQI classification is shown in Appendix D and the INWQS Malaysia river water classification is given in Appendix A.

3.10 WATER QUALITY MODELLING

Water quality modelling was done to predict water quality trend of Tunggak River by using QUAL2Kw river and stream water quality modelling software. This software is a complimentary copy obtained from USEPA website. QUAL2Kw is the modernised version of QUAL2E enhanced stream water quality model (Brown and

Barnwell, 1987) and was adopted from QUAL2K model (Chapra and Pelletier, 2003). In the present study, it was used to simulate the water quality parameters to know the trend of the water quality of Tunggak River. For simulation, the river was divided into seven reaches and from every reach water quality and hydrological data was collected. The model was executed for simulation of eight (8) water quality parameters, namely, DO, BOD, COD, ammoniacal-nitrogen, inorganic phosphorus, pH, inorganic suspended solids and temperature as these are the major contributing parameters to the water quality of Tunggak River. The model was calibrated with data from the dry season and validated by data the wet season. Sensitivity analysis was performed to check whether the model parameters responded well with the changed concentration of water quality parameters or otherwise. Finally, different pollution control strategies were checked to implement the model results for controlling the river water pollution.

Water quality and hydrological data were measured in the study period and the supplementary climatological data required for the simulations were obtained from Malaysian Meteorological Department in Kuantan. A detail discussion on methodology is given in this section:

3.10.1 River segmentation and monitoring stations

The total 7.51 km length of the lower part of the Tunggak River was segmented into 7 reaches, as shown in Figure 3.3. The figure shows the reaches of the river along with the locations of point sources of pollution loads. Based on the upper stream and lower stream boundary of the reaches, eight monitoring stations were selected (Table 3.8). Table 3.8 shows the stations along with the distance of reaches. The monitoring, water sampling and data collection were done in March-August for the dry season and on September- February for the wet season. In this study, water quality parameters observed were water flow, temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), total suspended solids (TSS), inorganic phosphorus (PO_4-P), ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), 5 days biochemical oxygen demand as mgO_2/L (CBOD or BOD) and chemical oxygen demand as mgO_2/L (COD).

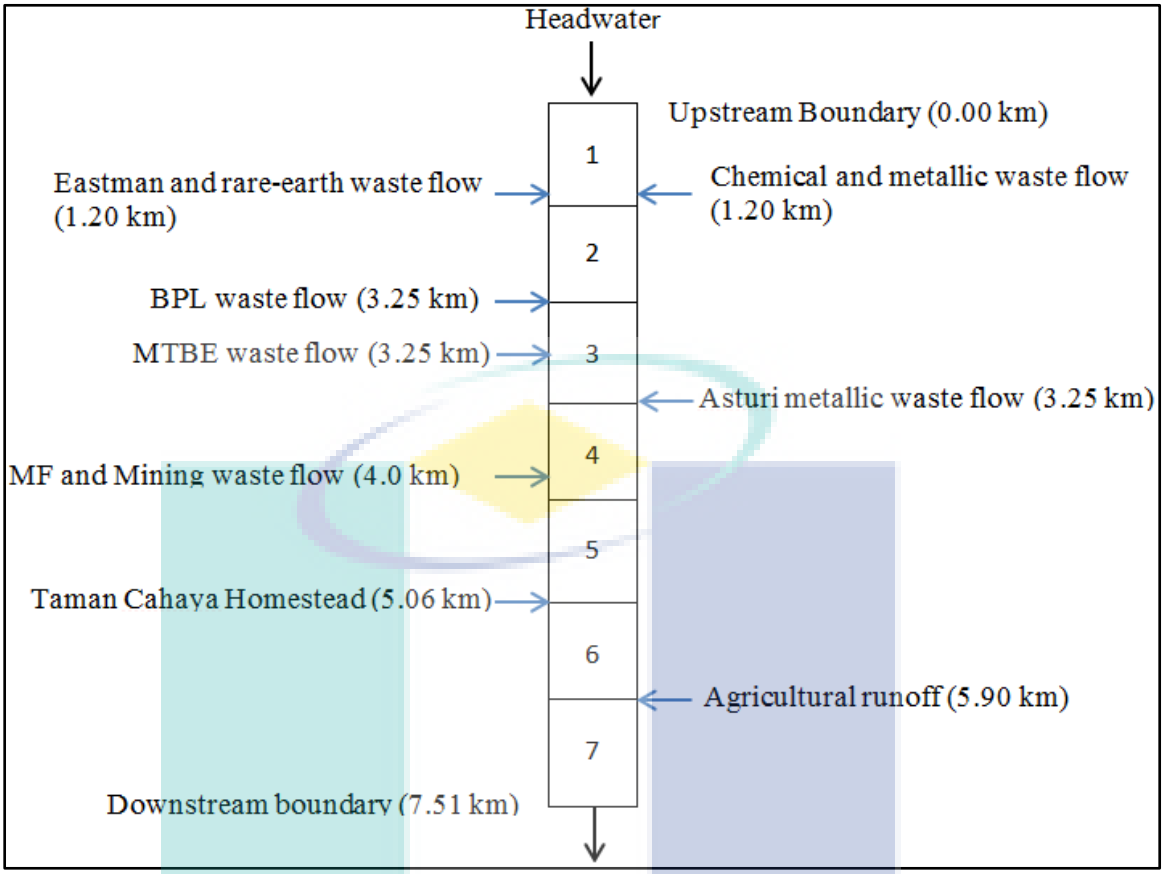


Figure: 3.3 QUAL2Kw segmentation scheme with location of pollution sources along Tunggak River

Table 3.8: Water quality monitoring stations in the Tunggak River

No.	Name of Stations	Distance from upper stream(km)	Location
1.	Upper Stream (US)	0.00	Near the bridge on Jalan Gebeng 2/6
2.	Eastman (EC)	1.27	Besides Eastman Chemical Sdn. Bhd
3.	British Petroleum (BPL)	1.17	50 meters from BP Chemicals Sdn. Bhd
4.	Astro (Ast)	0.87	Near Astro Sdn. Bhd.
5.	Mieco Factory (MF)	0.90	Near the bridge on Jalan Pintasan Kuantan
6.	Taman Balok (TBM)	0.85	50 meters from Taman Balok Makmur
7.	Seberang Balok (SB)	0.85	Near Perumahan Seberang Balok
8.	Lower Stream (LS)	1.60	Besides the bridge on Jalan Gebeng 2 (Port road)

3.10.2 Modelling Tools

In the study, a one-dimensional mathematical model QUAL2Kw was used. It can be used for river water quality simulation when the river water flow is steady but non-uniform and the pollution loading into it remains roughly constant (Oliveira et al., 2012;Zhang et al., 2012). It considers the influence of point source and non-point source pollution loads during simulation (Zhang et al., 2012). Moreover, the model has a number of new elements that make it usable for shallow and small river besides relatively large river basin (Anh et al., 2006; Cho and Ha, 2010).

The QUAL2Kw model has a general mass balance equation for all constituent concentration (Figure 3.4) in the water column (except bottom algae) of a reach *i* (excluding hyporheic) written as (Pelletier et al., 2006):

$$\frac{dc_i}{dt} = \frac{Q_{i-1}}{V_i}c_{i-1} - \frac{Q_{ab,i}}{V_i}c_i + \frac{E_{i-1}}{V_i}(c_{i-1} - c_i) + \frac{E_i}{V_i}(c_{i+1} - c_i) + \frac{W_i}{V_i} + S_i \text{-------- (7.1)}$$

Where, c_i = constituent concentration; Q_i = flow at reach *i* (m3/d); V_i = volume of reach *i* (m3/d); $Q_{ab,i}$ = abstraction flow at reach *i* (m3/d); E_i = bulk dispersion coefficient between reaches (m^3/d); E_{i-1}, *Ei* are bulk dispersion coefficients between reaches *i*−*1* and *I,* and *i* and *i* + *1*; W_i = external loading of the constituent (mg/day) and *Si* = sources and sinks of the constituent due to reactions and mass transfer mechanisms (mg/L/day). The detailed description of interacting water quality state variables process is described in Pelletier and Chapra (2008).

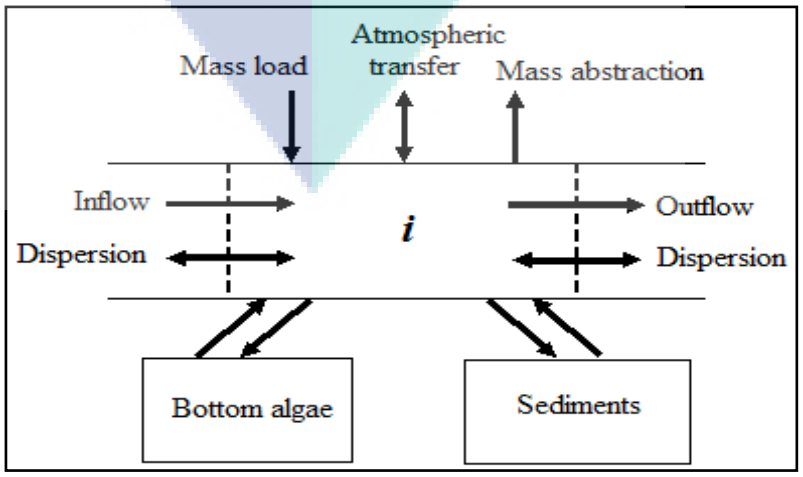


Figure 3.4: Mass balance in a reach segment *i* (Pelletier and Chapra, 2008)

The schematic diagram of the sources and sinks for water quality state variables are represented in Figure 3.5 (without the internal levels of nitrogen and phosphorus in the bottom algae) (Pelletier and Chapra, 2008). The figure shows the Model kinetics and mass transfer processes, where kinetic processes includes dissolution (ds), hydrolysis (h), oxidation (ox), nitrification (n), denitrification (dn), photosynthesis (p), respiration (r), excretion (e), death (d), respiration/ excretion (rx). Mass transfer process includes reaeration (re), settling (s), sediment oxygen demand (SOD), sediment exchange (se), and sediment inorganic carbon flux (cf).

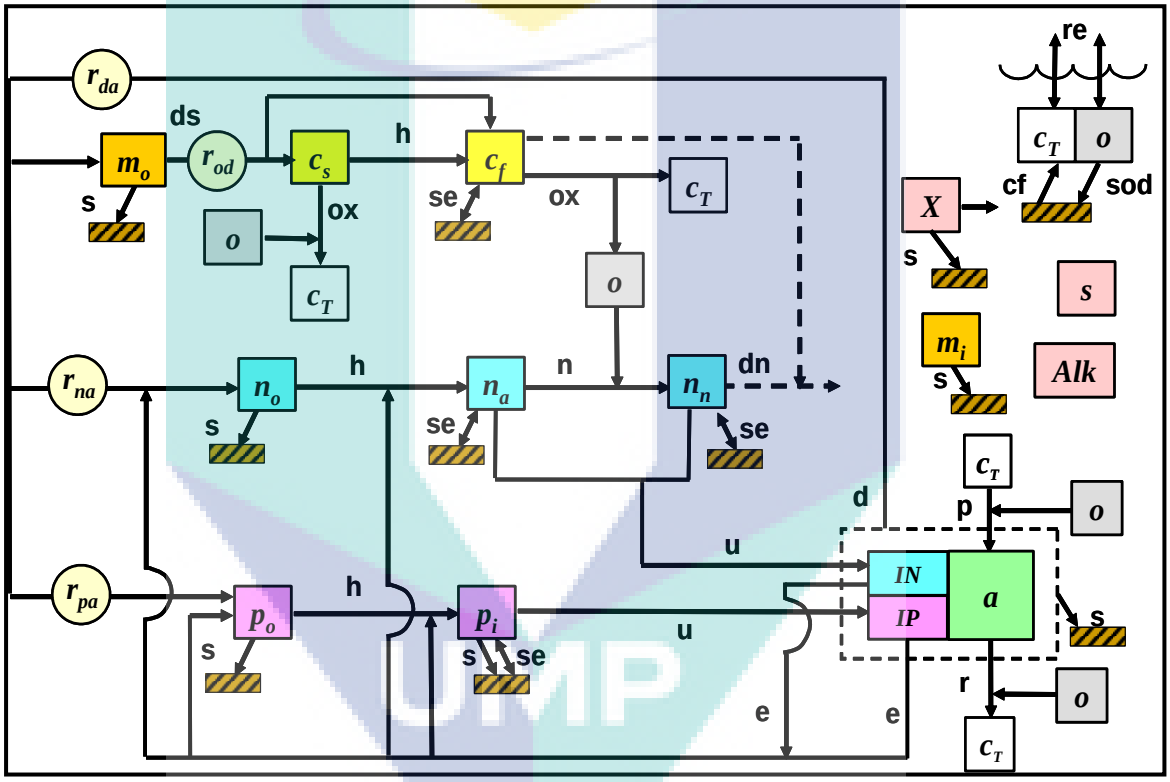


Figure 3.5: Schematic diagram of source and sink for water quality state variables (*a*: bottom algae, m_o: detritus, c_s: slow CBOD, c_f: fast CBOD, c_T: total inorganic carbon, o: oxygen, n_o: organic nitrogen, n_a: ammonia nitrogen, n_n: nitrate nitrogen, p_o: organic phosphorus, p_i: inorganic phosphorus, *IN*: Bottom algae nitrogen, *IP*: Bottom algae phosphorus, *mi*: ISS, *Alk*: alkalinity and *X*: pathogen).

For auto calibration, QUAL2Kw maximises the goodness of fit of the model results in comparison with measured data by using genetic algorithm (GA). It is the reciprocal of the weighted average of the normalised root mean squared error (RMSE) of the difference between the model predictions and the observed data for water quality constituents. The GA maximizes the fitness function *f(x)* as:

$$f(x) = \left[\sum_{i=1}^{n} w_i\right]\left[\sum_{i=1}^{n} \frac{1}{w_i}\left[\frac{\left(\sum_{j=1}^{m} O_{ij}/m\right)}{\left[\sum\left(p_{ij} - O_{ij}\right)^2/m\right]^{1/2}}\right]\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7.2)$$

Where, O_{ij} = observed values, P_{ij} = predicted values, m=number of pairs of predicted and observed values, w_i = weighting factors, and n =number of different state variables included in the reciprocal of the weighted normalized RMSE. Pelletier et al. (2006) described details about auto-calibration method in "QUAL2Kw – A framework for modelling water quality in streams and rivers using a genetic algorithm for calibration."

3.10.3 Model calibration and validation

Model calibration was run with the measured data of dry season. To avoid instability in the model calibration, the calculation step was set at 5.625 min (Kannel et al., 2007; Zhang et al., 2012). Euler's method was set for the solution of integration; Newton-Raphson method was used for pH modelling. The sediment diagnosis simulation was done for level I option. To perform goodness of fit different weighting factors were given to different parameters. The weight 50 was given for DO as it was the most influential parameter (Camargo et al., 2010; Kannel et al., 2007). Weight 2 was given for temperature, pH, CBOD and COD and for other parameters 1 was given as weighting factor. Model was run for a population size of 100 with 50 generations in the evolution (model runs in a population). According to Pelletier et al. (2006) a population size of 100 performs better than smaller numbers and as nearly as a population size of 500.

CHAPTER 4

WATER QUALITY ASSESSMENT

4.1 INTRODUCTION

Water quality is the chemical, physical and biological characteristics of water that express the measurement of the water condition in relation to the need for biotic species or human requirement or any other uses (Diersing, 2009; Johnson et al., 1997). Surface water is the main source of water, where the rivers are the major reservoir of this surface water. Rivers and lakes are the renewable sources of water, which are essential for the environment and important for domestic, industrial, agricultural and recreational purposes. Water assessment along with monitoring and water management are necessary for ensuing the sustainable use of water resources (Giardino et al., 2007).

Tunggak is an important river in Gebeng, Pahang Malaysia that originates in Tanah Merah peat swamp forest and falls into the South China Sea. It is of particular importance due to the vicinity of the Gebeng Industrial Estate (GIE). The river is flowing through the industrial estate along its eastern catchment that carries a major portion of industrial effluents. The surface water deterioration in the river as well as the surrounding areas of the GIE is the result of industrial pollution (Sujaul et al., 2013). GIE is one of the major industrial areas in the eastern peninsular Malaysia. It has been established since 1970. The area, which was formerly mainly peat swamp forest, had been converted to industrial areas by deforesting the area. Therefore, environmental degradation started from the inception of the estate. In the need of extension of the industrial areas, the forest and natural environmental impairment are still in progress. As a result, the water catchment area is decreasing and eventually water quality is deteriorating. Thus, water quality deterioration in the Gebeng industrial areas especially in Tunggak River is the ultimate result of industrial development and their effluents

(Nasly et al., 2013). Although the water quality and the environmental degradation still prevails in the area, there has not been any in-depth study carried out on water quality assessment that can help to ensure better management of the water resources along with the environment.

In the present study, water quality has been assessed by examining various physicochemical parameters and heavy metal contents of the surface water. The results of the physicochemical variables and selected heavy metals have been presented showing the spatial and temporal variation. Then, the statistical analyses of physicochemical parameters are done to identify the sources of the pollution. Analyses by Pearson correlation coefficient, hierarchical cluster analysis and principal component analysis of heavy metal concentration are done to investigate the metal contamination of surface water. The results that discussed in this chapter will give the actual situation of the water quality of Tunggak River, which can be used for better water quality management in the area.

4.2 SURFACE WATER QUALITY STATUS

A total of twenty-four (24) physicochemical parameters and heavy metals were analysed to assess the status of surface water quality of the Tunggak River and the surrounding areas of Gebeng Industrial Estate. All results obtained from the analyses are shown in Appendix GI- GX. However, the detail results of individual parameters are discussed in this section.

4.2.1 Temperature

Data for surface water temperature of the Gebeng industrial area was recorded and analysed to identify the spatial and temporal variation. The result indicated that the average temperature of Tunggak River was almost within the Malaysian standard (DOE, 2008) and in swampy area, it was comparatively lower than other parts of the area.

4.2.1.1 Spatial variation of water temperature among the monitoring stations

The average water temperature measured along the rivers of Tunggak River ranged from 26.5°C to 31.6°C (Figure 4.1). The highest mean temperature was recorded

at industrial zone 3 (IZ3) followed by industrial zone 4 (IZ4), and the lowest was in swampy area 1 (SA1). All stations in Tunggak River including industrial zone were found to have higher temperature and the average temperature was relatively low in swampy areas (SA1 and SA2). The downstream station (DS) of Tunggak River situated near the South China Sea was observed with comparatively low temperatures because of tidal inflow (Gianico and Souder, 2004).

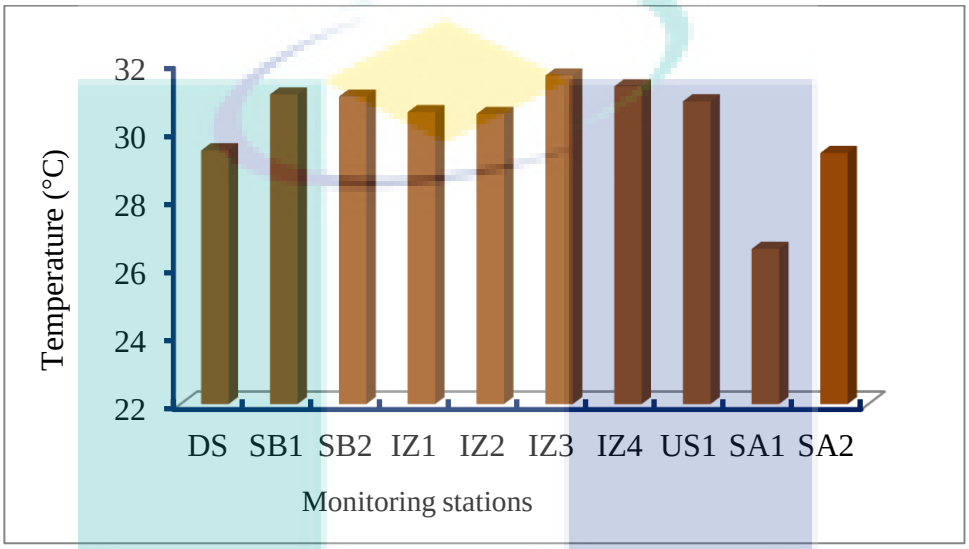


Figure 4.1: Average temperature of water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.1.2 Monthly Variations of Water Temperature among the monitoring stations

Monthly average values of water temperature at different stations are shown in Figure 4.2. The figure shows that the highest temperature (37.4°C) was recorded at IZ3 in July 2012 while the lowest temperature (25.4^{0}C) was observed on September 2012 at SA1. Although the temperature was comparatively higher in the dry season (March to August), the overall trend at all stations and all-round the year was very similar. At the industrial zone of Tunggak River the temperature was recorded higher than the normal temperature of Malaysia (DOE, 2008). On the contrary, the monthly temperature was within the normal level at SA1 and SA2.

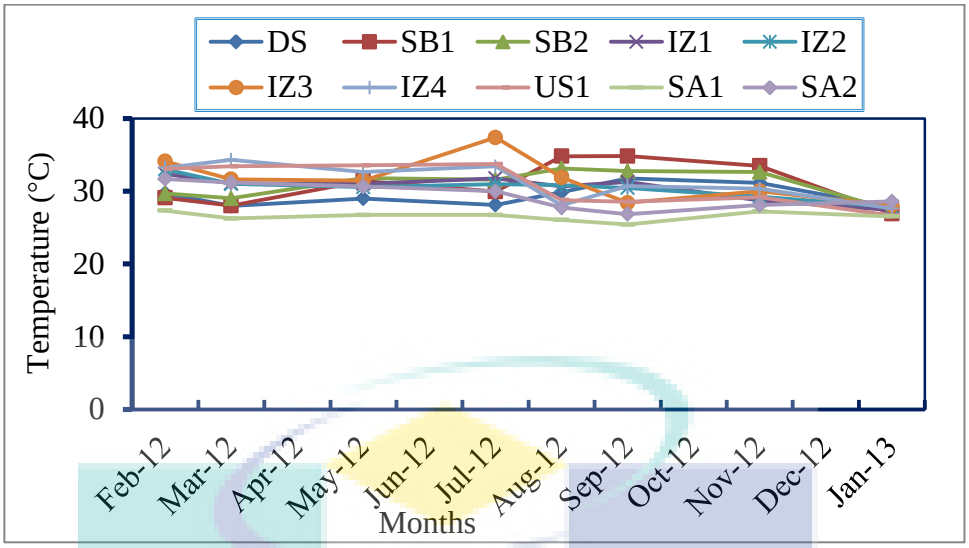


Figure 4.2: Monthly variations of temperature at ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.2 pH

The pH values of all stations were recorded and their spatial and monthly variations are shown in Figures 4.3 and 4.4. The results from the Figures indicate that the average pH of the river water is within the standard limit, except for the upstream station (US). The pH values of SA1 and SA2 including upstream station were recorded in lower concentration than the normal level, which are acidic in nature.

4.2.2.1 Spatial variation of pH among the monitoring stations

The average pH values of all monitoring stations are shown in Figure 4.3. The results have expressed the average pH that ranged from 4.9 to 7.5. The highest mean pH (7.5) was recorded at station IZ3 and the lowest (4.9) at the upstream station. However, the pH values in all river stations were within 6.5-7.5 except for the upstream station; whereas, at swampy areas including the upstream (US1) station, pH was at lower level indicating acidic in nature.

4.2.2.2 Monthly Variations of pH among the monitoring stations

Monthly variations of pH of the 10 monitoring stations are demonstrated in Figure 4.4, which indicated the trend of pH for the whole year. In spite of some

fluctuations, the trend of pH values was nearly similar throughout the year. However, the highest pH (8.9) was recorded in February 2012 at station IZ2 followed by IZ3 (8.7); pH was also noted at higher levels on August 2012 at station IZ3 and the lowest (4.2) was recorded in March 2012 at station SA1.

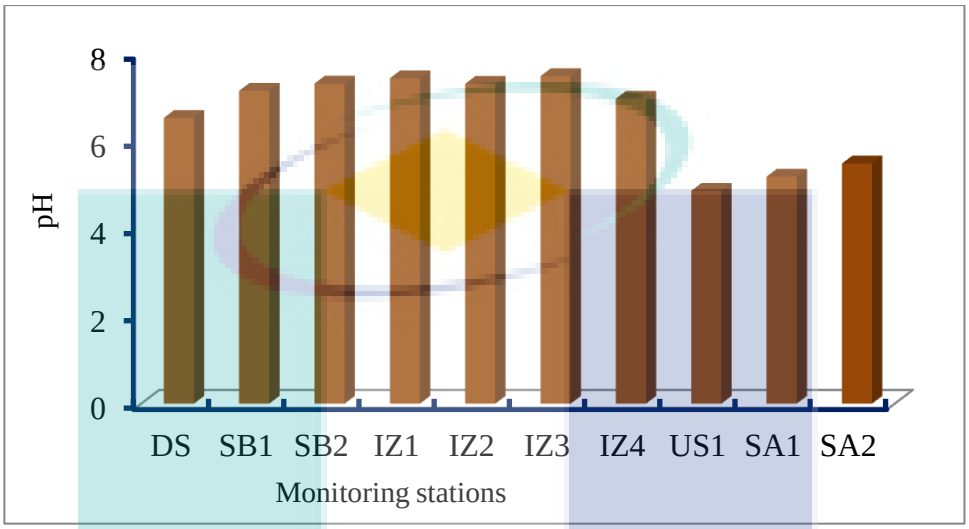


Figure 4.3: Average pH values of water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

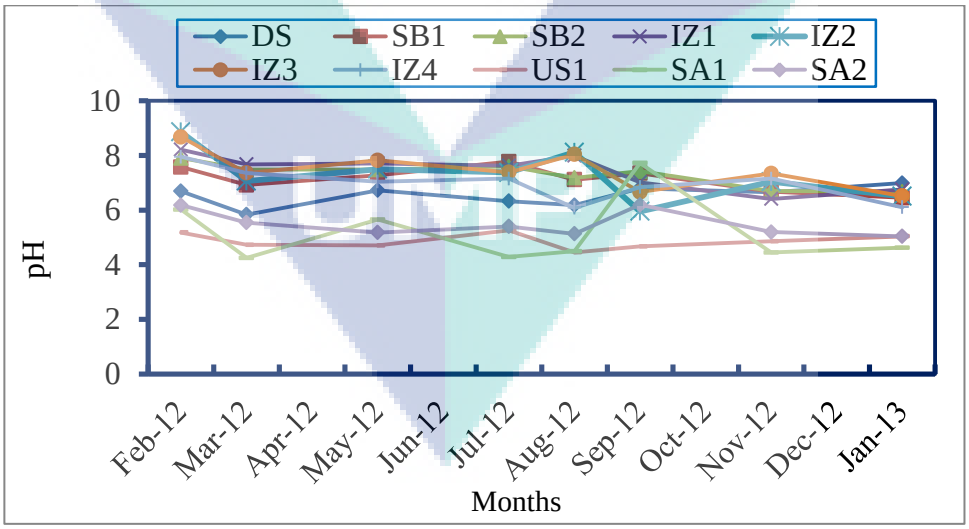


Figure 4.4: Monthly variations of pH of ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

Regarding monthly distribution, the pH value was recorded very high in February and August at the industrial zone of Tunggak River; where, BOD, COD,

ammoniacal nitrogen, nitrate nitrogen and phosphate were observed at high concentrations. The highly significant correlation of pH with those parameters (Appendix H) was the possible potential cause of higher pH at the area. However, the overall pH range was within the standard level, thus favourable for aquatic life.

4.2.3 Conductivity

Measurement of conductivity was done from all collected water samples and the average results are shown in Figures 4.5 and 4.6. The Figures 4.5 and 4.6 state the spatial variation and the temporal distribution of conductivity throughout the year respectively. The result denoted that the conductivity was the highest in downstream station where the tidal interference is most common that occurred twice daily.

4.2.3.1 Spatial variation of conductivity among the monitoring stations

Spatial distribution of conductivity of Tunggak River and the surrounding surface water from Gebeng industrial area are shown in Figure 4.5. The Figure showed that the highest average conductivity (14073.5µS/cm) was measured at the downstream station followed by Seberang Balok (SB1) (4445.4µS/cm) and the lowest was at SA1 (22.0µS/cm). As can be seen, the decreasing trend of conductivity was observed from the downstream to upstream of Tunggak River; although the significant variation was observed at DS station. However, the average concentration of the downstream station was very high compared to the other stations.

4.2.3.2 Monthly Variations of conductivity among the monitoring stations

The results on Conductivity obtained for one year sampling is analysed on monthly basis and are shown in Figure 4.6. The results show that the monthly variation of conductivity was almost insignificant and the concentration was very low although the DS and SB1 showed a significant variation with high concentrations. The highest conductivity level (25223.30 µS/cm) was recorded in November 2012 at DS station followed by August and March 2012 at the same station. Other than that, 13440.30 µS/cm of conductivity was obtained in February 2012 at SB1.

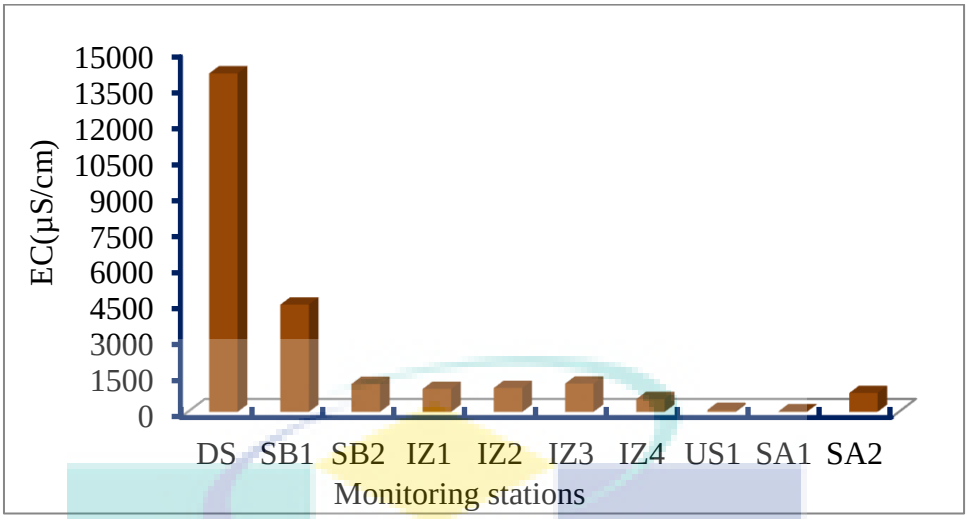


Figure 4.5: Average EC of water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

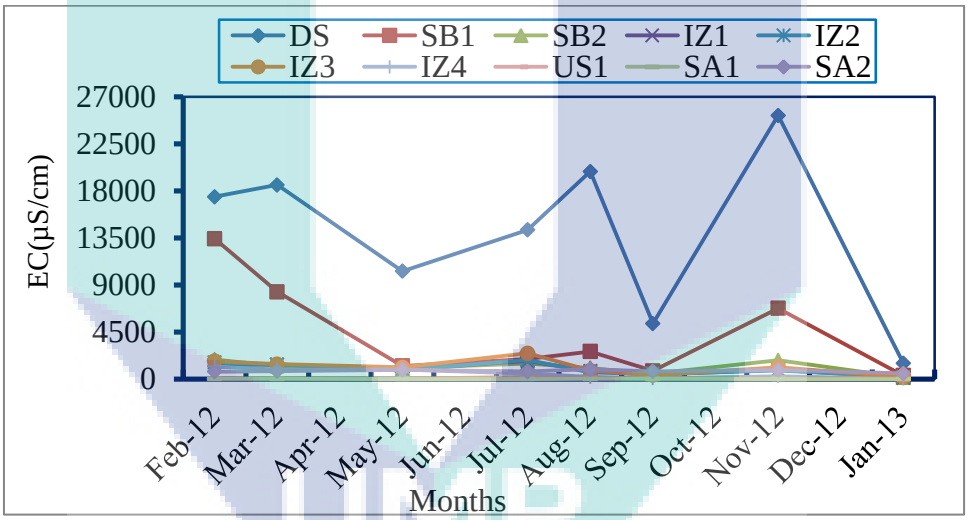


Figure 4.6: Monthly variations of EC of ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.4 Salinity

Salinity of all samples was estimated and the data were analysed to determine the spatial and temporal variation. Results are demonstrated in Figures 4.7 and 4.8. Similar to the conductivity the salinity was also observed in higher level at downstream station. The upstream station and swampy area were found with low salinity concentration including the industrial zone.

4.2.4.1 Spatial variation of salinity among the monitoring stations

The Average concentrations of salinity of all stations are shown in Figure 4.7 that indicated the spatial variation among the stations. The result shows that the average concentration of salinity ranged from 0.01 to 7.7%; where the highest average concentration of salinity (7.7%) was observed at DS station followed by SB1 (2.3%) and SB2 (0.6%), and the lowest average value was recorded at station SA1 (0.01%) followed by upstream (US) station (0.03%).

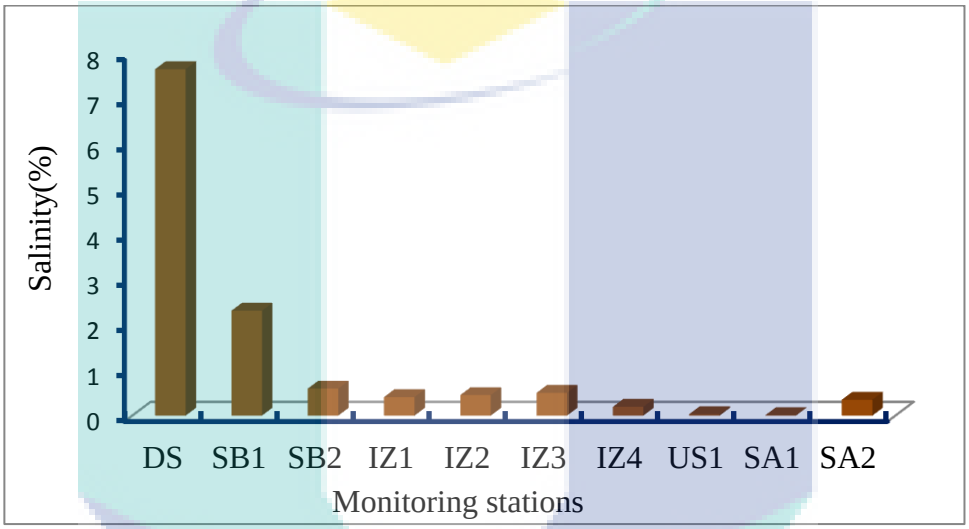


Figure 4.7: Average salinity of water samples from different monitoring stations of Tunggak river and the surrounding water bodies of Gebeng industrial areas

4.2.4.2 Monthly Variations of salinity among the monitoring stations

The monthly distributions of salinity among the monitoring stations are presented in Figure 4.8**.** The result reveals that significant variation was observed at downstream station and SB1, similar to the conductivity trend. The highest salinity (15.2%) was recorded on November 2012 at DS station and the lowest (0.02%) at IZ4 on January 2013. In addition to November, the salinity was observed higher on August, July and February at the DS station. Eventually, higher concentration was observed on February (7.1%), March (4.3%) and November 2012, at SB1 station.

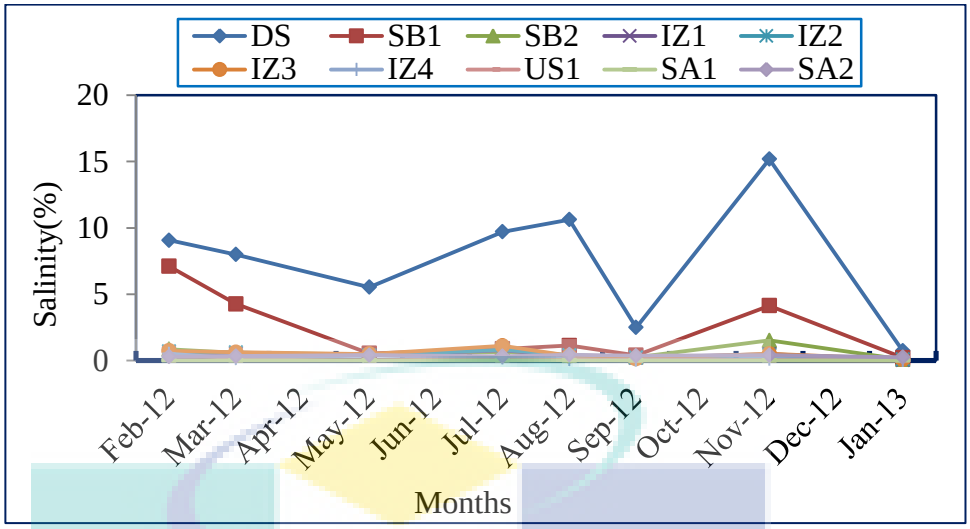


Figure 4.8: Monthly variations of salinity of ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.5 Turbidity

Turbidity is a visual property of water that indicates the lack of clarity and the extent of interfering with the straight-line transmission of light into the water (Chen et al., 2007; Allen et al., 2008). In the present study, turbidity was measured and the observed data was analysed to know the spatial and temporal variation. The results of the analysis are presented in Figures 4.9 and 4.10. The study showed that all monitoring stations of the study area had high turbidity.

4.2.5.1 Spatial variation of turbidity among the monitoring stations

The measured average concentrations of turbidity from all stations are shown in Figure 4.9, which stated the spatial distribution of the parameter. As can be seen, the highest average turbidity (206.1 NTU) was recorded at station IZ3 and the lowest (10.7 NTU) was at station SA1. The range of average turbidity in the river water was 18.6 to 206.1 NTU, while the average range was comparatively lower at the swampy area (Figure 4.9). Compared to all of the stations the concentration of turbidity was higher in the stations of industrial zone in Tunggak River.

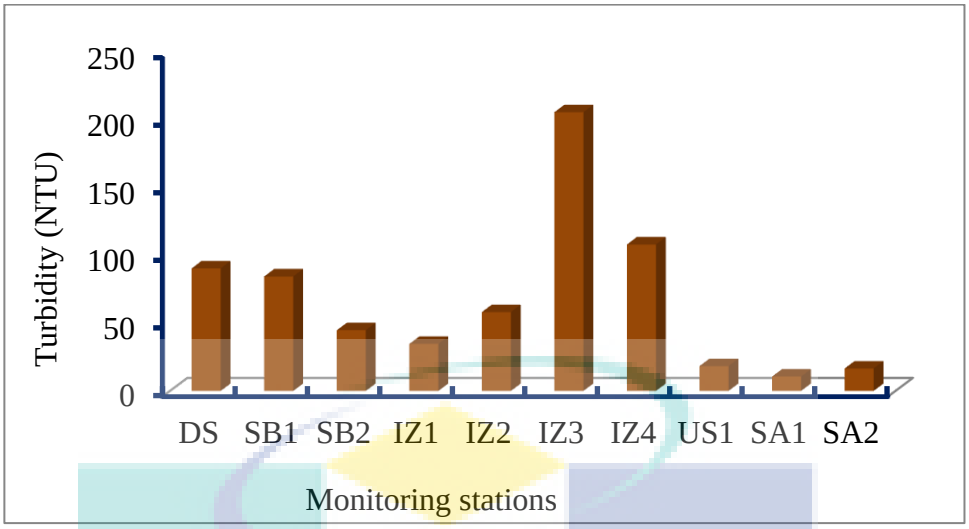


Figure 4.9: Average turbidity of water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.5.2 Monthly Variations of turbidity among the monitoring stations

To determine the temporal variation, the data was analysed and average monthly values of turbidity are demonstrated in Figure 4.10.

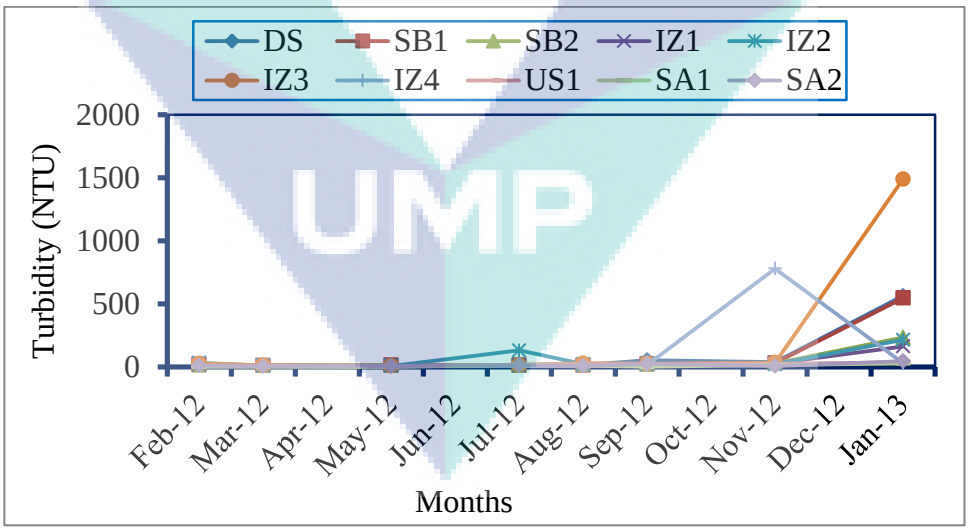


Figure 4.10: Monthly variations of turbidity of ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

The figure shows that there was no significant variation of turbidity in the dry season; although high significant variation was observed in the wet season at stations IZ2, IZ3, IZ4 and SB1. The highest turbidity (1489.7 NTU) was recorded in January

2013 at station IZ3 followed by IZ4 where the concentration was 780.3 NTU on November 2012. The lowest turbidity (3.2 NTU) was obtained on February 2012 at station SA1.

4.2.6 Total dissolved solids (TDS)

TDS refers to the all kinds of solids (organic and inorganic) that are dissolved in water. It is one of the important parameters for water quality management. TDS concentrations were estimated from all monitoring stations and data obtained was analysed. The result shows that average TDS was higher in DS station including the industrial zone. The overall average and monthly average concentrations of TDS are displayed in Figures 4.11 and 4.12 that show the spatial and temporal variation of the TDS concentration.

4.2.6.1 Spatial variation of TDS among the monitoring stations

The average data obtained from the samples of all monitoring stations are displayed in Figure 4.11. The Figure states that the highest average amount of TDS (37772.1 mg/L) was recorded at the DS station, while the lowest concentration (39.34 mg/L) was at station SA1. The range of average TDS in the Tunggak River water was 171.6 to 37772.1 mg/L and in swampy area, it was relatively lower. Industrial zone especially IZ3 were found to be loaded with more TDS next to the DS station (Figure 4.11); similarly, SB1 was also observed with high TDS.

4.2.6.2 Monthly Variations of TDS among the monitoring stations

The monthly data on TDS concentrations are presented in Figure 4.12. It indicates the trend of TDS throughout the year among the monitoring stations. The figure reveals that, significant variations of TDS were observed at the DS, IZ3 and SB1 stations; even though, it was insignificant at other stations during the research period. The highest TDS (88,700.0 mg/L) was observed in November 2012 at DS station followed by IZ3 in January 2013 with a concentration of 81800.0 mg/L. On the other hand, the lowest concentration of TDS (48.1 mg/L) was recorded in November 2012 at the SA1 station (Figure 4.12). The concentrations were comparatively higher in the wet

season and the trend was almost similar throughout the year except at DS, SB1 and IZ3 stations.

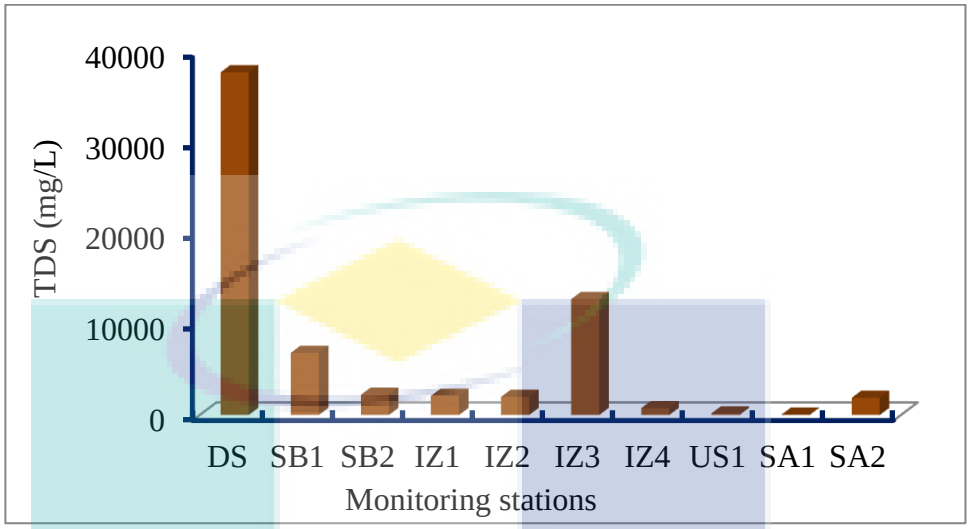


Figure 4.11: Average TDS concentrations of water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

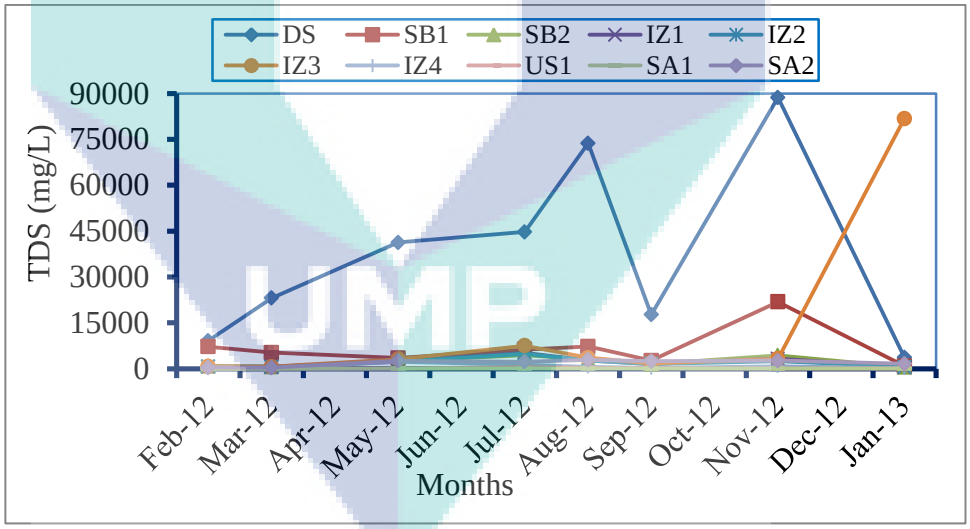


Figure 4.12: Monthly variations of TDS of ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.7 Total Suspended Solids (TSS)

Total suspended solids (TSS) include all particles suspended in water, which cannot pass through a filter. TSS was measured from all water samples and the results are shown in Figures 4.13 and 4.14. Figure 4.13 shows the spatial variation of TSS in

the surface water of Gebeng industrial area including the Tunggak River and Figure 4.14 indicates the temporal variation among the monitoring stations.

4.2.7.1 Spatial variation of TSS among the monitoring stations

The average concentration of TSS from all monitoring stations was measured and the results are shown in Figure 4.13. Results show that, the highest average TSS (99.7 mg/L) was recorded at IZ4 station followed by IZ3 with a concentration of 73.8 mg/L and the lowest (9.5 mg/L) was measured at SA2 station. Regarding the water of Tunggak River, the average range of TSS concentration was 12.4 mg/L at US1 to 99.7 mg/L at IZ4. As can be seen, all monitoring stations of Tunggak River had higher TSS concentrations than the surrounding stations in the study area, except for the upstream (US1) and IZ1 stations.

4.2.7.2 Monthly Variations of TSS among the monitoring stations

The monthly average concentrations of TSS among the monitoring stations are shown in Figure 4.14. The Figure illustrates the trend of TSS concentration throughout the study period. Results indicate that the trend of TSS in the dry season was almost similar (no significant fluctuation); but, significant variation was observed in wet season especially at industrial zone, downstream and SB2 stations. The highest concentration was recorded in November 2012 at IZ4 with a value of 723.7 mg/L followed by IZ3 (of 479.3 mg/L) in January 2013; while the lowest was in August 2012 at SA2 (Figure 4.14). Meanwhile, compared to the wet season (September to February), concentration of TSS was observed lower in the dry season.

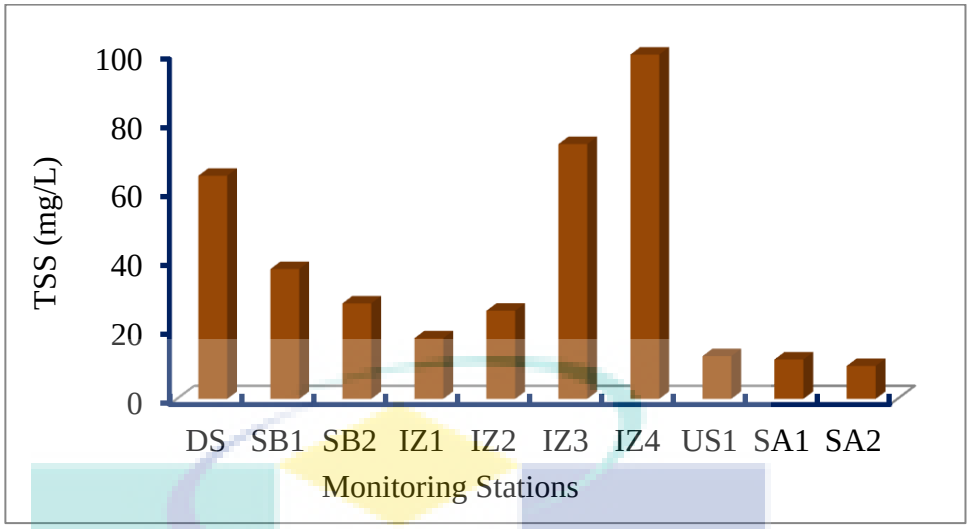


Figure 4.13: Average TSS in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

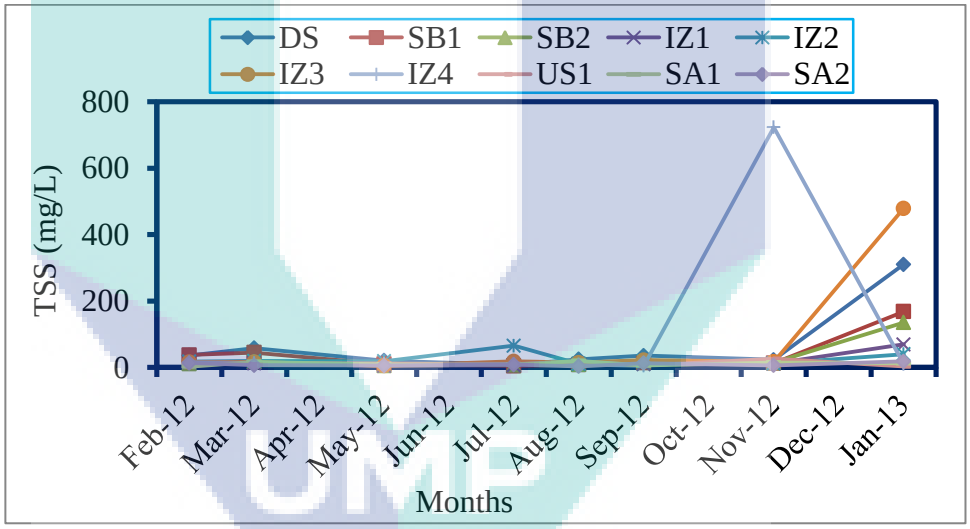


Figure 4.14: Monthly variations of TSS at ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.8 Discussion on physical parameters

Physical parameters of river water were founded in different concentration in the area. Temperature, pH, conductivity and salinity level of the area was observed within the threshold level in most of the stations. In Malaysian rivers, water temperature usually ranges from 24 °C to 31.3 °C (UKM-DOE, 2000; Yusof 2002) and the normal water temperature in Malaysia is 27°C-31°C (Saad et al., 2008; Sujaul et al., 2013). According to INWQS Malaysia, the threshold level of temperature for Malaysian rivers

is quoted as Normal temperature ± 2.0 °C (DOE, 2008) (Appendix A). The measured temperature from one (1) year of sampling indicated that the average temperature was within the threshold level at all monitoring stations, although the temperature was above the threshold level in IZ3, IZ4 and Seberang Balok (SB2) during the dry period (March to August). It was might be due to the significant correlations with pH, BOD, COD, ammoniacal nitrogen, nitrate nitrogen and sulphate (Appendix H), which were higher concentration at industrial zone and a residential area. Nedeau et al. (2003) showed similar results in his research. The range of average pH values recorded at seven sampling stations of Tunggak River during February 2012 to January 2013 was within the INWQS threshold range for Malaysian river water, while the other three stations at upper stream and swampy area were recorded with lower level of pH value. Upper stream station received water from peat swamp forest and water from swampy areas and peat swamp forest are naturally acidic that was directly drained into the Tunggak River and resulted low pH values at SA1 and SA2, as well as upstream station. Similar results were observed by several researchers, Gasim et al. (2007); Rosli et al. (2010); Yusuf (2001).the water from swampy area.

Regarding the conductivity and salinity, the observed values were within the normal limit in most of the area except the downstream station. For the downstream station, the conductivity and salinity were the important factor. Conductivity and salinity at DS station were observed always higher than any other stations and it was beyond the INWQS Malaysia threshold level (1000.0 µS/cm and 0.5% respectively) (Appendix A). Higher concentration at the downstream station was due to the tidal interference from the South China Sea. Because of saline water intrusion, which has positive correlation with conductivity (Appendix H) was the reason of higher conductivity at the station. Similar results were stated by Karikari et al. (2009). The tidal water of South China Sea usually goes up to the industrial zones that cause relatively higher conductivity and salinity in those areas. Besides tidal water intrusion, the industrial effluents from the Gebeng industrial estate also contributed to the higher level of conductivity at the industrial zone; as supported by some previous researches (Paul, 2011; Muwanga and Barifaijo, 2006). However, the concentrations of conductivity and salinity were within the normal limit except downstream station.

Rügner et al. (2013) stated the turbidity as the proxy of TSS, which confirmed that higher TSS might result from higher turbidity. The turbidity was observed higher at industrial zone and at the DS stations; while the TSS concentration was higher at river stations except IZ1 and US1. Higher turbidity and TSS indicated the water quality deterioration in the area. The highest concentration of turbidity at industrial zone was may be due to the industrial wastewater from the GIE. Similar result was also published by Muwanga and Barifaijo (2006). Another cause of high concentration of those two parameters was the massive run-off during monsoon due to deforestation for developing new sites of industrial areas (new phase) that resulted from substantial run-off from the area during heavy shower. Moreover, inter-correlations of turbidity and TSS (Appendix H), was also responsible for higher concentration at the industrial zone. At the lower stream-stations along with the residential areas, the higher concentrations were may be due to the industrial wastewater from manufacturing industries as well as the domestic wastewater, agricultural runoff from SB1 area and the tidal interference. Several researchers in their finding stated the cause of high turbidity as urban and agricultural runoff, mangrove vegetation and tidal interference (Bramato et al., 2010; Launay et al., 2013; Ma, 2012; Smith et al., 2009). According to the INWQS Malaysia threshold level of turbidity, all monitoring stations were found to be beyond the threshold level (Appendix A). However, the average level of TSS was within the maximum permissible level for aquatic life, with exception at some stations in the wet season.

Regarding TDS that represents the total concentration of dissolved substances including inorganic salts and small amount of organic matter in water, the concentration was found to be beyond the threshold level at all stations except US1 and SA1. Higher concentration at lower station was due to the tidal interference from the South China Sea and the presence of mangrove vegetation. Agricultural runoff and urban wastewater were also responsible for the high concentration of TDS at the stations. Higher concentration at industrial zone was might be due to the industrial effluent. Similar results were also obtained by several researchers (Ideriah et al., 2010; Lawson, 2011; Ogedengbe and Akinbile, 2010). Furthermore, the TDS was found highly correlated with EC ($r = 0.70$), salinity ($r = 0.73$), turbidity ($r = 0.36$) and sulphate ($r = 0.61$), which was also responsible for higher TDS value (Appendix H).

4.2.9 Dissolved Oxygen (DO)

Dissolved oxygen (DO) concentration was measured from water samples of all monitoring stations and the data obtained were analysed. The average range of DO was recorded 1.8 to 4.9 mg/L in the surface water of the study areas. Analysed results are shown in Figures 4.15 and 4.16. Figure 4.15 presents the spatial variation of DO, while Figure 4.16 shows the temporal variation of DO among the monitoring stations.

4.2.9.1 Spatial variation of DO among the monitoring stations

The average concentrations of DO from all monitoring stations are presented in Figure 4.15. The figure indicates that the highest average DO concentration (4.9 mg/L) was recorded in IZ4 followed by IZ1 with a concentration of 4.8 mg/L; while, the lowest concentration (1.8 mg/L) was recorded at the SA1 station. DO concentration was lower in all monitoring sites of Tunggak River as well as other part of the study area. In the river portion, the average range was 2.8 mg/L to 4.9 mg/L; very low concentrations were recorded in the industrial zone stations of IZ2 and IZ3 along with along with the upstream station compared to other stations. However, the variation was somehow significant all over the area (Figure 4.15).

4.2.9.2 Monthly variation of DO among the monitoring stations

The monthly variations of the DO concentration are shown in Figure 4.16. The figure states a significant variation of DO concentration among the monitoring stations throughout the year. Concentration of DO fluctuated in all stations and all months. The highest concentration (7.0 mg/L) was recorded in May 2012 at IZ1 station followed by DS station (6.3 mg/L) in January 2013 (Figure 4.16). On the contrary, the lowest DO reading (0.8 mg/L) was recorded in August 2012 at IZ3 station followed by SA1 with a concentration of 0.9 mg/L. The monthly readings showed variations, and comparatively higher concentrations at maximum stations were noted in May and September of 2012, and in January 2013. Inversely, the lower concentrations were recorded in August, February and November 2012. Based on the season, relatively higher concentration was in the wet season and lower in the dry season.

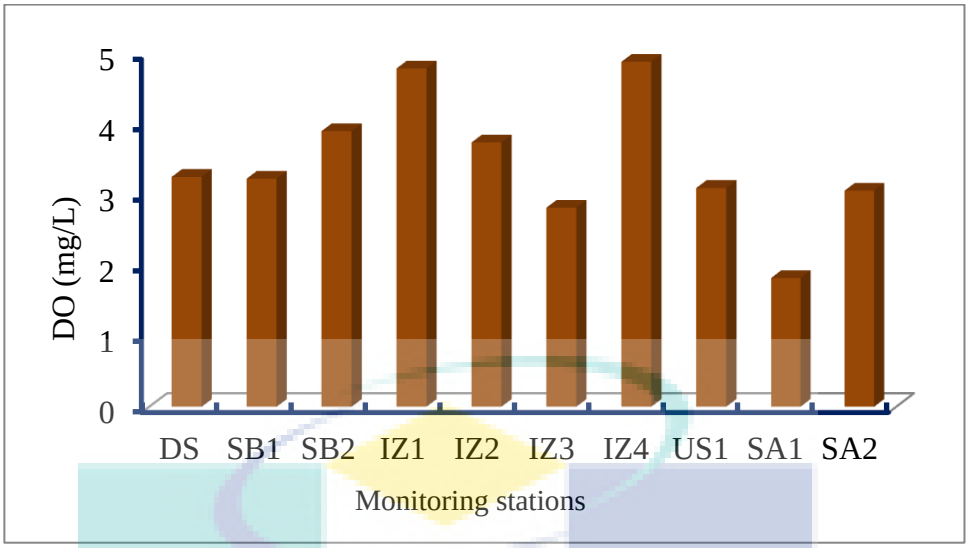


Figure 4.15: Average DO of water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

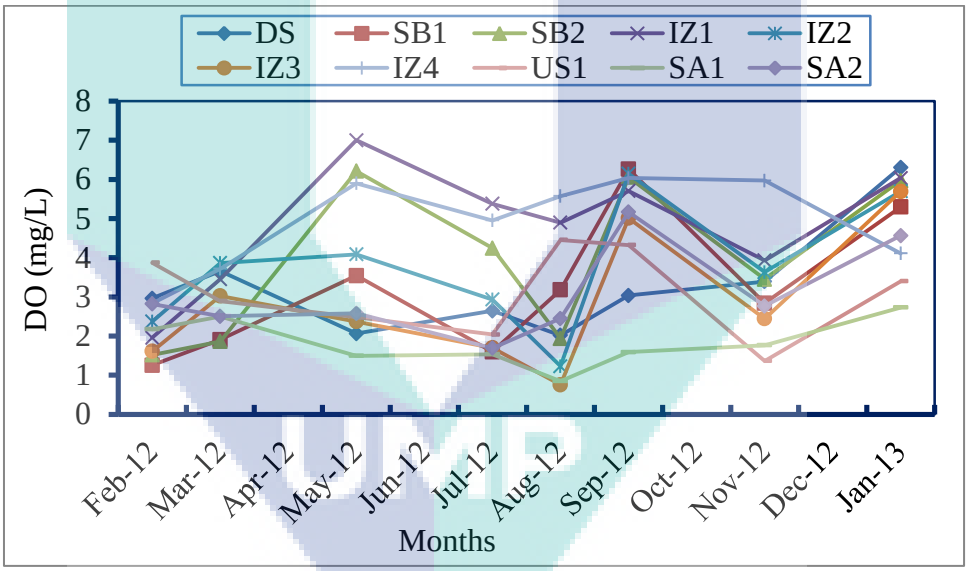


Figure 4.16: Monthly variations of DO of ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.10 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand (BOD) was calculated for all monitoring stations for a year. The average BOD level of all monitoring stations was higher than the Malaysian standard. The results are shown in Figures 4.17 and 4.18. Figure 4.17 expresses the spatial variations, while Figure 4.18 discusses the monthly variations of BOD among the monitoring sites.

4.2.10.1 Spatial variation of BOD among the monitoring stations

The average BOD concentrations of all monitoring stations are shown in Figure 4.17. The figure states that, the average range of BOD at the study area was 6.9 mg/L to 27.1 mg/L. The highest average level (27.1 mg/L) was estimated at IZ4 and the lowest was at SA1 station. All stations of Tunggak River were found to have higher BOD compared to the swampy area, although the concentration at swampy area was beyond the standard level for Malaysian river water. The range of BOD at Tunggak River was 8.5 mg/L to 27.1 mg/L. Based on zones, BOD distribution was found to be higher at the industrial zone than any other zones (Figure 4.17). The BOD concentrations at the residential cum industrial area SB1 and SB2 were a little bit lower than the industrial zone; but higher than the swampy area and the DS station. SA1 and the DS station were found to have relatively low BOD.

4.2.10.2 Monthly variation of BOD among the monitoring stations

Monthly distributions of BOD among all monitoring stations are shown in Figure 4.18. The figure shows a significant variation of the BOD concentrations regarding months and stations. Based on the seasonal variation the concentration was higher in the dry season (March to August) compared to wet season. The highest concentration of BOD (38.0 mg/L) was measured in July 2012 at IZ4 station followed by August and May (37.9 mg/L) at the same station. Higher BOD was also measured at other industrial stations and residential areas between April and August. The lowest concentration of BOD (0.9 mg/L) was observed on March 2012 at SA1 stations (Figure 4.18). Based on the individual situation of the stations, IZ4 station was found to have higher BOD and SA1 had lower BOD all the year round. In the wet season, higher concentration was observed on November 2012 at almost all monitoring stations.

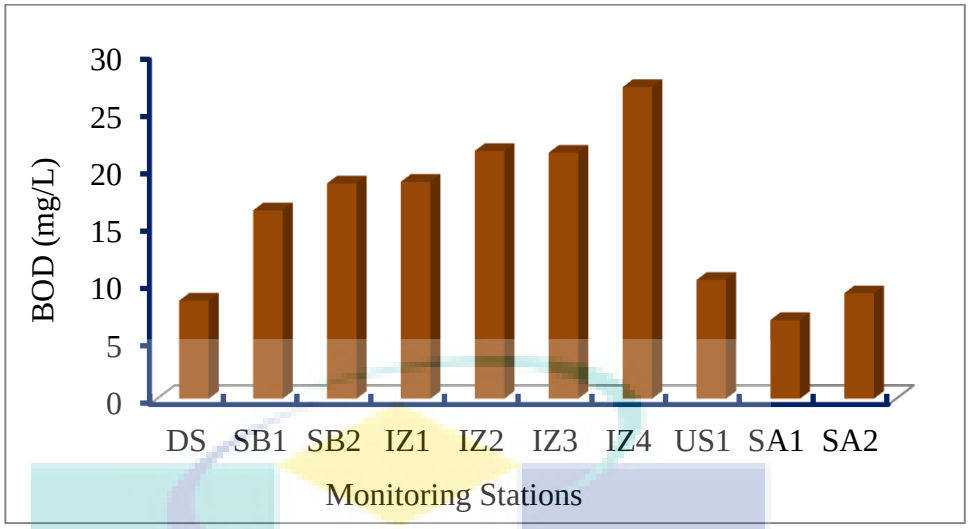


Figure 4.17: Average BOD in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

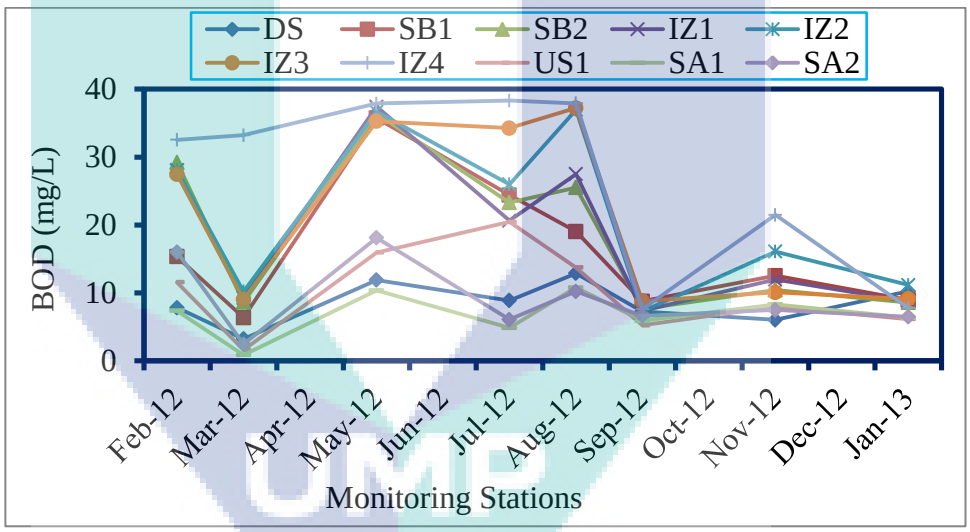


Figure 4.18: Monthly variations of BOD at ten different monitoring stations of Yunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.11 Chemical Oxygen Demand (COD)

The concentrations of Chemical oxygen demand (COD) were measured and the results are presented in Figures 4.19 and 4.20. The results show that the average COD level obtained from the one-year data were higher than the threshold values. However, the consecutive two figures discuss the spatial and temporal variation of COD at all monitoring stations in Gebeng industrial areas.

4.2.11.1 Spatial variation of COD among the monitoring stations

The average COD concentrations from different monitoring stations are demonstrated in Figure 4.19. The figure shows that, the average range of COD at the surface water from Gebeng industrial areas was 14.0 to 59.6 mg/L. At the Tunggak river stations, the range was 35.0 to 59.6 mg/L. The highest concentration was at IZ4 and the lowest was at SA2 station. At Tunggak River, the lowest value was 35.0 mg/L at the upstream stations. As can be seen, the average COD level was higher at the industrial zone followed by the lower stream stations (Figure 4.19).

4.2.11.2 Monthly variation of COD of among the monitoring stations

Temporal variations of COD among all of the monitoring stations are presented in Figure 4.20. Likewise the BOD concentrations, there was a significant variation of COD level based on the monthly distributions. The results reveal that, COD level was higher in the dry season compared to the wet season. The highest concentration was in August 2012 at IZ3 with a value of 137.00 mg/L; while the lowest value (2.7 mg/L) was in February 2012 at SA1 (Figure 4.20). Higher concentrations were also obtained at DS and IZ2 in the same month (August) and at IZ4 in March, May and July 2012. On the contrary, the lower concentration was recorded at SA1 in throughout the year. All monitoring stations were found with lower concentrations in September 2012 and January 2013. However, within the wet season in November 2012 the concentration was a little bit higher compared to the rest of the season.

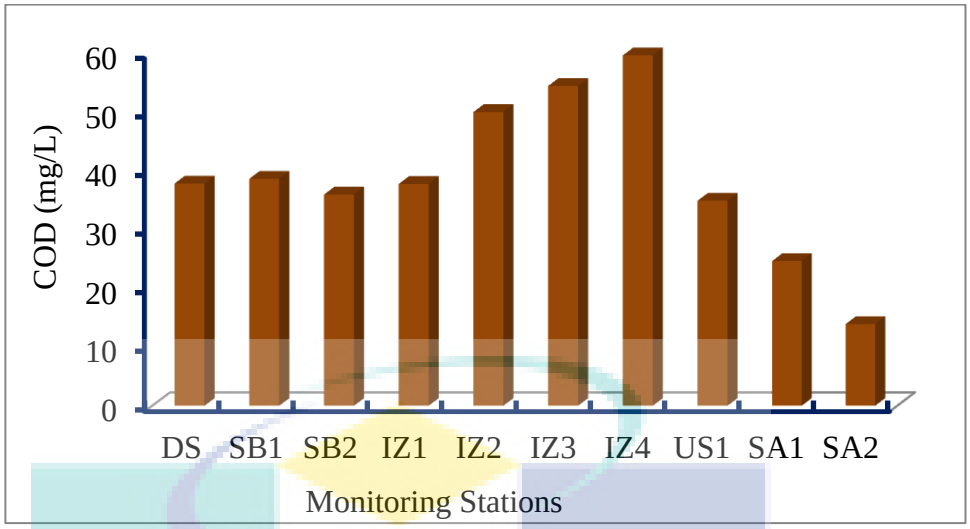


Figure 4.19: Average COD in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

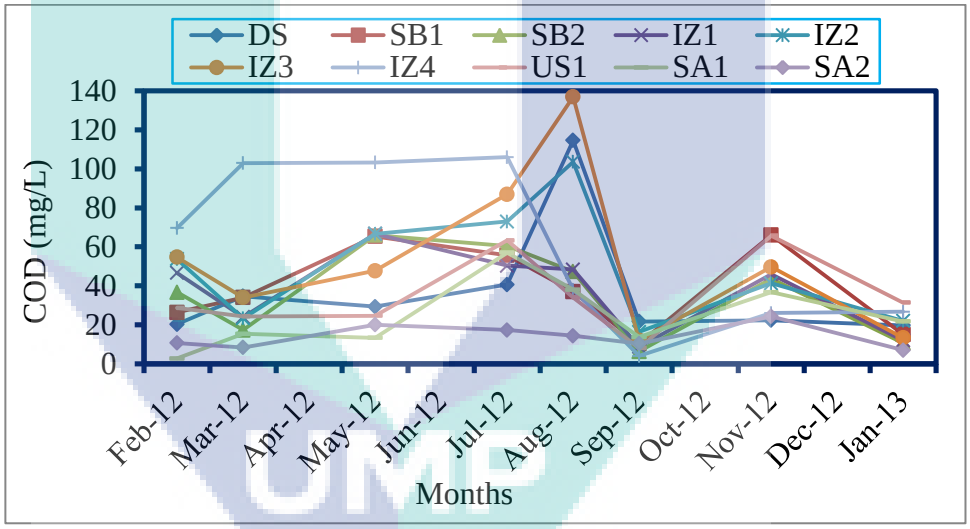


Figure 4.20: Monthly variations of COD of ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.12 Discussion on DO, BOD and COD

The concentrations of DO, BOD and COD in water are the most important parameters in determining the water quality, as DO indicates whether there is any water pollution or not (Ibanez et al., 2008) and it also directly negatively correlated with BOD and COD (Appendix H). Including the Tunggak River, all stations were found to be loading with low DO level and higher level of BOD and COD. The highest average level of DO was 4.9 mg/L whereas the lowest level of BOD and COD was 9.6 and

14.04 mg/L respectively; meaning that the DO level was below the minimum requirements but, BOD and COD values observed in the study area exceeded the threshold level. According to the INWQS Malaysia the minimum threshold level of DO, maximum threshold level of BOD and COD is 7.0 mg/L, 3.0 mg/L and 10.0 mg/L respectively for class I water (DOE, 2008) (Appendix A).

The lower level of DO and higher concentrations of BOD and COD were mainly because of the anthropogenic actions like industrial activities of the GIE that generated industrial wastewater containing higher amount of organic matters. The industrial activities that generate effluents with high oxygen demanding organic matters had attributed to the observed higher BOD value in the area. Industries such as, food, manufacturing, petrochemical, poly-propylene, chemical, mining, paper and palm oil mills were producing a lot of effluents with high oxygen demanding organic matters that were discharged into the river flow either treated or partially treated was the main cause of DO depletion as well as higher level of BOD and COD (Nasly et al., 2013 ; Sujaul et al., 2013). Similar results for DO depletion and higher amount of BOD and COD were published by Ahmed et al. (2012); Dai et al. (2006); Emongor et al. (2005); Qadir et al. (2008); Sánchez et al. (2007); Singare et al. (2010); Shah and Pant 2013) Ansari et al. (2012); Gyawali et al. (2012); M S Islam et al. (2012); Pawar (2013); Vishwakarma et al. (2013) and Yadav et al. (2012); Kanu and Achi (2011); Naddeo et al. (2013); Walakira and Okot-Okumu (2011); Zhao et al. (2011). Higher BOD and COD level and lower DO concentration were also observed at swampy area and upstream of Tunggak River, which were in the vicinity of less or no industries; but the region was near to the peat swamp forest, from where high oxygen demanding organic matters added to the water and resulted the pollution. DeAngelis et al. (2013); Rosli et al. (2010); Yusuf (2001) also found similar results in their research. Urban wastewater from residential areas and agricultural wastes also contributed to the less DO level at station SB1 and SB2. Similar results were obtained by Decker et al. (2013); Girija et al. (2007); Mallin et al. (2009); Mallin and McIver (2012); Qadir et al. (2008). Low DO levels in the downstream station might be due to the tidal interference, as low tide caused high water temperature that resulted in low DO. (Abowei, 2010; King, 2013). Regarding the temporal variation, BOD and COD were recorded higher in the dry season compared to the wet season. It was because of the dilution factor during wet

season; as of water flow increased and due to this increased volume, the concentration was comparatively lower. Varol et al. (2012) and Garg et al. (2010) also investigated similar results in their research.

However, according to the INWQS Malaysia water classification, based on DO and COD concentration six stations of Tunggak River falls into class III and the other stations in class IV(DOE, 2008) (Appendix D). Based on BOD concentration, maximum part of river stations falls into class V except for DS and US1 stations that were in class IV and the swampy areas also falls in class IV (Appendix D). The results indicated that the water of the river could not be used for any purpose even after extensive treatment. Water under class IV can be used for irrigation only after extensive treatment but due to the same flow of Tunggak, which is heavily polluted; it made the whole water body unsuitable for any purpose.

4.2.13 Ammoniacal-Nitrogen

The concentration of ammoniacal nitrogen was measured from all monitoring stations for the duration of one year from February 2012 to January 2013. Data were analysed and the average concentrations of ammoniacal nitrogen are displayed in Figures 4.21 and 4.22. The figures explained the spatial and temporal variation of the ammoniacal nitrogen concentration respectively.

4.2.13.1 Spatial variation of ammoniacal-nitrogen of among the monitoring stations

The average concentrations of ammoniacal nitrogen from ten (10) monitoring stations in Gebeng industrial areas are shown in Figure 4.21. The figure shows a significant variation in the concentration among the stations. The highest average concentration (2.28 mg/L) was at SB1 station followed by 2.12 mg/L at SB2 and 1.96 mg/L at SA2 stations. The lowest concentration of ammoniacal nitrogen (0.32 mg/L) was at the SA1 station (Figure 4.21). Comparatively higher concentration was obtained at the industrial zone and also in the upstream station. Regarding the Tunggak River, the average range of ammoniacal nitrogen was 1.18 mg/L at IZ4 to 2.28 mg/L at SB2 station. Considering the residential area, the concentration at industrial zone and at the downstream station (DS) was a little bit lower.

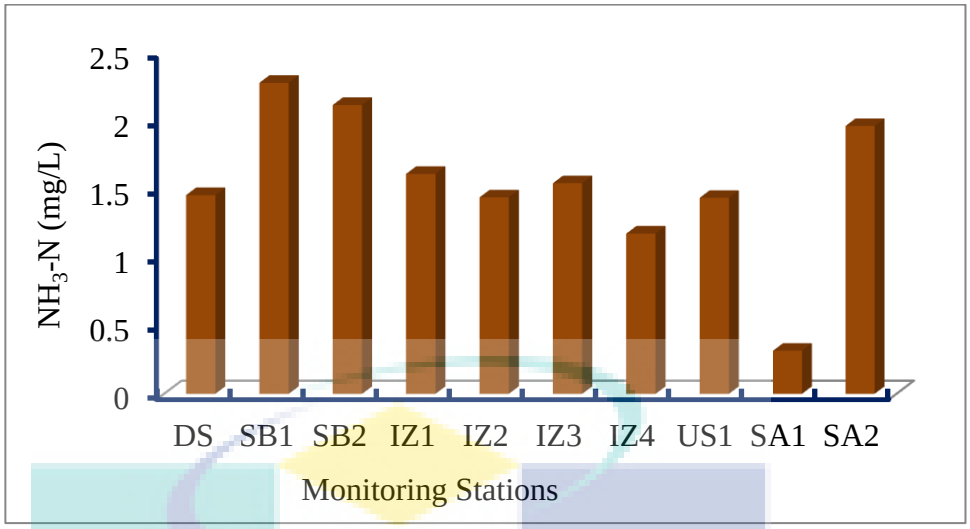


Figure 4.21: Average NH_3-N in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.13.2 Monthly variation of ammoniacal-nitrogen among the monitoring stations

Monthly distributions of the concentration of ammoniacal nitrogen are displayed in Figure 4.22 that shows the temporal variation of the concentration among the stations of the study area. The results reveal that significant variation was persistent among the stations based on the time variations. Higher concentration was obtained in dry season compared to the wet season. Among the dry season, there were also significant variations; as of May 2012, the concentration was relatively lower than other months of the dry season. As can be seen, the highest concentration (3.83 mg/L) was obtained in March 2012 at SB2 station followed by SB1 in July 2012, with a concentration of 3.43 mg/L and IZ3 (3.33 mg/L) in March. Higher concentration was also found at most stations in March and July 2012 (Figure 4.22). On the contrary, the lowest concentration (0.05 mg/L) was recorded in May 2012 at SA1 station. Among the wet months, concentration of ammoniacal nitrogen was comparatively higher in November 2012 (Figure 4.22).

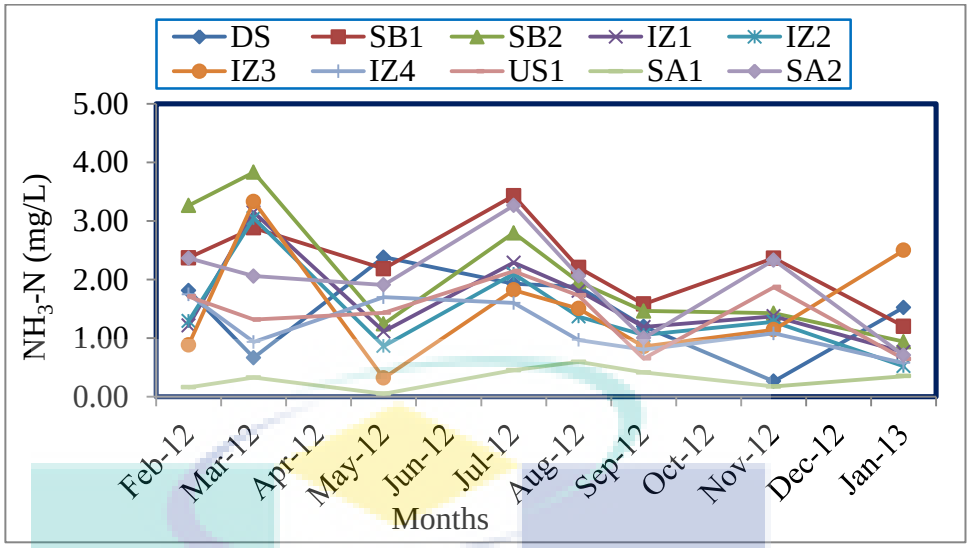


Figure 4.22: Monthly variations of NH_3-N concentration at ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.14 Nitrate-nitrogen

Nitrate-nitrogen concentration was measured from different monitoring stations for one year and the data obtained were analysed to know the spatial and temporal distribution among the stations. The average concentrations are presented in Figure 4.23 that shows the spatial variations, and the temporal distributions are shown in Figure 4.24.

4.2.14.1 Spatial variation of nitrate-nitrogen among the monitoring stations

The average concentrations of nitrate-nitrogen are displayed in Figure 4.23. The figure shows that the highest average concentration of nitrate-nitrogen (1.04 mg/L) was at IZ3 followed by IZ2 (1.01 mg/L). In contrast, the lowest concentration was obtained at SA1 (0.00 mg/L) followed by US1 (0.003 mg/L). The concentration was lower throughout the study area. In Tunggak River, the average range of concentration was 1.04 mg/L at station IZ3 to 0.11 mg/L at station DS (Figure 4.23). Despite the lower concentration at all stations, overall concentration was higher in the industrial zone compared to other zones or stations.

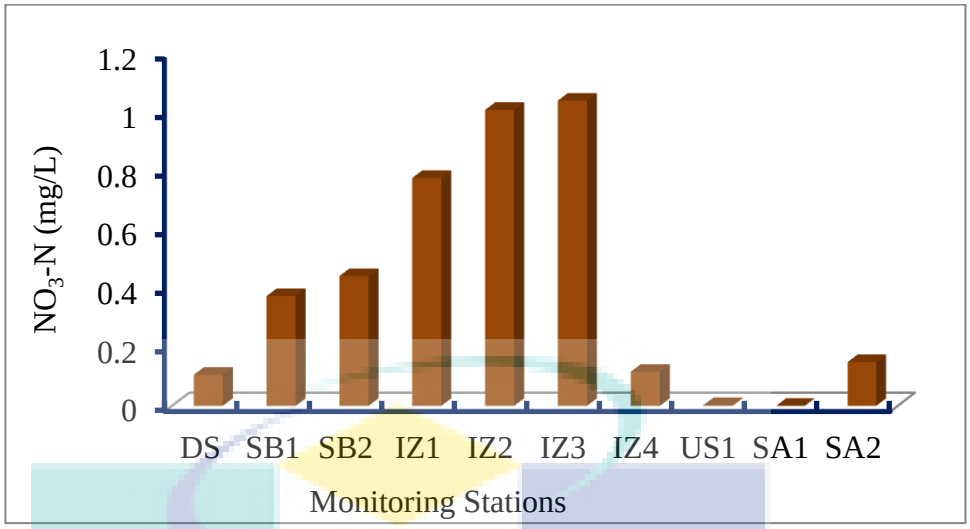


Figure 4.23: Average NO_3-N in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.14.2 Monthly variation of nitrate-nitrogen among the monitoring stations

Data from all sampling stations were analysed to know the monthly variation among the stations and the results are shown in Figure 4.24.

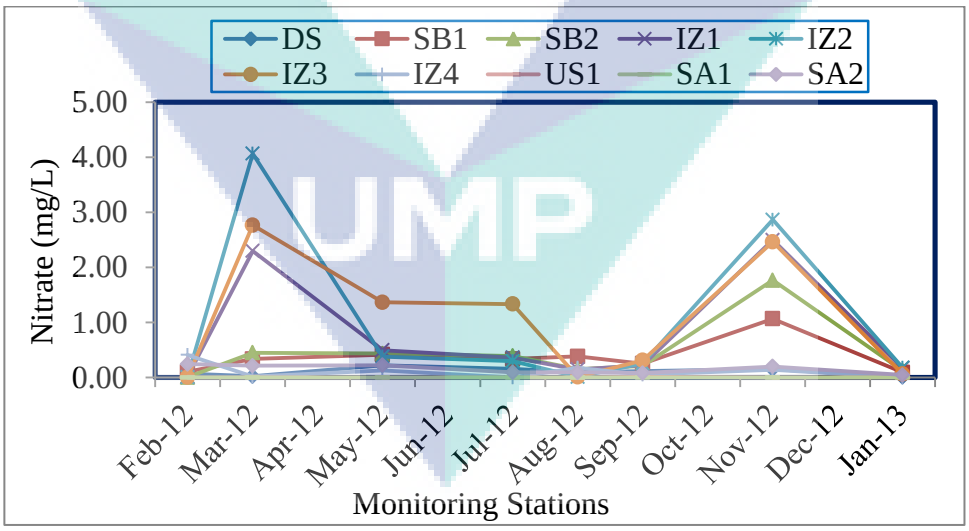


Figure 4.24: Monthly variations of NO_3-N of ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

The figure indicates a significant variation among the stations especially in the wet season. The highest concentration (4.07 mg/L) was obtained in March followed by (2.87 mg/L) in November 2012 at station IZ2 and the lowest was 0.00 mg/L at SA1 in

May 2012 and at IZ4 in January 2013 (Figure 4.24). In addition, of IZ2, stations IZ3 and IZ1 were loaded with relatively higher concentrations of nitrate-nitrogen in March and IZ3, SB1 and SB2 were found with higher concentrations in November 2012. At other stations, the trend was almost similar in throughout the year.

4.2.15 Phosphate-Phosphorous

The concentration of phosphate-phosphorous was measured from one year sampling and the data generated has been analysed. Analysed results are exhibited in Figures 4.25 and 4.26. These figures discussed the spatial and temporal variations of the phosphorus content among the monitoring stations respectively.

4.2.15.1 Spatial variation of phosphate-phosphorous among the monitoring stations

The average concentrations of phosphate-phosphorous are presented in Figure 4.25. It expresses the spatial distribution of the parameter among the monitoring stations. The figure reveals that, the average range of phosphorus concentration was 0.04 mg/L to 1.13 mg/L. The highest amount was obtained at SA2 and the lowest was at US1. There was significant variation among the stations; where the mid-zone of the Tunggak River (industrial zone) was found to have moderate concentrations compared to the residential area (SB1 and SB2).

4.2.15.2 Monthly variation of phosphate-phosphorous among the monitoring stations

Monthly distributions of phosphate phosphorus are shown in Figure 4.26. The Figure shows some variations among the stations based on the time factor. Station SA2 was found with the highest concentration (5.47 mg/L) in July 2012, which was unusual. Other than that, all other stations were found to have almost similar trend. Without considering the SA2, the highest concentration of phosphorus (2.73 mg/L) was in November 2012 at IZ3 followed by SA2 (2.23 mg/L) in February 2012 (Figure 4.26). Conversely, the lowest concentration (0.01 mg/L) was obtained in February 2012 at SA1.

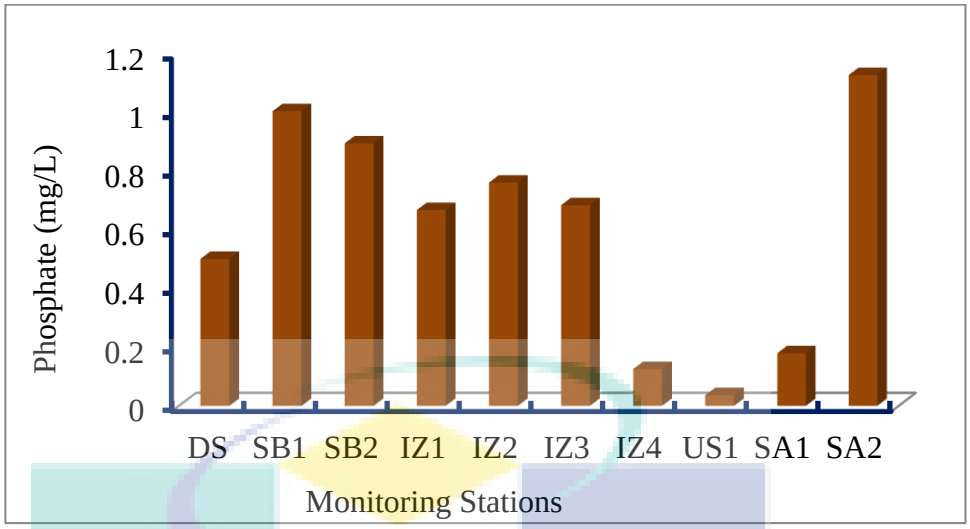


Figure 4.25: Average phosphate in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

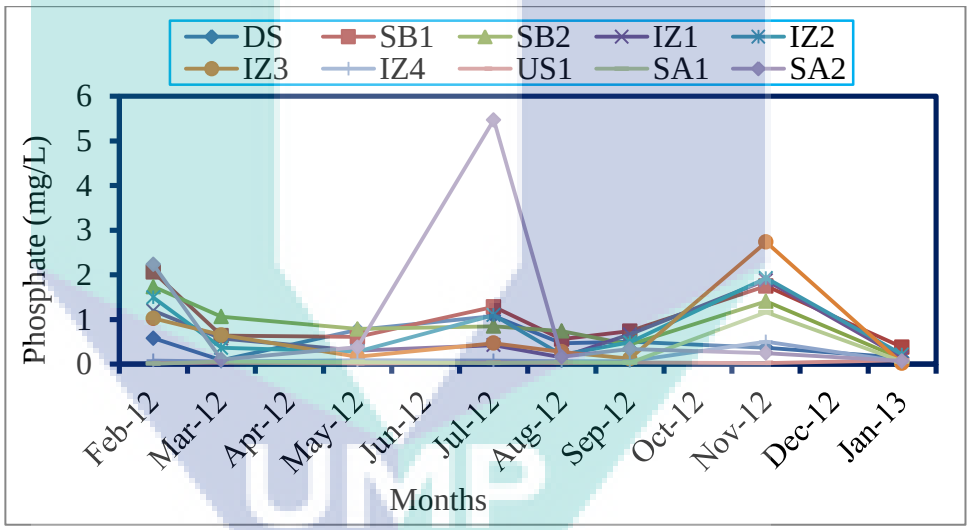


Figure 4.26: Monthly variations of phosphate at ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.16 Sulphate

From all the monitoring stations sulphate concentration was obtained during one-year of sampling period. The average concentrations of sulphate from each monitoring station are shown in Figure 4.27 to discuss the spatial variation of the parameter. To know the temporal variation among the stations, monthly data are presented in Figure 4.28.

4.2.16.1 Spatial variation of sulphate among the monitoring stations

Data of the average sulphate concentrations are displayed in Figure 4.27. Results reveal that the concentration of sulphate was comparatively lower at all stations except for the downstream station (DS). The average range of sulphate concentration was 0.50 mg/L to 585.38 mg/L. The highest average concentration was at DS and the lowest was at SA1. Other than the DS station, the highest concentration was at IZ4 (197.63 mg/L) followed by SB1 (136.04 mg/L). For the river water, the average range was 51.04 mg/L at SB2 to 585.38 mg/L at DS station (Figure 4.27). Based on the zone distribution, the swampy area was found to be of a relatively lower concentration of sulphate.

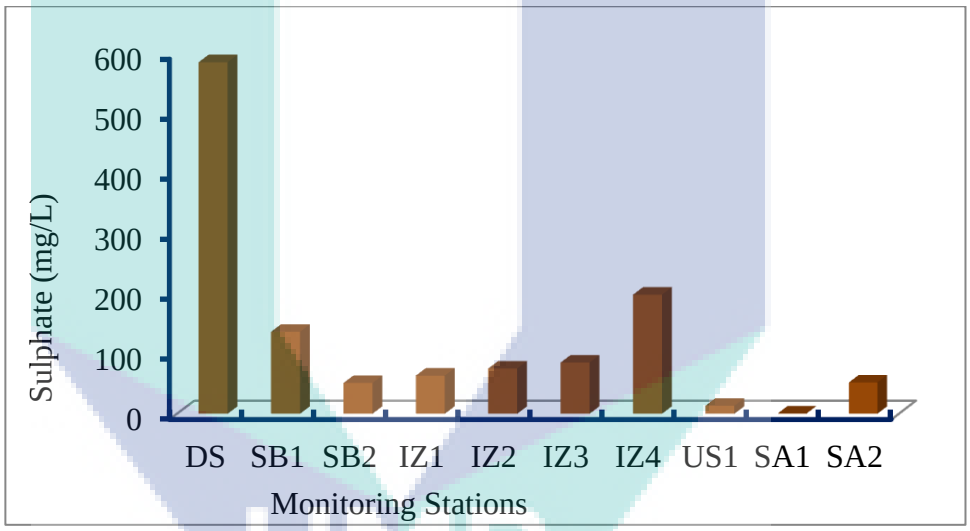


Figure 4.27: Average sulphate in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.16.2 Monthly variation of sulphate among the monitoring stations

Monthly data obtained from all stations are presented in Figure 4.28. It discusses the temporal variations of the sulphate concentration. The figure shows significant variations of sulphate concentration among the stations throughout the year. The highest concentration of sulphate (1213.33 mg/L) was in November 2012 at DS station followed by the same station in March 2012 with a concentration of 1160.0 mg/L. Maximum variations were observed in March, July, August and November 2012, while

in the other months the trend was rather uniform (Figure 4.28). However, the concentration was moderately higher in the dry seasons.

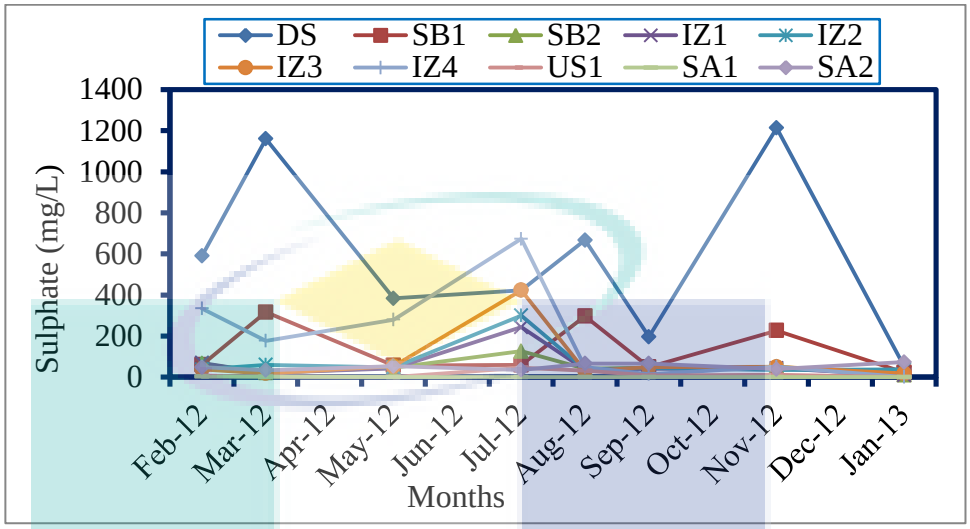


Figure 4.28: Monthly variations of sulphate at ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.2.17 Discussion on chemical parameters

Ammoniacal-nitrogen and nitrate nitrogen are two important parameters for water quality. Higher concentrations of those two parameters decrease the suitability of water for aquatic life as well as for other uses. In the present study, the range of average concentration of ammoniacal-nitrogen was obtained at 0.32 mg/L to 2.28 mg/L (Figure 4.21). Based on the INWQS water classification, one station (SA1) was categorized as class III and the rest (nine) stations were found to be in class IV unsuitable to use for any purpose except irrigation (Appendix D). Therefore, from the ammoniacal-nitrogen concentration point of view, the water at Gebeng industrial areas was not suitable for aquatic life as well as for other purpose, other than irrigation. On the other hand, nitrate nitrogen was observed below the threshold level in most of the stations. However, the higher concentration of ammoniacal-nitrogen in the study area was due to the industrial effluents from the GIE. Effluents from chemical industries and fertiliser industries might be the major source of ammoniacal nitrogen in the industrial areas. Similar results were also obtained by several researchers (Kanu and Achi, 2011; Varol et al., 2012; Yusuf, 2001; Walakira and Okot-Okumu, 2011). Besides the industrial effluents the higher concentrations of ammoniacal-nitrogen at the lower stream stations SB1 and SB2

might be due to the municipal wastes and agricultural activities that used the nitrogen rich fertilizer for agricultural production Varol et al. (2012); Bu et al. (2010) also showed the same results in their research. Although, ammoniacal nitrogen concentration was deteriorating the water quality of all stations, the nitrate nitrogen concentration was not a problem for aquatic life at the study area.

Other chemical parameters that were observed in the present study are phosphate phosphorus and sulphate. Regarding the phosphate phosphorus, the concentration was observed more than the threshold range in seven stations and in one station it was below the threshold range (0.2 mg/L to 0.1 mg/L) (WEPA, 2008) (Appendix A). Higher concentrations of phosphate-phosphorus at the residential areas might be due to the domestic wastes containing detergent and human excreta and due to the runoff from agricultural sites. This is common in such area where domestic and agricultural wastes are mixed with the water flow (Ahlgren et al., 2012; Comber et al., 2013; Donnert et al., 2002; Tyler et al., 2012; Yuan et al., 2012; Yusuf, 2001). In the industrial zone, the higher concentration might be because of chemical and detergent industries that produced effluents containing phosphorus-rich compound. Regarding the SA2 station, which was in swampy area but contained a maximum concentration of phosphorus, it was beside the new phase of industrial expansion. At that place, people might use detergent and other chemicals for cleaning, and in July 2012 when there was huge rainfall (Appendix E) that caused runoff from the area, resulting in high concentration of phosphorus. The average sulphate concentration in the study area was relatively lower except for the DS stations. Only one station (DS) was founded with higher concentration of sulphate that was above threshold value; otherwise the concentration was suitable for aquatic life (WEPA, 2008). Higher concentration at DS station was due to the presence of several salts in the seawater during tide. Station DS was found with concentration of sulphate above the threshold level. Usually sulphates are discharged into the water bodies in form of wastes from several industries that use sulphates or sulphuric acid as raw ingredients (Meays and Nordin, 2013; Yisa and Jimoh, 2010; Vasanthavigar et al., 2010). However, the concentration obtained was not harmful to aquatic life.

4.3 HEAVY METALS CONTAMINATION

Nowadays heavy metals are common contaminants of surface water with great concern due to their toxicity (Cheng et al., 2012). Occurrence of trace metal in water indicates the presence of natural and anthropogenic sources of pollution. Accompanying natural origins, anthropogenic sources of metals in water include mining and mineral processing activities, which have strong influences of bio-geochemical cycles of heavy metals (Krishna et al., 2009; Prasanna et al., 2012) and industrial activities, especially electroplating, metal coating, tyre, tractor, power plant, dyeing and food industries (Pathak et al., 2013). Gebeng, which is the present study area, is an industrial estate. Considering the major industrial activities in Gebeng area, ten (10) heavy metals were selected, measured and the results are discussed in this section. The basis of the selection of ten metals was the literature-reviewed types of industries in the study area and the geological condition.

4.3.1 Arsenic (As)

Arsenic is a toxic element and has been known for its toxicity since ancient times (Pfeifer et al., 2002). The contamination of arsenic in surface water of Gebeng industrial area is estimated and the results are presented in Figures 4.29 and 4.30. Figure 4.29 describes the spatial variations and Figure 4.30 displays the temporal variation of arsenic.

4.3.1.1 Spatial variation of arsenic among the monitoring stations

The average concentration of arsenic contamination has been analysed and the spatial distributions among the monitoring stations are shown in Figure 4.29. The figure shows that the average range of arsenic in the study areas was 0.002 ppm to 0.157 ppm. The highest concentration was at IZ4 and the lowest was at SA2. Regarding the river water, the average range of As concentration was 0.002 ppm at US1 to 0.157 ppm at IZ4. Except for the IZ4 station, the highest concentration was 0.017 ppm at DS, followed by IZ3. However, the river water was found to have relatively higher concentration of arsenic than the swampy area (Figure 4.29).

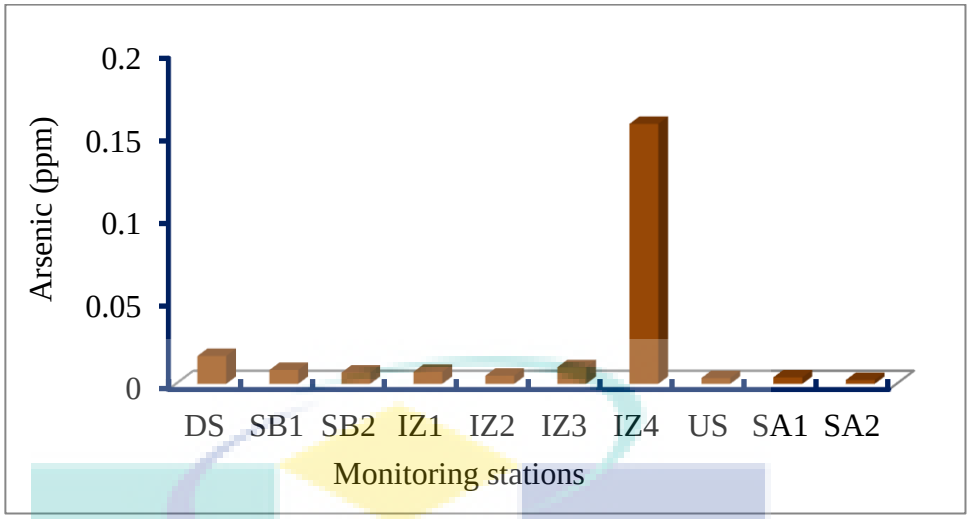


Figure 4.29: Average As concentrations in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.3.1.2 Monthly variation of arsenic among the monitoring stations

The spatial distributions of arsenic contamination are shown in Figure 4.30. Results reveal that without the IZ4 station there is no significant variation among the stations based on temporal changes. The highest concentration (0.530 ppm) was obtained in November 2012 followed by January 2013 (0.365 ppm) and February 2012 (0.320 ppm). As can be seen, the station IZ4 was more contaminated with As in the wet season than the dry. Other than that, the trend was somewhat uniform all year round at all stations (Figure 4.30).

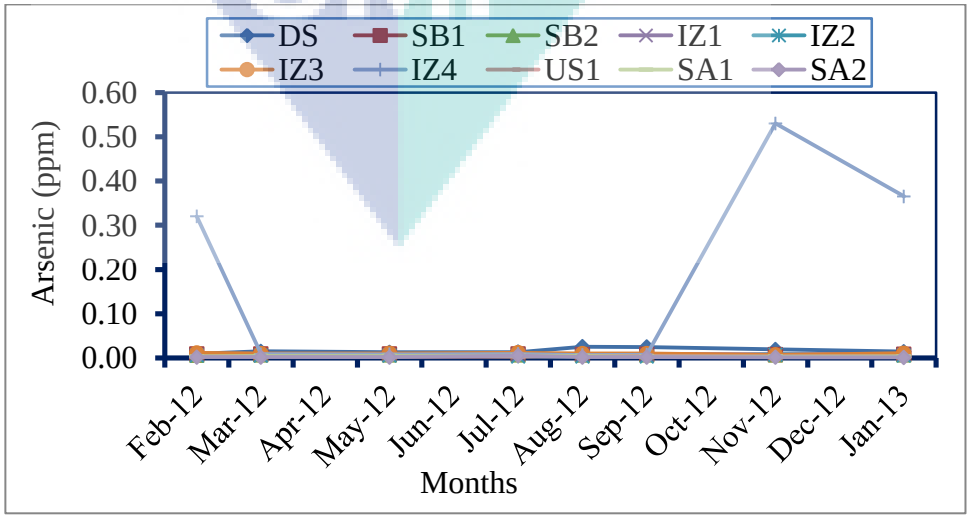


Figure 4.30: Monthly variations of As at ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.3.2 Barium (Ba)

Barium (Ba) concentration was measured from one year sampling of the study area. The average concentrations are displayed in Figure 4.31 that states the spatial variation of the metal. The monthly average data are shown in Figure 4.32 that discusses on the temporal variation.

4.3.2.1 Spatial variation of barium among the monitoring stations

From Figure 4.31, it can be seen that the range of average concentration of barium is 0.017 ppm to 0.059 ppm. The highest concentration was at SA2 and the lowest was at US1. The Figure 4.31 states that the distribution of Ba concentration among the stations was significantly different. The swampy area SA2 had the highest average concentration, while the SA1 had a lower value. Likewise, IZ1 and IZ2 stations were charging with comparatively higher concentrations, while IZ3 and IZ4 stations had lower concentrations. The Tunggak River had an average range of 0.017 ppm at US1 to 0.039 ppm at the DS station (Figure 4.31).

4.3.2.2 Monthly variation of barium among the monitoring stations

Monthly variations of the Ba concentration among the stations are shown in Figure 4.32. The figure reveals that highly significant variation has been observed among the stations for barium concentration based on the temporal changes. As can be seen, the highest concentration (0.112 ppm) was obtained for July 2012 at IZ2 followed by IZ4 (0.109 ppm) in November 2012 and IZ1 (0.104 ppm) in July 2012. In contrast, the lowest was observed on March 2012 at SA1 and IZ2 with no barium (0.00 ppm). However, Ba concentration was comparatively higher in the dry season, whereas in July it was the highest.

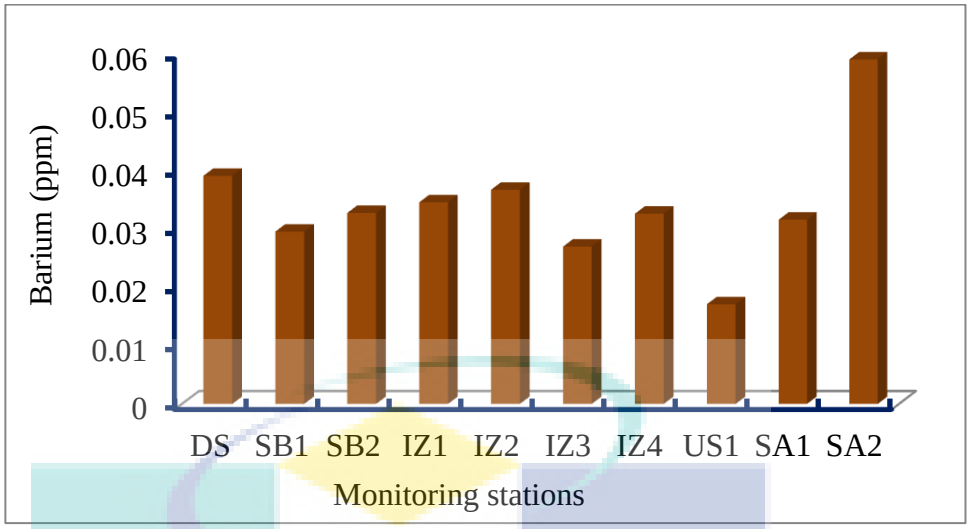


Figure 4.31: Average Ba concentrations in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

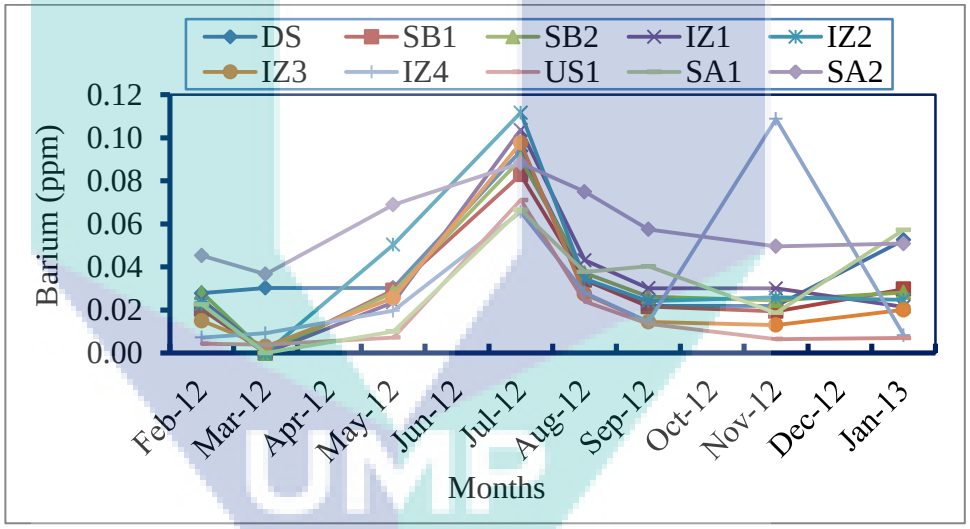


Figure 4.32: Monthly variations of Ba at ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.3.3 Cadmium (Cd)

Cadmium (Cd) is a natural, usually a minor element in surface and groundwater; but it is toxic to aquatic life even at concentrations only slightly higher (USEPA, 2001). In the present study, cadmium concentrations have been measured and analysed. The average concentrations of cadmium are presented in Figure 4.33 for the spatial variation and the monthly variation in Figure 4.34.

4.3.3.1 Spatial variation of cadmium among the monitoring stations

The range of average concentration of cadmium at different monitoring stations in the Gebeng industrial areas was between 0.005 to 0.137 ppm (Figure 4.33). Figure 4.33 states that the highest average concentration of Cd was obtained at station IZ3 and the lowest was at SB2. Without the station IZ3, all other stations were found with relatively low cadmium. Regarding the river water, the stations in Tunggak River show significant variation in cadmium concentration. Based on the zone distribution, the swampy area contained comparatively higher cadmium than the residential area and industrial zone, except for IZ3 stations. At IZ3, the concentration was very high compared to any other stations. The downstream station also contained significant amount of cadmium that can be toxic to the aquatic life.

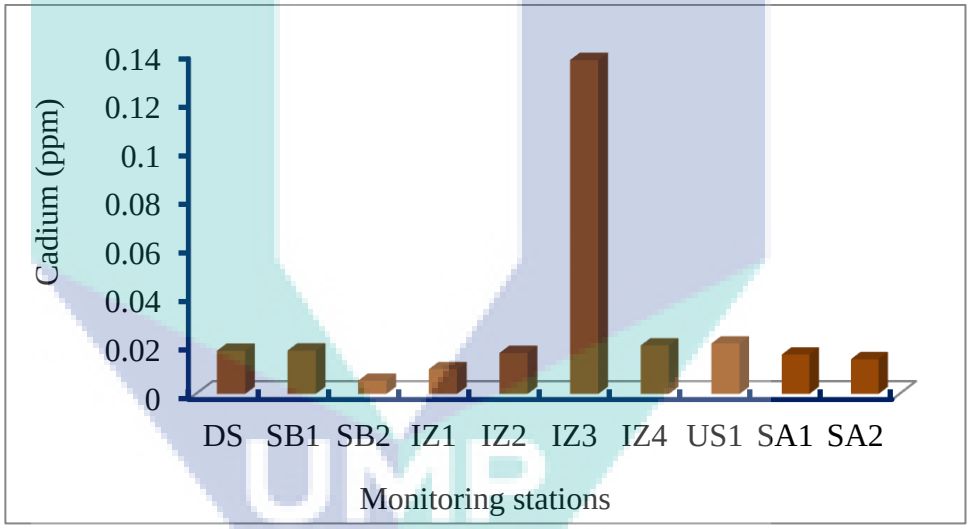


Figure 4.33: Average Cd concentrations in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.3.3.2 Monthly variation of cadmium among the monitoring stations

Temporal variations in cadmium concentration among the monitoring stations are displayed in Figure 4.34. The figure reveals that concentration at IZ3 showed a significant variation; whereas the other cases the trend of cadmium was quite similar with least variation. However, the highest concentration (0.300 ppm) was obtained in July followed by May (0.297 ppm) and March 2012 (0.287 ppm) at station IZ3. On the other hand, the lowest concentration was recorded as 0.000 ppm in March 2012 at SB2

station. Based on the seasonal variations the concentration was slightly higher in dry season compared to the wet season (Figure 4.34); though in July 2012 cadmium concentration was observed at lower level at all stations.

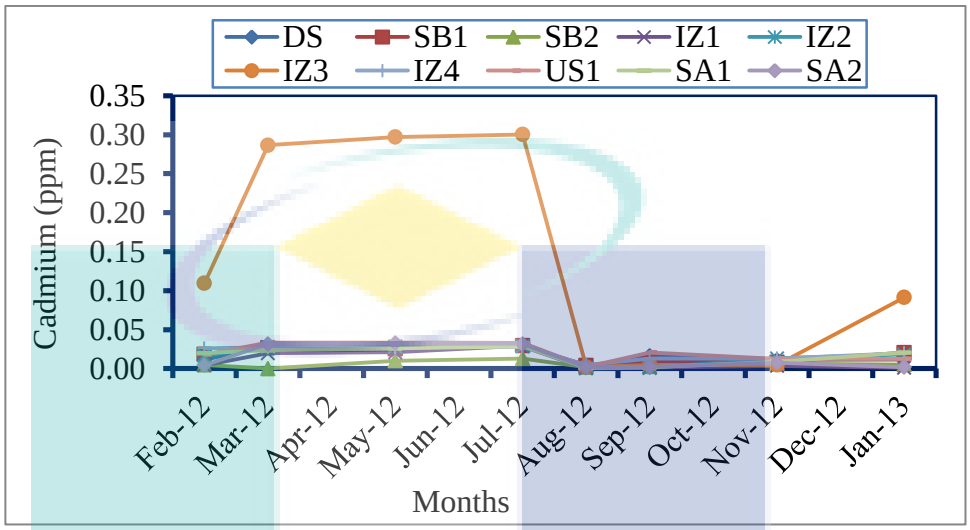


Figure 4.34: Monthly variations of Cd at ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.3.4 Cobalt (Co)

Cobalt is a naturally occurring chemical element. It is an essential elements for the formation of vitamin B 12 (Env.Canada, 2013). However, its toxic level in water is harmful for aquatic lives and for water use. The concentration of cobalt in the present study had been measured and analysed. The results are shown in Figures 4.35 and 4.36. Figure 4.35 explains the spatial variations and Figure 4.36 discusses the monthly variation of cobalt concentration among the monitoring stations.

4.3.4.1 Spatial variation of cobalt among the monitoring stations

The average concentrations of cobalt of all stations are shown in Figure 4.35. The Figure shows that the range of average concentration of cobalt was 0.0097 ppm to 0.7583 ppm. The highest concentration was at IZ3 followed by IZ2 (0.4602 ppm) and IZ1 (0.3562 ppm). In contrast, the lowest was at US1 followed by the IZ4 and the swampy area (Figure 4.35). In the Tunggak River, the average concentration was higher especially at the industrial zone.

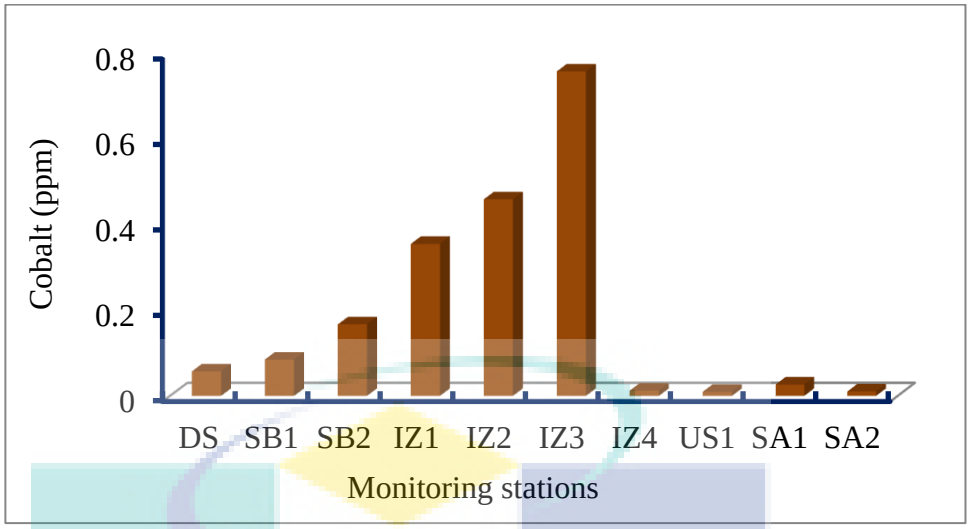


Figure 4.35: Average Co concentrations in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.3.4.2 Monthly variation of cobalt among the monitoring stations

Temporal variations in cobalt concentration among the monitoring stations are illustrated in Figure 4.36.

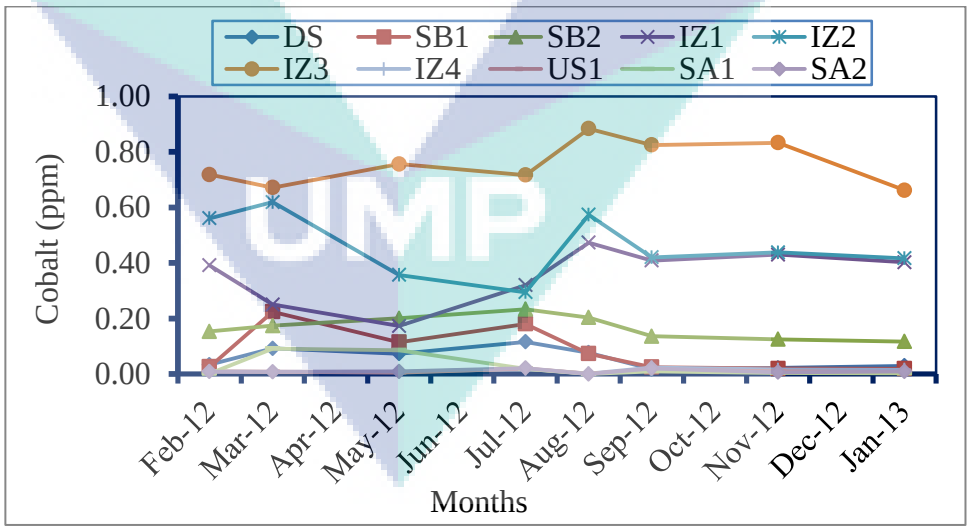


Figure 4.36: Monthly variations of Co at ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

Results reveal that there was a significant variation of cobalt concentration among the stations based on the monthly distribution. As can be seen, three industrial stations (IZ1, IZ2 and IZ3) were found with lower concentrations of cobalt in the dry

season compared to the wet season. But all other stations were found to have relatively higher concentration in dry season than the wet season (Figure 4.36). Nevertheless, the highest concentration of cobalt (0.8837 ppm) was obtained in August 2012 followed by November (0.8329 ppm) and September (0.8249 ppm) at IZ3 station. Conversely, the lowest concentration was recorded in August 2012 at SA2 station with no cobalt (0.00 ppm) followed by November (0.0063 ppm) at the same station (Figure 4.36).

4.3.5 Chromium (Cr)

Chromium is a naturally occurring metal that can be found in water mostly in hexavalent Cr (VI) form. Its toxicity can cause skin allergy and cancer in human body (Yusof et al., 2007). The concentration of chromium (Cr) has been detected from 10 different monitoring stations of the surface water of Gebeng industrial area and the data obtained was analysed. Results are shown in Figure 4.37 that expresses the spatial variation of Cr and Figure 4.38 describes the temporal variations of Cr among the monitoring stations.

4.3.5.1 Spatial variation of chromium among the monitoring stations

The average concentrations of chromium obtained from the data of ten different monitoring stations are shown in Figure 4.37. The figure expresses that the concentration of Cr among the stations was significantly different. The highest average concentration (0.0556 ppm) was obtained in IZ4 stations and the lowest (0.004 ppm) at IZ3. The swampy zone had a comparatively higher concentration of Cr than the other zones. Although the highest concentration was at the industrial zone, the other stations except for IZ4 were found to have a relatively lower concentration (Figure 4.37).

4.3.5.2 Monthly variation of chromium among the monitoring stations

Temporal variations of chromium concentration among the monitoring stations are shown in Figure 4.38. It reveals that significant variation of chromium concentration was observed with temporal changes among the monitoring stations. The average range of Cr concentration was recorded 0.0007 ppm to 0.1244 ppm. The highest concentration was observed in January 2013 at downstream station (DS) and the lowest was in March 2012 at IZ3 station. DS and IZ4 was had higher concentration at wet season while, the

other stations had higher concentration in the dry season (Figure 4.38). Among the dry seasons, all monitoring stations recorded high in August 2012; conversely, the lower values were observed in September of the wet season.

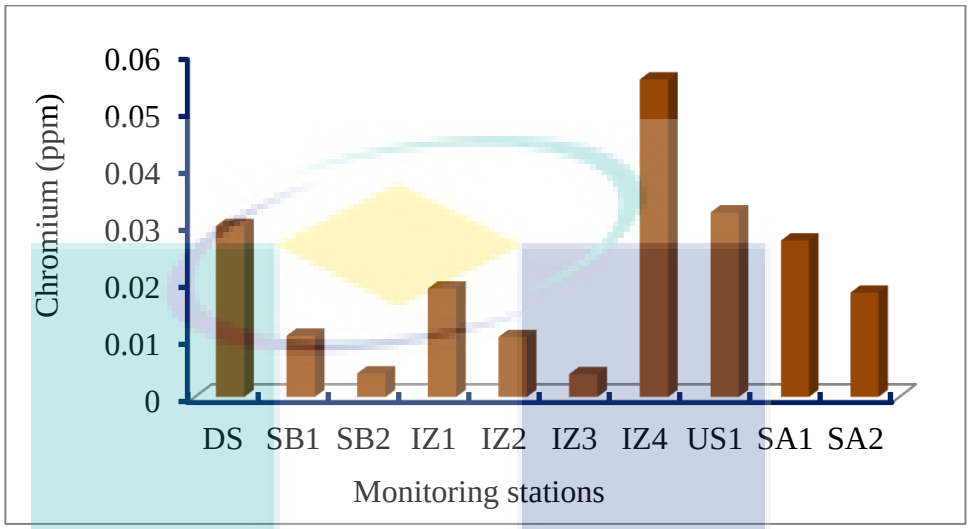


Figure 4.37: Average Cr concentrations in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

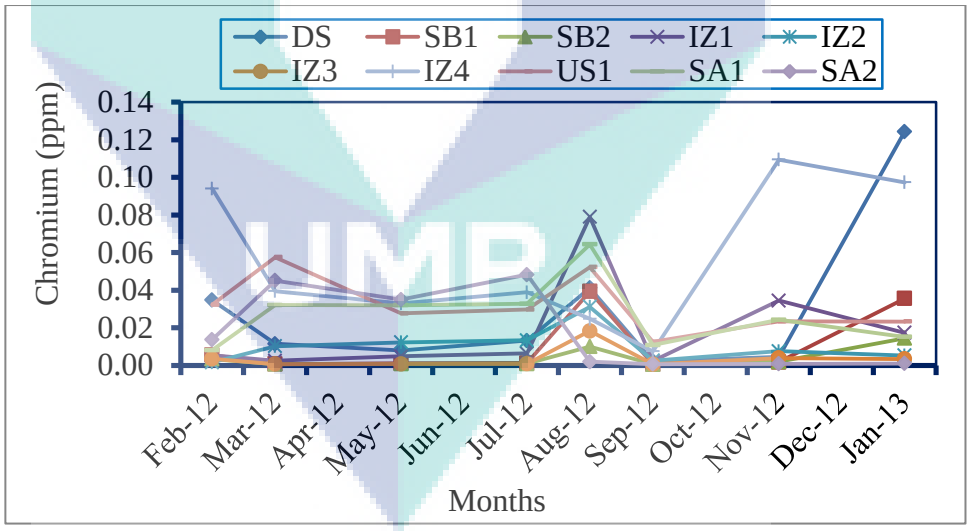


Figure 4.38: Monthly variations of Cr at ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.3.6 Copper (Cu)

Copper is essential to all living organisms as a trace dietary mineral; but its higher concentration is toxic for aquatic life and also for human health. In the present

study, copper concentration of the surface water of Gebeng industrial areas was measured and the data obtained were analysed to determine the spatial and temporal variations. Spatial variations of the copper content are shown in Figure 4.39 and the temporal variations are presented in Figure 4.40.

4.3.6.1 Spatial variation of copper among the monitoring stations

The average copper concentrations from 10 different monitoring stations are shown in Figure 4.39. The figure indicates that except for the downstream (DS) and IZ4 stations the trend of Cu concentration was similar with lower values. The average rang of Cu in the study area was recorded at 0.0014 ppm to 0.2673 ppm. The highest concentration was obtained at IZ4 followed by DS (0.1950 ppm) and the lowest was at US1 followed by SA1 (0.0016 ppm). In the Tunggak River, the concentration was relatively higher than the swampy area.

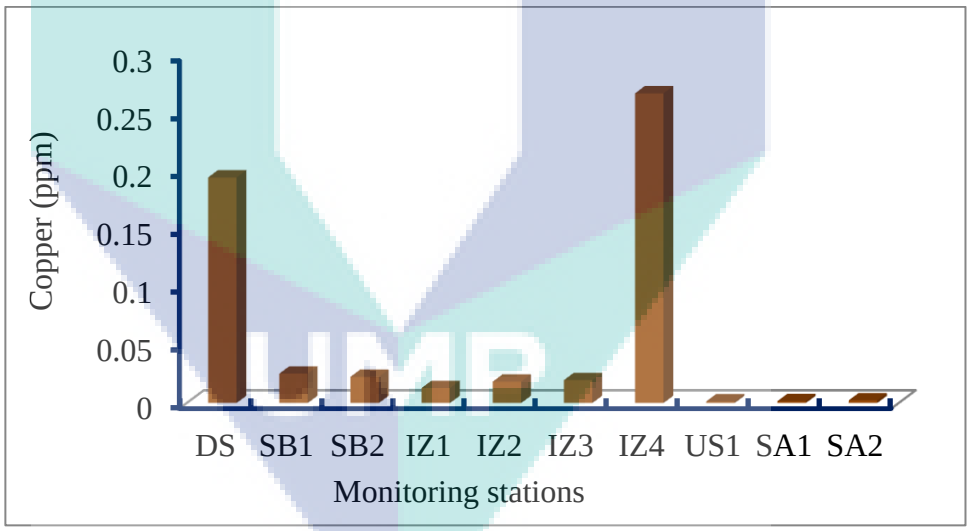


Figure 4.39: Average Cu concentrations in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.3.6.2 Monthly variation of copper among the monitoring stations

Monthly distributions of the copper concentration among the stations are presented in Figure 4.40. Results reveals that stations DS and IZ4 had some variations of copper content while the other stations showed almost similar temporal trend. As can be seen, a little variation was observed among the wet and dry season. However, the

highest concentration (0.5064 ppm) was obtained in July followed by May (0.4886 ppm) at IZ4 and in March 2012 (0.4496 ppm) at IZ4 and DS stations (Figure 4.40). In contrast, the lowest concentration (0.0010 ppm) was recorded in August 2012 at SA2 station.

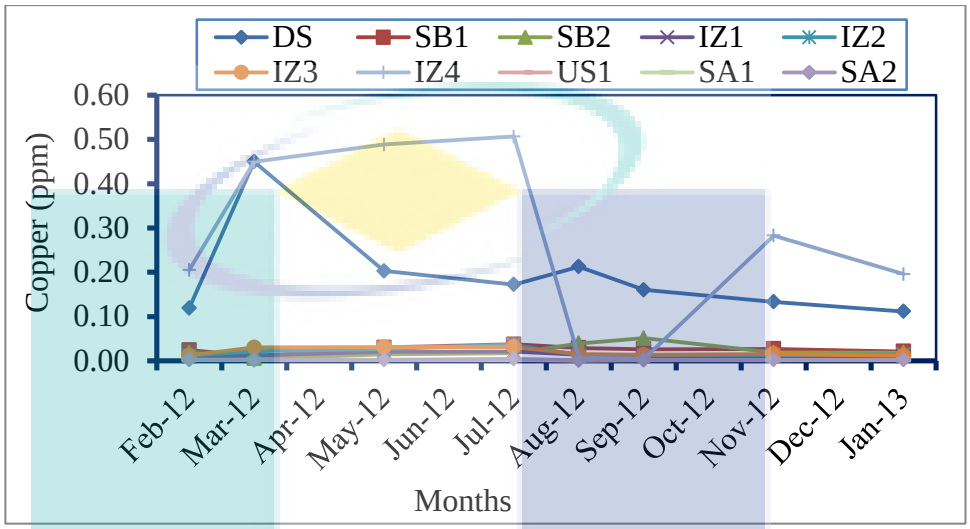


Figure 4.40: Monthly variations of copper ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.3.7 Mercury (Hg)

Mercury is a known heavy metal that pollutes the environment. and is usually discharged from power plants, gold mining, volcanic emissions, and ignition of solid wastes (Darbha et al., 2007). As methyl-mercury, it affects the central nervous system, and in severe cases irreversibly damages areas of the brain. The way of entering mercury in human body is the contaminated fish consumption and vapour. Therefore, it is important to identify the mercury concentration of river water. The mercury concentration of the surface water of Gebeng was determined and the data recorded was examined to identify the spatial and temporal variations of the parameters among the monitoring stations.

4.3.7.1 Spatial variation of mercury among the monitoring stations

The average concentrations of mercury (Hg) from all monitoring stations are presented in Figure 4.41. The figure shows a significant variation of Hg concentration among the stations. The average range of Hg was recorded at 0.0348 ppb to 0.1961 ppb.

The highest concentration was obtained at IZ2 while the lowest was at SA2 station. Apart from the IZ2, the lower stream stations DS, SB1 and SB2 were found with relatively higher concentration of Hg compared to other stations. The stations at swampy area also had a considerable amount of Hg.

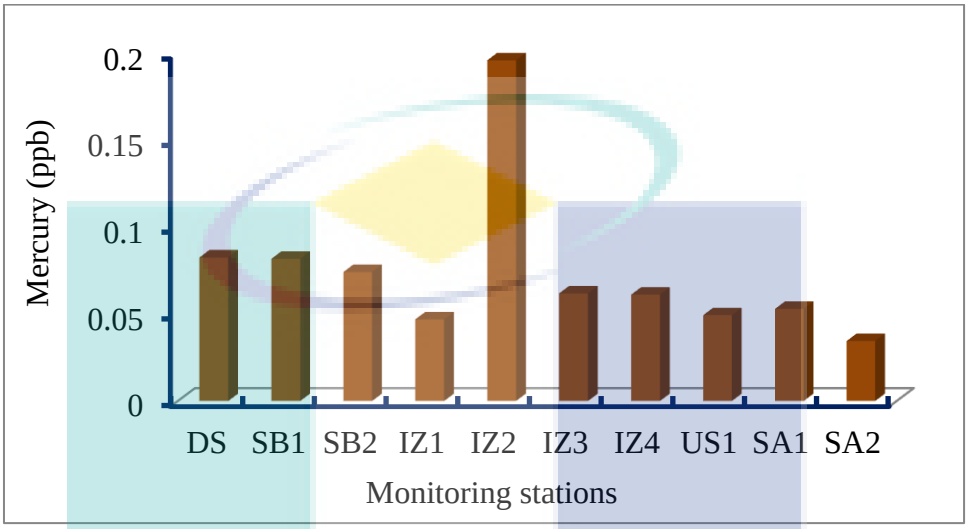


Figure 4.41: Average Hg concentrations in water samples from different monitoring stations of Tunggak River and surrounding water bodies of Gebeng industrial areas

4.3.7.2 Monthly variation of mercury among the monitoring stations

To know the temporal variation, monthly distribution of Hg concentration among the monitoring stations are displayed in Figure 4.42.

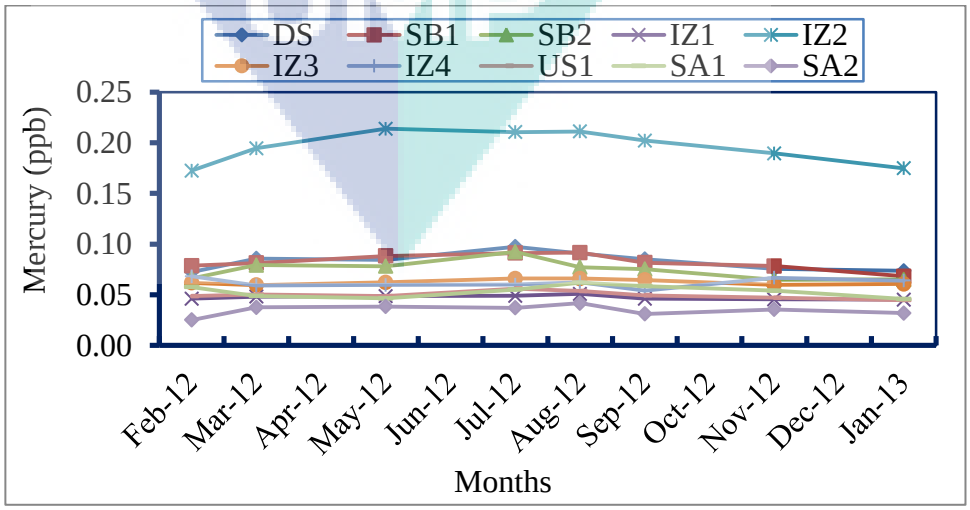


Figure 4.42: Monthly variations of Hg at ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

The results show that the concentration of Hg was marginally higher in dry season compared to the wet season, but the trend of Hg content was almost similar at all stations all year round (Figure 4.42). However, the highest concentration (0.2137 ppb) was recorded in May 2012 at IZ2 station followed by in August (0.2111 ppb) and in July (0.2104 ppb) at the same station. Inversely, the lowest concentration was obtained in February 2012 at SA2 station.

4.3.8 Nickel (Ni)

Nickel is a naturally occurring metallic element that is nutritionally essential for some plants, microorganisms and animal species; so either deficiency or toxicity can hamper the lifecycle of those living being (Cempel and Nikel, 2006). The concentration of nickel in the surface water of Gebeng industrial area was investigated and the collected data were analysed to determine the spatial and temporal variability. The results are presented in Figure 4.43 for the spatial variation and Figure 4.44 for the temporal variation.

4.3.8.1 Spatial variation of nickel among the monitoring stations

The average data of nickel concentration from 10 different monitoring stations are shown in Figure 4.43. The figure shows that the average range of nickel at the study area was 0.0202 ppm to 0.0828 ppm. The highest concentration was recorded at IZ3 while the lowest was at SA1 station. In the case of river water, all stations at Tunggak River were found with higher level of nickel compared to the surrounding (swampy area) stations. The average range in river water was 0.034 ppm at US1 to 0.0828 ppm at IZ3 station. Without the highest one (IZ3), other stations at industrial zone also contained a significant level of Ni. Station SB2, which is semi-industrial and residential area, contained Ni concentration similar to the industrial stations (Figure 4.43). However, the downstream stations DS and SB1 contained slightly lower nickel compared to the industrial zone.

4.3.8.2 Monthly variation of nickel among the monitoring stations

Monthly variations of nickel contamination are presented in Figure 4.44. The figure shows a significant variation among the stations based on the temporal changes.

As can be seen, there was a little fluctuation of concentration at wet season from dry season. The highest concentration of nickel (0.0919 ppm) was recorded in March 2012 at IZ2 followed by IZ1 (0.0912 ppm) in November 2012. In contrast, the lowest concentration (0.0100 ppm) was recorded in May 2012 at SA1 (Figure 4.44). In the dry season, most of the station had slightly higher concentration than the wet season. Except for the SA1 station, all monitoring stations had lower concentration of nickel in September 2012.

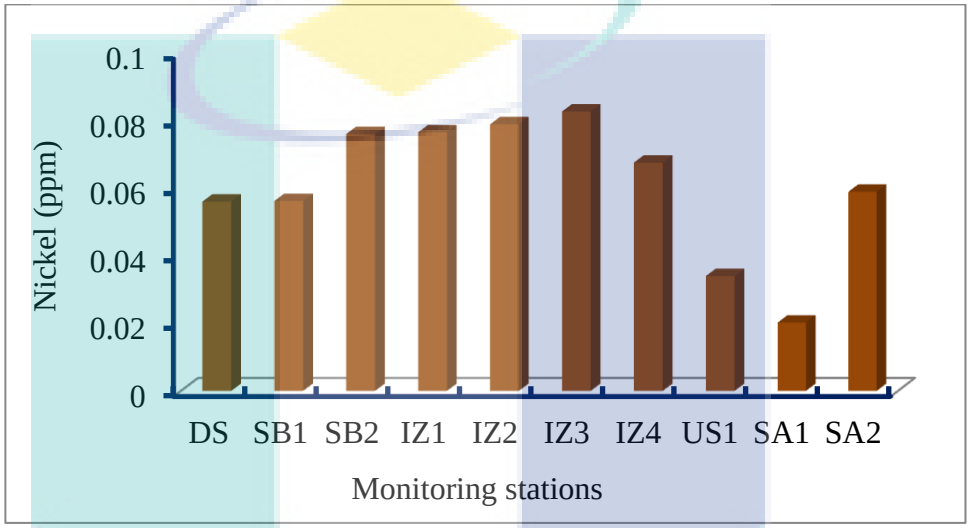


Figure 4.43: Average Ni concentrations in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

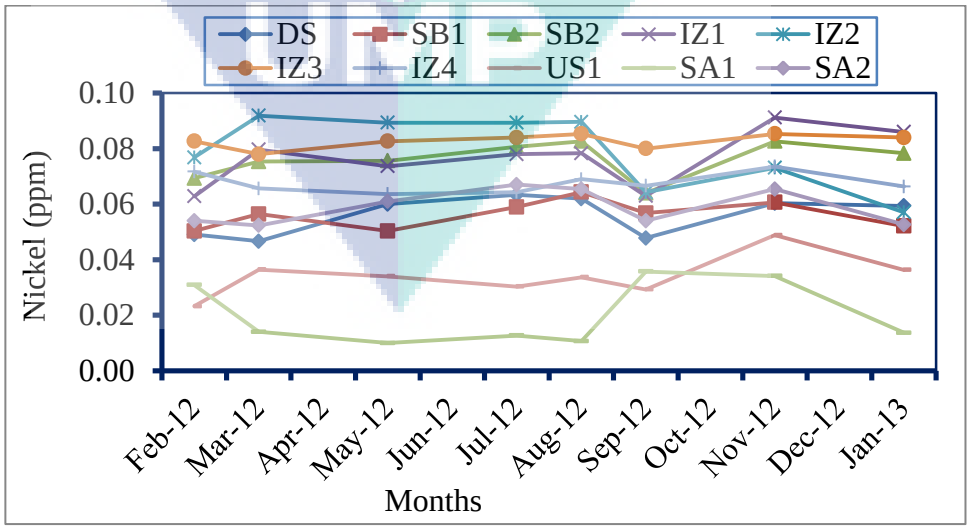


Figure 4.44: Monthly variations of Ni at ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.3.9 Lead (Pb)

Lead is a metallic element that disseminates into surface water primarily as the result of anthropogenic activities (USDHHS, 2006). The concentration of Pb was measured from 10 different monitoring stations of Gebeng industrial areas. Collected data was analysed and results are presented in Figures 4.45 and 4.46.

4.3.9.1 Spatial variation of lead (Pb) among the monitoring stations

The average concentrations of lead (Pb) from one year sampling of surface water are shown in Figure 4.45. The figure describes the spatial variation of Pb among the monitoring stations. As can be seen, the highest concentration (0.2945 ppm) was recorded at IZ4 and the lowest (0.0663 ppm) at IZ3 station. Other stations were also found with comparatively higher concentration of Lead (Pb), but at relatively lower concentrations at stations IZ3 and US1.

4.3.9.2 Monthly variation of lead (Pb) among the monitoring stations

Monthly variations of the Pb concentration among the stations are shown in Figure 4.46. The figure demonstrates some significant variations among the stations in dry season while the trend of Pb loading in wet season was very nearly similar, except for IZ4 station. IZ4 station had the highest concentration of Pb (1.1504 ppm) in November 2012. During the wet season, the concentration was lower compared to the dry season other than at station IZ4. IZ4 station also had higher concentration in May 2012. Among the dry season, higher concentrations were observed at all stations in March 2012 but in lower concentrations were in August. However, the lowest Pb concentration (0.00 ppm) was obtained in August followed by September and May (0.0020 ppm) at SA2 station.

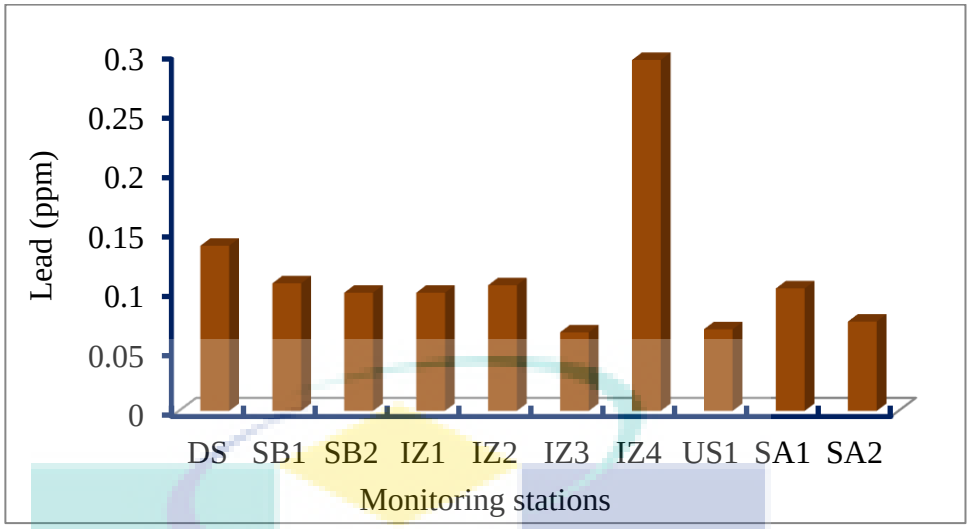


Figure 4.45: Average lead (Pb) concentrations in water samples from different monitoring stations of Tunggak River and the surrounding water bodies

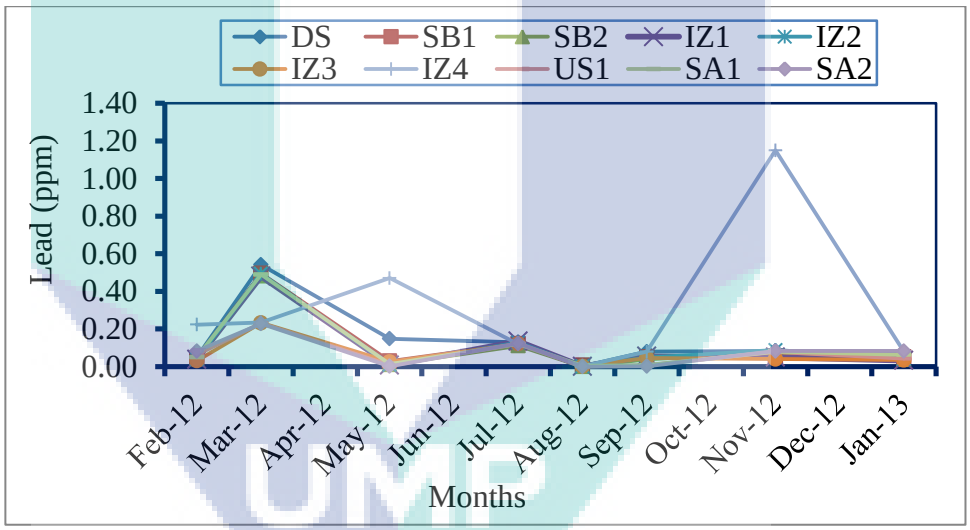


Figure 4.46: Monthly variations of lead (Pb) at ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.3.10 Zinc (Zn)

Zinc (Zn) concentration of surface water from ten different monitoring stations of the Tunggak River and surrounding area of Gebeng was detected. Recorded data were analysed and results are presented in Figures 4.47 and 4.48. Figure 4.47 explains the spatial variations and Figure 4.48 discusses the temporal distribution of Zn among the monitoring stations.

4.3.10.1 Spatial variation of zinc among the monitoring stations

The average concentrations of Zn at different stations of the study area are shown in Figure 4.47. The figure shows that the concentration of Zn varies from station to station. The average range of Zn was observed to be 0.1837 ppm to 1.2490 ppm. The highest concentration was recorded at IZ2 station followed by DS (1.1832 ppm) and SA2 (1.1724 ppm). Conversely, the lowest amount was recorded at SA1 followed by SB2 (0.3804 ppm). Higher concentration was observed in the industrial zone compared to other areas. However, the concentration of Zn was within the threshold level of Malaysia, indicating that the water of the area was quite free from Zn contamination.

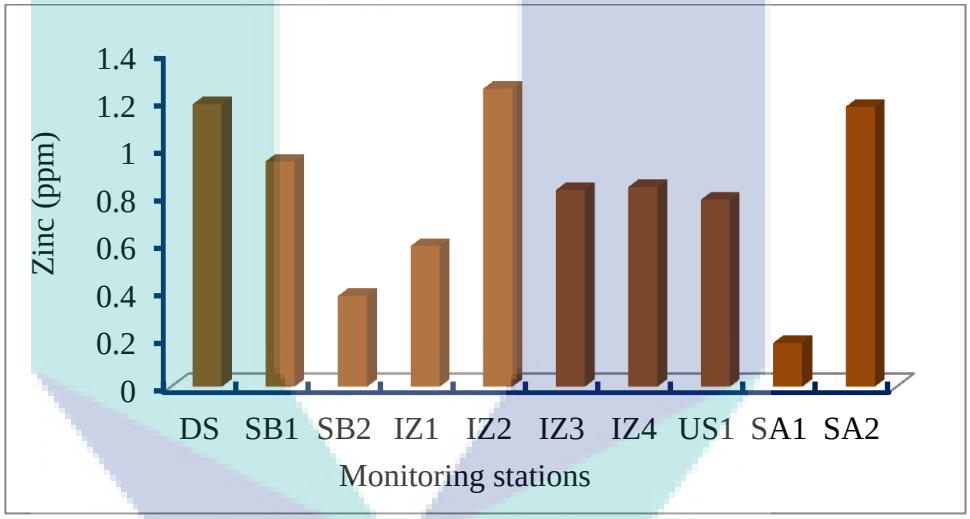


Figure 4.47: Average zinc concentrations in water samples from different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.3.10.2 Monthly variation of zinc among the monitoring stations

Monthly data from the monitoring stations are graphically presented in Figure 4.48. The figure states that the concentration of Zn in dry season was marginally higher than the wet season. The highest concentration of Zn (1.9435 ppm) was recorded in March 2012 at IZ2 followed by July 2012 (1.6718 ppm) at the same station (Figure 4.48). On the contrary, the lowest concentration (0.1358 ppm) was obtained in May 2012 at SA1 station. Three stations (IZ2, IZ1 and SA2) showed difference in the concentration trend while the other stations had almost similar trend of concentration throughout the year.

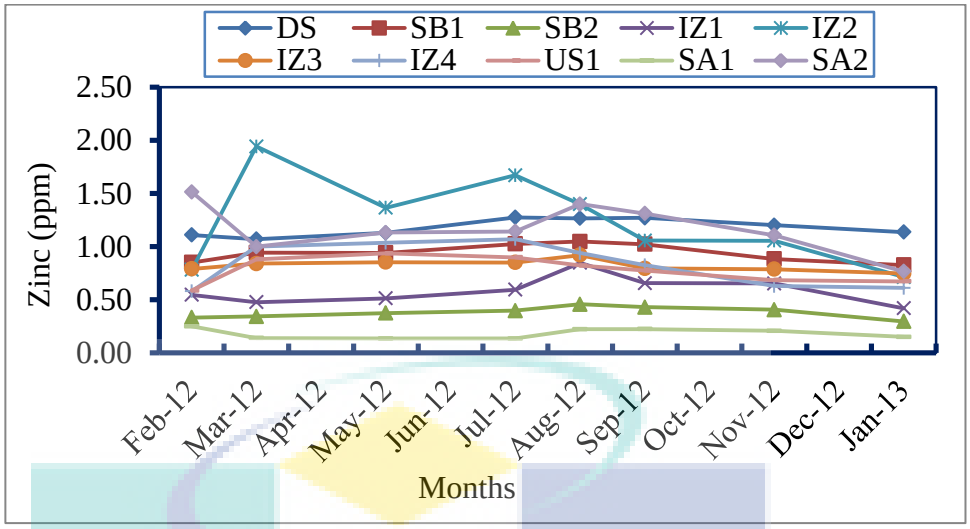


Figure 4.48: Monthly variations of zinc of ten different monitoring stations of Tunggak River and the surrounding water bodies of Gebeng industrial areas

4.3.11 Discussion on heavy metal concentration

The concentration of heavy metal in the surface water of the study area revealed that five metals out of ten were found with toxic level at maximum stations. Among those, cobalt and lead were beyond the threshold level at all stations, cadmium was observed toxic at nine stations, nickel was toxic at eight stations and copper was beyond the threshold level at four stations (WEPA, 2008; Nagpal, 2004). Besides those five heavy metals, arsenic was found toxic at one station. Other than those, the contamination of rest four metals (Ba, Cr, Hg and Zn) was still under safe level.

Cobalt and cadmium are positively inter-correlated metals. Although currently there is no recommended threshold level for cobalt in Malaysia, it demands the attention of the researchers because of its toxicity. According to the recommendation of Water Protection Section of British Columbia, the threshold level of cobalt is 4 ppb (0.004 ppm) to protect freshwater aquatic life from chronic toxic effects of cobalt (Nagpal, 2004). In this study, the average range of cobalt concentration found to be 0.0097 ppm to 0.7583 ppm, well above the recommended level. The causes of higher concentration of cobalt might be due to the industrial effluents from those industries that used cobalt compound, mining industries, phosphate fertilizer industries and sewage sludge associated with natural sources. Urban and agricultural run-off might also be the

potential anthropogenic sources of cobalt to the aquatic environment. A number of previous researches also support the present findings (Hodge and Dominey, 2001; IPCS, 2006; Env.Canada, 2013; Nagpal, 2004). Moreover, the cobalt was found to have highly positive correlation with cadmium and pH, which were higher in that area. Linear relation between cobalt and cadmium indicated that these two metals had similar trend of dispersion. The acceptable level of cadmium in the Malaysian river water is 0.01 ppm (WEPA 2008; Yusuf 2001). Based on this level, only one station (SB2) was within the threshold limit; whereas all other stations were beyond the threshold level indicating that the surface water of the Gebeng industrial areas were not suitable for aquatic life or other purposes. Higher concentration of cadmium in the water might be due to the effluent from the industrial and sewage treatment plants of Gebeng industrial estate. Domestic wastes in the residential areas (Seberang Balok), mining activities at the industrial estate and the natural sources were also responsible for the higher concentrations. A good number of the similar results were investigated by numerous researchers (Banerjee and Gupta, 2012; Ekpo et al., 2008; Hoo et al., 2005; Pan et al., 2010; UNEP, 2010; Yusuf, 2001). Regarding the temporal variations, the concentration was a little bit higher in the dry season, due to dryness or drought that would had negative impact on cadmium concentration that resulted in high concentration during dry season (Delpla et al., 2009; Zwolsman and Bokhoven, 2007).

Similar to cobalt, Lead (Pb) that is a non-essential metallic element and toxic in even lower concentration than any other heavy metals (Fontenele et al., 2009; Pescim et al., 2012) was found toxic at all stations. The concentration of Lead made the water of the area unsuitable for aquatic environment. Higher concentrations of Pb at the industrial zone were might be due to the effluents from metal industries that used lead as raw materials and also from corrosion of lead pipes, which is supported by the similar result the researches of several authors (Sayegh, 2011; Srinivasa Gowd et al., 2010). Higher concentration at the upper part and swampy areas, which were located at the roadside, might be the cause of motor vehicle exhaust fumes. Srinivasa Gowd et al. (2010) also reported similar results.

Regarding the nickel contamination, the higher concentration was due to the industrial effluents from the industries that used nickel and nickel compounds. It could

also come from the effluents from industries like ceramic, steel and alloys (metal industries), electroplating and refractory of Gebeng industrial estate. Similar results were investigated and published by Cempel and Nikel (2006) and Srinivasa Gowd and Govil (2008). Accompanying the industrial effluents, the domestic sewage sludge, wastewater from sewage treatment plant and the natural sources were also contributed to the contamination at some stations (SB1 and SB2). Related results were reported in earlier several researches all over the world (Gowd and Govil, 2008; Cempel and Nikel, 2006; Ritter et al., 2002; USDHHS, 2005). At two stations, the concentration was lower comparing the recommended threshold level. However, based on the recommended threshold level of the nickel in surface water, the water of the area was found unsuitable for aquatic environment.

Though copper is an essential element, it is poisonous in some instances. It usually occurs in surface water from natural and anthropogenic sources. In freshwater systems, the concentrations of naturally occurring copper ranges from 0.0002 ppm to 0.030 ppm (USEPA, 2012). In the present study, the toxic level at four (4) stations (DS, IZ4, SB1 and SB2) were might be due to the industrial effluents from those industries that used copper as raw materials, fertilizer industries, harbour activities, use of antifoulant paints for boat protection and obviously the natural sources (USDHHS, 2004). Similar results were also reported from several researches (Augusto and Gonzalez, 2011; Lassiter, 2010). Besides anthropogenic and natural sources correlation among the metals and other parameters were also responsible for higher contamination of heavy metals in water (Table 4.9).

4.4 SOURCE APPORTIONMENT OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS IN SURFACE WATER

Identification of the sources of pollutants and the contribution of the parameters is one of the major challenges in assessing surface water quality (Mustapha and Abdu, 2012). Use of principal component analysis (PCA) in identifying pollution sources is now a widely used unbiased statistical method (Satheeshkumar and Khan, 2012) and eventually multiple linear regressions (MLR) is useful in estimating the contribution of parameters. These two techniques can expose the potential pollution sources and are practically usable in various types of data (Praveena et al., 2012). PCA helps in the

interpretation of complex data in a simplified way (Pejman et al., 2009) for better understanding by investigating the structural information of uncertain data (Ragno et al., 2007). On the other hand, MLR is the tool to examine the relationship between single dependent variable and a set of independent variables to best represent relationship in each factor (Mustapha and Abdu, 2012). It also identifies important parameters to determine the major sources of pollution. In this section, source identification of physical and chemical parameters and heavy metals by using multivariate statistical technique is discussed.

4.4.1 Physical parameters of surface water quality

The source apportionment of physical parameters, such as temperature, pH, TDS, turbidity, TSS, conductivity and salinity were done by using the principal component. A descriptive statistics was also conducted to show the average concentration and their variation.

4.4.1.1 Descriptive statistics of physical parameters

A descriptive statistics of the physical parameters of surface water quality are demonstrated in Table 4.1 that shows the mean and standard deviations of the parameters in the study area. As can be seen, the temperature of the study area is within the standard limit of Malaysia (DOE, 2008); but pH was found with acidic at the upstream station along with swampy area (Table 4.1). Regarding TDS, the concentration was above threshold level at all stations except for the US1 and SA1, while the turbidity was above the threshold level at all stations. Similar to the TDS, TSS was also above standard level at most stations. Higher mean and standard deviation of TDS, TSS and turbidity can determine the common source of origin of those parameters. Similar results are explained by Mustapha and Abdu (2012). The concentration of conductivity and salinity were similar indicating the same source of these two elements at the downstream stations, and it was due to tidal water. However, concentration of EC and salinity were above the threshold level at the three lower stream stations and IZ3. Higher mean and standard deviations of the parameters indicates the anthropogenic impact on the water quality.

Table 4.1: Mean and standard deviations of Physical parameters in the surface water

Stations	Temp.(^{0}C)	pH	TDS (mg/L)	Turbidity (NTU)	TSS (mg/L)	EC (µS/cm)	Salinity (%)
DS	29.43±1.55	6.52±0.42	37772.1±29259.1	91.35±189.48	64.63±96.82	14073.5±7903.3	7.67±4.58
SB1	31.07±2.94	7.14±0.44	6869.2±6245.5	85.38±178.24	37.63±56.23	4445.4±4449.5	2.33±2.42
SB2	31.01±2.01	7.30±0.45	2231.3±1531.0	45.35±73.42	27.67±46.19	1153.1±581.6	0.60±0.43
IZ1	30.55±1.57	7.42±0.63	2113.1±1585.8	35.09±50.47	17.58±20.68	915.7±482.9	0.41±0.21
IZ2	30.50±1.42	7.30±0.87	2003.5±1390.5	58.93±82.93	25.54±18.13	988.9±562.1	0.46±0.23
IZ3	31.62±2.94	7.47±0.69	12809.1±26762.0	206.11±495.87	73.75±157.04	1168.1±704.3	0.51±0.32
IZ4	31.30±2.43	6.96±0.77	764.5±691.3	108.91±259.98	274.67±714.03	525.5±422.9	0.20±0.17
US1	30.87±2.75	4.86±0.40	171.6±173.7	18.57±13.06	12.38±9.14	80.3±59.0	0.03±0.02
SA1	26.54±0.69	5.19±1.21	39.3±19.5	10.74±9.75	11.42±8.10	22.0±5.5	0.01±0.00
SA2	29.35±1.70	5.48±0.48	1903.0±988.7	16.78±14.50	9.54±5.61	781.6±122.4	0.35±0.06

4.4.1.2 Principal components analysis (PCA)

PCA was done with SPSS 16.0 statistical software. It was used to obtain composite variables (Principal Component, PC) for identifying pollution factors that affect the water quality and the latent pollution sources (Zhao et al., 2011). The primary objective of this analysis is to create a new set of factor (VF) for reducing the contribution of less significant variables; that are much smaller than the original data set in subsequent analysis (Mustapha and Abdu, 2012; Satheeshkumar and Khan, 2012). Before applying PCA, Kaisere-Meyere-Olkin (KMO) and Bartlett's test were performed to check the sampling adequacy. KMO test indicates the proportion of common variance and a value close to 1 denoting that PCA may be useful (Shrestha and Kazama, 2007). For KMO, there is a general rule of thumb that the value should be greater than 0.5 to precede a satisfactory PCA (Hinton et al., 2004). In the present study, KMO was found to be 0.518 (Table 4.2), indicating that the variables were correlated enough for appropriate PCA. Likewise, the Bartlett test of sphericity, significant level was 0.000 ($p < 0.01$) concluding that there were relationships between the variables. With those variables PCA could be performed.

In this study, a total of three factors (PC) had been extracted by PCA based on Eigen value >1. A varimax rotation was conducted to reduce the overlapping of genuine variables over every PC (Zhang et al., 2011). The communality values were over 0.72 that supported the decision to use the three factors. Factor loading matrix is given in Table 4.3 and component plot of seven variables are also shown in Figure 4.49. After rotation with Varimax with Kaiser Normalization method, summary of the PCA result demonstrated various parameters loadings, Eigen values, % variance of each component and cumulative variance (Table 4.3). As can be seen, three (3) significance factors (PC) are extracted by PCA with Eigen value >1, altogether explaining the 82.42% of total variance. The first factor (PC1) explains 37.375% of the total variance that is found dominating with salinity, conductivity and TDS. PC1 indicates that this factor group is highly positively correlated, and were contributed from the natural sources related variables like ionic groups of salts in the basin from inflows, soil erosion and runoff. All three events were prevailing at the study area, as it was adjacent to the South China Sea that triggered saline water intrusion.

Table 4.2: KMO and Bartlett's Test for physical parameters

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.518
Bartlett's Test of Sphericity	Approx. Chi-Square	1218
	df	21
	Sig.	0.000

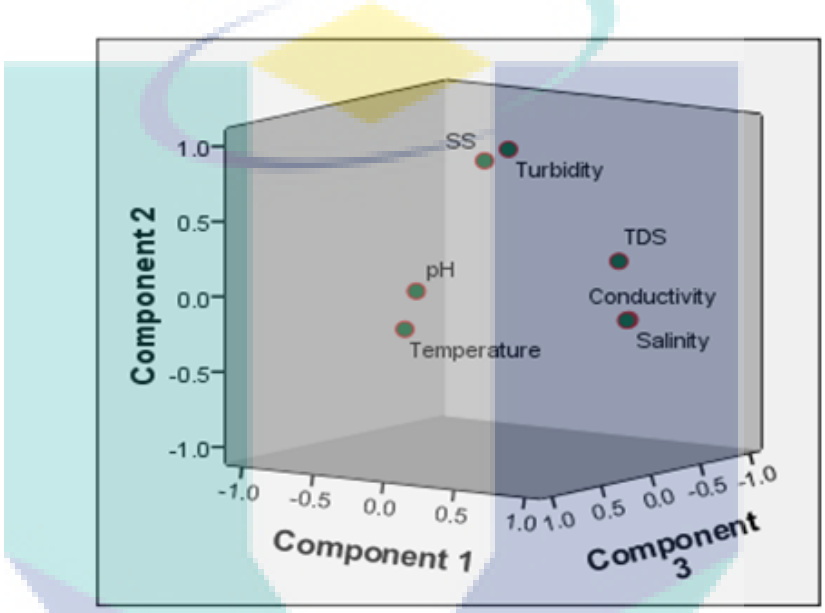


Figure 4.49: Component plot in rotated space for physical parameters

Newly developed zone and agricultural areas caused soil erosion and run-off. Similar results were also obtained by Varol et al. (2012). This factor group is also referred to as ionic pollution factor group which amounts to lots of ions and their compounds that lead to high loading of those variables (Zhang et al., 2011).

Factor 2 (PC2) explains 24.577% of total variance and had strong positive loading with turbidity and TSS. It indicates the common source of origin of this factor group, which was due to natural associated with anthropogenic causes. The factor explains that soil erosion from upland and diluted to the river flow had increased the level of TSS and due to the significant positive correlation (Appendix H) between TSS and turbidity, turbidity was also increased. Soil erosion that occurred due to the expansion works of the new phase of Gebeng industrial estate like, deforestation,

reclamation using fill quarried from the nearby hilly areas and subsequently heavy raining had caused run-off at the areas. Run-off had also occurred because of some natural reasons. Similar investigation was also reported by Shrestha and Kazama (2007). The third (3rd) factor (PC3) is found strong loading with pH and temperature that explains 20.47% of total variance (Table 4.3). High loading of temperature and pH represent the physiochemical source of variables that were also strongly influenced by climatologic and other environmental factors. Although, the temperature and pH were within the threshold levels, pH at the upstream was acidic due to the peat swamp forest and chemical effluents into river flow that contain acidic substances. The results is supported by the findings from a number of researches (Shrestha and Kazama, 2007; Wang et al., 2007). However, the sources of the physical parameters of the water quality at Tunggak River as well as Gebeng areas were mainly from the natural sources associated with anthropogenic activities.

Table 4.3: Rotated Component Matrix for physical parameters of water quality

Parameters	**Components**			**Communalities**
	PC1	**PC2**	**PC3**	
Salinity	0.973	-0.100	0.020	0.734
Conductivity	0.963	-0.105	0.029	0.938
TDS	0.858	0.268	-0.042	0.956
Turbidity	0.048	0.924	-0.083	0.863
SS	-0.030	0.859	0.047	0.810
pH	0.048	0.116	0.848	0.741
Temperature	-0.041	-0.149	0.838	0.726
Eigenvalues	2.620	1.738	1.412	
Variance (%)	37.375	24.577	20.470	
CV* (%)	37.375	61.952	82.422	

*CV= Cumulative variance
Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalisation

4.4.2 Chemical parameters of surface water quality

The potential source of chemical parameters of the surface water quality was identified by using principal component analysis and multiple linear regressions (MLR) analysis. Principal component analysis identified the sources and MLR investigated the contribution of each factor.

4.4.2.1 Descriptive statistics of chemical parameters

The mean and standard deviations of chemical parameters are shown in Table 4.4. The table indicates a very low mean value of DO, while the BOD and COD values are very high compare to DO. The higher mean value of the BOD was recorded at industrial zone and in the residential area (SB1 & SB2). The mean concentration of BOD is above the standard level of Malaysia (DOE, 2008) at all stations. Similar to BOD the mean concentration of COD is also higher over the whole area and is beyond the threshold level. Higher mean values and standard deviations of these two elements indicate the same source of origin; and the source might be of the anthropogenic associated causes with some natural pressure that has increased the concentration. Similar results are also stated by Mustapha and Abdu (2012). NH_3-N was higher at all stations dominating the residential areas where some agricultural activities existed. It was mainly because of the domestic wastes, industrial effluents and agricultural run-off. Nitrate concentration was lower compare to the standard level. PO_4^{3-} was also higher in concentration (Table 4.4) while the mean value of sulphate was very low in relation to the threshold level, except in the downstream station (DS).

4.4.2.2 Principal components analysis (PCA)

To identify the source of chemical parameters of surface water, principal component analysis was conducted. Before conducting the PCA, Kaisere-Meyere-Olkin (KMO) and Bartlett's test were performed to check the sampling adequacy. Value from KMO test of 0.553 (Table 4.5), indicates that the variables are correlated enough for application of PCA. Similarly, the Bartlett test of sphericity significant level 0.000 ($p < 0.01$), confirms that PCA can be applicable for source apportionment.

Table 4.4: Mean and standard deviations of Chemical parameters in the surface water

Stations	pH	DO(mg/L)	BOD(mg/L)	COD (mg/L)	NH_3N (mg/L)	NO_3N(mg/L)	PO_4^{3-}(mg/L)	Sulphate(mg/L)
DS	6.52±0.42	3.26±1.35	8.54±3.23	37.90±30.88	1.46±0.69	0.11±0.07	0.50±0.32	585.38±407.54
SB1	7.14±0.44	3.23±1.72	16.39±9.40	38.71±21.26	2.28±0.69	0.37±0.30	1.00±0.62	136.04±153.48
SB2	7.30±0.45	3.91±1.97	18.73±10.86	36.04±21.95	2.12±1.08	0.44±0.56	0.89±0.54	51.04±34.00
IZ1	7.42±0.63	4.79±1.58	18.88±10.73	37.83±19.99	1.61±0.74	0.78±0.98	0.67±0.59	63.29±71.74
IZ2	7.30±0.87	3.75 ±1.58	21.56±11.42	50.00±29.75	1.44±0.78	1.01±1.52	0.76±0.66	75.08±87.39
IZ3	7.47±0.69	2.82±1.64	21.41±12.71	54.42±39.67	1.55±0.94	1.04±1.13	0.68±0.86	85.00±131.32
IZ4	6.96±0.77	4.89±1.16	27.10±12.57	59.58±39.87	1.18±0.43	0.12±0.13	0.13±0.27	197.63±219.06
US1	4.86±0.40	3.10±1.21	10.34±6.08	35.00±19.47	1.44±0.53	0.00±0.01	0.04±0.03	13.33±16.01
SA1	5.19±1.21	1.83±0.67	6.86±3.09	24.79±18.53	0.32±0.18	0.00±0.00	0.18±0.59	0.50±0.98
SA2	5.48±0.48	3.07±1.17	9.19±5.11	14.04±8.51	1.96±0.77	0.15±0.08	1.13±1.86	52.04±18.26

Table 4.5: KMO and Bartlett's Test for chemical parameters

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.553
Bartlett's Test of Sphericity	Approx. Chi-Square	416.166
	df	21
	Sig.	0.000

In the PCA analysis, three (3) factors (principal component, PC) had been extracted based on Eigen value >1. After varimax rotation (to reduce the overlapping of genuine variables over every PC), the summary of the PCA results is demonstrated in Table 4.6 and component plot of seven variables are shown in Figure 4.50. The table explains the parameters loadings, Eigen values and variance, and the figure shows the parameters plotted in a rotated space. As can be seen, three PC altogether explain a total 71.251% of variance.

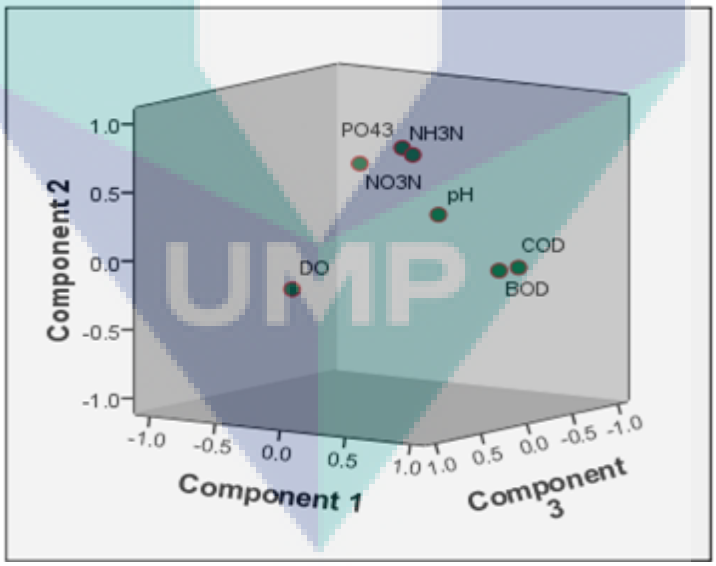


Figure 4.50: Component plot in rotated space for chemical parameters

The first factor (PC1) explains 29.708% of total variance with strong loading of BOD and COD, and moderately loading of pH. BOD and COD were also found highly positively correlated (Appendix H). The positive correlation and strong loading in PCA indicate that the source of these two parameters are similar and it may be due to organic

pollutant from industrial effluents, sewage treatment plant and domestic wastewater (Zheng et al., 2008).

The industries of Gebeng discharged their treated or partially treated effluent into the river flow (Sujaul et al., 2013) that contained oxygen demanding organic matter, which ultimately increased the concentration of BOD and COD. A number of similar investigations were reported by several authors (Ansari et al., 2012; Gyawali et al., 2012; M S Islam et al., 2012; Pawar, 2013; Vishwakarma et al., 2013; Yadav et al., 2012; Zheng et al., 2008).

PC2 explains 24.626% of total variance, which is strongly dominated by PO_4^{3-} and NH_3-N, and moderately dominated by NO_3-N. These three parameters were also found highly positively correlated (Appendix H). This factor represented that source of these variables were attributed to the non-point source pollution from agricultural areas; and organic & nutrient pollutions from point sources like, domestic wastewater, industrial sewage and wastewater treatment plants. Similar studies and results were published by a good number of researchers (Fukasawa, 2005; Shrestha and Kazama, 2007; Varol et al., 2012; Zhao et al., 2011; Zheng et al., 2008). Agricultural and stream runoff carry many suspended solids bearing significant level of inorganic phosphorus and nitrogen.

Third factor (PC3) is strongly dominated by DO that explains 17.017% of total variance (Table 4.6). DO was found negatively correlated with COD and NH3-N (Appendix H). Although, these two parameters are not strongly loading in this factor they show negative loading here. It indicates that the source of the DO and those two parameters were not similar. Actually, DO loading extremely depends upon point sources like organic wastes bearing supplementary organic matters and some natural process like temperature variability; whereas the source of COD and ammoniacal nitrogen are largely point source associated with non-point sources. Regarding sulphate, its contribution was less in the water quality and it was ignored in the PCA analysis.

Table 4.6: Rotated Component Matrix for chemical parameters of water quality

Parameters	Component			Communalities
	PC1	PC2	PC3	
BOD	0.935	-0.015	0.047	0.860
COD	0.857	-0.048	-0.277	0.877
pH	0.669	0.407	0.331	0.814
PO_4^{3-}	-0.046	0.732	-0.294	0.559
NH_3N	0.139	0.721	-0.144	0.539
NO3N	-0.004	0.697	0.231	0.624
DO	-0.044	-0.124	0.918	0.722
Eigenvalues	2.245	1.589	1.161	
Variance (%)	29.708	24.626	17.017	
CV* (%)	29.708	54.334	71.351	

*CV= Cumulative variance
Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization

4.4.2.3 Multiple linear regression analysis

Multiple linear regressions analysis is a statistical method to predict the relationship between a dependent variable and a set of explanatory (independent) variables (several predictors) (Koklu et al., 2010). MLR analysis was done with SPSS 16.0 statistical software to identify the contribution of variables towards the water quality of Tunggak River and surrounding water bodies. To detect the best predictors and remove the less significant variables (predictors) of water quality variation, stepwise multiple linear regressions model was used (Hinton et al., 2004). Classical assumptions of linear regressions were checked before the interpretation of MLR model results; with normal p-p plot of regression-standardised residuals analysed (Figure 4.51a). The Figure explains that all the observed values fall roughly along the straight line and indicates that the residuals are from normally distributed population. Furthermore, scatter plot of regression standardises the predicted values against observed values (Figure 4.51b) to show the linear relationship between the dependent variable and the predictors, with the residuals variances being equal or constant.

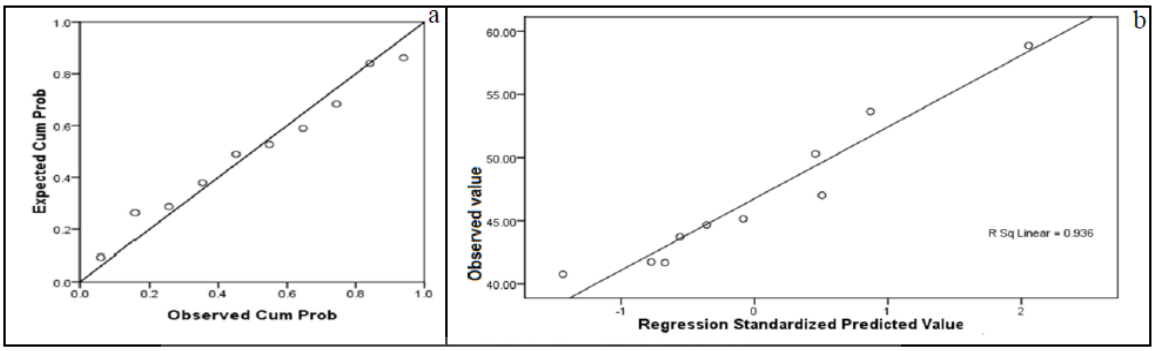


Figure 4.51: a) Normal p-p plot of regression standardised residuals and b) Scatter plot of regression standardised predicted values against observed values

Stepwise multiple linear regression models was used to remove the less significant variables and using this model four best predictor namely BOD, COD, pH and NH_3-N were detected. This detection means that the maximum water quality variation of Tunggak River is explained by those four predictor variables. Model summary in Table 4.7 shows that R^2 = 0.934; in short 93.4% variation of water quality of the river is explained by the above-mentioned four predictors. The coefficients of the predictors are estimated in the model and presented in Table 4.7. As can be seen, COD makes the strongest unique contribution in water quality variation with Beta coefficient value of -0.567. The second highest Beta value is for BOD (-0.500) followed by NH_3-N (-0.454). The least contributor is pH with a Beta value 0.223. The negative sign of Beta value indicates that water quality is negatively associated or correlated with those predictors. Nathans et al. (2012) also investigated and reported similar results in their publications.

In conclusion, the PCA investigated the sources of chemical parameters into the water bodies and it was supported by the multiple linear regression (MLR) analysis. MLR identified the contribution of each variable with significant values of R = 0.968 and R^2 = 0.936; it identified four major contributors of chemical parameters. As can be seen, the sources of COD and BOD were mainly from the anthropogenic activities, such as, industrial wastewater, domestic wastes and sewage treatment plants, while the NH_3-N, nitrate nitrogen and inorganic phosphorus were primarily from the non-point sources associated with anthropogenic activities. Finally, DO concentration was lower due to the

extended demand of oxygen from oxygen demanding organic matter of industrial effluents.

Table 4.7: Estimated coefficients of the multiple linear models

MLR model	Unstandardised Coefficients		Standardised Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	60.043	5.216		11.511	0.000
BOD	-0.354	0.186	-0.500	-1.902	0.116
COD	-0.190	0.083	-0.567	-2.307	0.069
pH	1.227	1.136	0.223	1.080	0.329
NH3N	-4.337	1.412	-0.454	-3.072	0.028

4.4.3 Heavy metal contamination

Nowadays, heavy metals are a common contaminant of surface water and are of concern due to their toxicity (Cheng et al., 2012). Occurrence of trace metal in waters indicates the presence of natural and anthropogenic sources of pollution. Economic developments including industrialization make the situation more critical. The present study area of Gebeng is an industrial town. Population growth and rapid industrialization at the area are creating extra pressure on available surface water resulting in water quality deterioration (Hossain et al., 2012; Nasly et al., 2013). Wastewater from metal and chemical industries and natural sources cause heavy metal contamination in water. For better surface water quality management, source apportionment of those metal contaminations is essential. In this study, source apportionment of heavy metal was done using PCA and hierarchical cluster analysis (HCA). A descriptive statistical analysis of the selected heavy metals was done to show the mean value among the monitoring stations. Pearson correlation coefficient was accomplished to identify the relationship among the metals that can help to ascertain the source of contamination.

4.4.3.1 Descriptive analysis

Mean concentrations and standard deviations of heavy metals in each monitoring site are given in Table 4.8. It is important to bear in mind that low concentrations with

homogeneous distributions across the area accompanied with lower standard deviations, indicate a major natural sources, whereas high pollutant concentrations along with high standard deviations suggest anthropogenic sources (Pérez and Valiente, 2005). As can be seen, higher concentrations and standard deviations are found in maximum heavy metal in DS, IZ2 and IZ4 stations indicating an anthropogenic source for metals contaminations, while almost homogeneous distributions are obtained for the other monitoring stations. Among three stations DS, IZ2 and IZ4, DS is located at the lower most part of the river and thus, was in a position to magnify the pollution at the end of the Tunggak River basin. This pollution may have multiple types of inputs due to the presence of big homestead, mangrove vegetation and agricultural activities at the vicinity of the station. Another two stations IZ2 and IZ4 are adjacent to the dense industrial areas, highlighting a peak of concentration related to anthropogenic sources.

4.4.3.2 Pearson Correlation Coefficient

Pearson correlation coefficient was done to determine the correlation among the metals that can help to identify the metal sources (Table 4.9). Table 4.9 shows that metals are correlated with each other either positively or negatively. Positive correlation indicates similar source of origin and similar contamination trend, while the negative correlation indicates opposite nature of sources.

Table 4.8: Mean and standard deviation of heavy metal concentration for water samples (n=240) of the study area

Stations	Cr	Ni	Co	Cu	Zn	As	Cd	Ba	Pb	Hg
DS	0.037±0.05	0.058±0.01	0.056±0.04	0.196±0.11	1.19±0.25	0.019±0.01	0.018±0.01	0.041±0.02	0.143±0.16	0.091±0.02
SB1	0.014±0.02	0.056±0.01	0.086±0.08	0.025±0.01	0.948±0.13	0.008±0.00	0.018±0.01	0.030±0.02	0.107±0.16	0.077±0.02
SB2	0.005±0.01	0.077±0.01	0.167±0.05	0.023±0.03	0.388±0.28	0.007±0.00	0.006±0.01	0.033±0.03	0.095±0.16	0.135±0.18
IZ1	0.023±0.03	0.080±0.02	0.358±0.10	0.013±0.01	0.561±0.32	0.007±0.00	0.010±0.01	0.034±0.03	0.099±0.16	0.059±0.02
IZ2	0.011±0.01	0.080±0.02	0.444±0.14	0.019±0.01	1.236±0.66	0.005±0.00	0.017±0.01	0.036±0.04	0.101±0.16	0.270±0.19
IZ3	0.004±0.01	0.082±0.01	0.762±0.24	0.020±0.01	0.809±0.22	0.009±0.01	0.135±0.15	0.027±0.03	0.063±0.08	0.066±0.01
IZ4	0.046±0.07	0.066±0.01	0.013±0.01	0.275±0.22	0.852±0.3	0.165±0.23	0.019±0.01	0.036±0.04	0.316±0.39	0.065±0.01
US1	0.030±0.02	0.036±0.02	0.010±0.01	0.001±0.00	0.794±0.28	0.003±0.00	0.020±0.01	0.017±0.02	0.066±0.08	0.059±0.01
SA1	0.028±0.02	0.018±0.02	0.027±0.05	0.002±.00	0.170±0.06	0.004±0.00	0.015±0.01	0.032±0.03	0.101±0.16	0.053±0.02
SA2	0.017±0.02	0.058±0.02	0.010±0.01	0.002±0.00	1.053±0.50	0.002±0.00	0.014±0.01	0.058±0.02	0.075±0.08	0.041±0.01

All concentrations were in ppm except Hg (ppb)

Table 4.9: Pearson Correlation Coefficient of heavy metals of surface water of Gebeng industrial areas

	Cr	Ni	Co	Cu	Zn	As	Cd	Ba	Pb	Hg	pH
Cr	1										
Ni	-0.053	1									
Co	-0.202**	0.507**	1								
Cu	0.168**	0.041	-0.197**	1							
Zn	0.032	0.229**	0.053	0.192**	1						
As	0.325**	0.051	-0.120	0.313**	-0.015	1					
Cd	-0.112	0.148*	0.471**	0.001	0.018	-0.024	1				
Ba	0.164*	0.113	-0.085	0.085	0.160*	0.152*	0.060	1			
Pb	0.147*	0.018	-0.083	0.404**	0.031	0.512**	0.039	0.086	1		
Hg	-0.056	0.219**	0.191**	-0.048	0.132*	-0.042	-0.048	-0.027	-0.079	1	
pH	-0.107	0.618**	0.499**	0.168**	0.172**	0.077	0.213**	0.012	0.224**	0.139*	1

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

4.4.3.3 Principal component analysis and hierarchical cluster analysis

- ***Principal component analysis***

Principal components analysis was run using SPSS 16.0 statistical software. Before conducting the PCA, Kaisere-Meyere-Olkin (KMO) and Bartlett's test were performed to check the sampling adequacy. KMO test scored at 0.572 (Table 4.10) confirms the appropriateness of the PCA application.

Table 4.10: KMO and Bartlett's Test for heavy metals contamination

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.572
Bartlett's Test of Sphericity	Approx. Chi-Square	378.949
	df	45
	Sig.	0.000

Likewise, the Bartlett test of sphericity significant level 0.000 ($p < 0.01$) further recognises that PCA is applicable for source apportionment. However, PCA has extracted four (4) principal components (PC) based on the Eigen value > 1 (Table 4.11). The table displays the factor scores of ten (10) available metal concentrations; i.e. the loadings of the principal components and cumulative percentages for the rotated matrix including communalities.

Table 4.11: Varimax rotated component matrix for surface water samples (n=240)

Parameters	Components				Communalities
	PC1	PC2	PC3	PC4	
Pb	0.831	0.072	-0.064	-0.049	0.703
As	0.795	-0.011	-0.051	0.088	0.642
Cu	0.675	-0.104	0.122	0.126	0.551
Co	-0.138	0.825	0.273	-0.150	0.796
Cd	0.020	0.816	-0.216	0.077	0.719
Hg	-0.052	-0.033	0.766	-0.195	0.628
Ni	0.077	0.530	0.577	0.131	0.637
Zn	0.032	0.002	0.563	0.476	0.544
Ba	0.046	0.071	-0.036	0.850	0.731
Cr	0.359	-0.255	-0.074	0.405	0.364
Eigenvalues	1.938	1.714	1.385	1.223	
Variance	19.385	17.136	13.853	12.232	
CV* (%)	19.385	36.521	50.374	62.606	

*CV-Cumulative variance
Extraction Method: Principal Component Analysis

Four component factors altogether explain more than 84% of the total variance. The communalities values of more than 0.54 have supported the decision to use the four factors. Among the four factors, PC1 being the principal contributor that explains 19.385 % of the total variance. PC1 is strongly positively loading with Pb and moderately loading with arsenic (As) and Cu (Table 4.11). The second factor, PC2, is highly dominated by Co, Cd, and weakly with Ni, that accounts for 17.136 % of the total variance. The third factor, PC3, is strongly dominated by Hg and moderately by Ni

and Zn, which explains 13.853 % of the total variance. PC4, the fourth factor explains 12.232% of total variance and is strongly dependent on Ba. However, the significant loading of Chromium concentration does not dominate and it is found insignificant.

❖ ***Hierarchical Cluster analysis (HCA)***

Hierarchical cluster analysis (HCA) was performed with the factor loadings obtained from the PCA using SPSS 16.0 statistical software. HCA was applied using Ward's method of agglomeration and squared Euclidean distance as the measurement of similarity (Li and Zhang, 2010; Pérez and Valiente, 2005). HCA classified the sampling stations with respect to the concentration of heavy metals in surface water, which has resulted in five clusters, summarized in Table 4.12. As can be seen, the cluster 1 comprises of 184 water samples that contained similar and lower metal concentrations from all stations. Cluster 2, 4 and 5 include 12, 8 and 15 samples respectively, from industrial and semi-industrial cum residential areas, whereas cluster 3 has grouped 21 samples from industrial areas.

Table 4.12: Clustering of monitoring stations for whole period data (n=240) according to the Ward's method using squared Euclidean distance

Cluster	Number of samples	Monitoring stations
Cluster-1	184	DS, SB1, SB2, IZ1, IZ2, IZ3, IZ4, US1, SA1, SA2
Cluster-2	12	DS, IZ2, IZ4
Cluster-3	21	IZ1, IZ2, IZ3
Cluster-4	8	IZ2, SB2
Cluster-5	15	IZ4, SB1, IZ2

4.4.3.3.1 *Discussion*

The higher peak values of arsenic (As), Pb, and Cu (Factor, PC1) were loaded mainly in DS, IZ2 and IZ4, as shown by cluster 2. The highest concentration of Arsenic was obtained in I4, which was located near rare earth plant, coal mining activities and metal industries. Effluents from those industries associated with natural causes were the sources of As at the station IZ4. At DS station, the arsenic contamination was due to

the arsenic bearing sediments that released arsenic to water column at the station. Moreover, industrial pollution has influenced in occurrence of organic forms of As in surface water. Similar investigations and findings have been reported by a number of authors (Bibi et al., 2006; Garelick et al., 2008; Govil et al., 2011; Jayaprakash et al., 2012; Navas and Machín, 2002; Thangarajan, 2007; Yang and Rose, 2005). Pb concentration was higher in all three stations, among those, IZ4 and IZ2 were near various metal industries that used Pb and Pb pipes and the ceramic industries that used lead salt. Effluents from those industries and from corrosion of lead pipes were the potential sources of Pb contamination in water at those stations. Including IZ4, all three stations were beside roads; as road dust is the potential source of Pb and release from exhaust fumes of motor vehicle and smelting, as well. Macklin et al. (2006) and Srinivasa Gowd et al. (2010) also reported similar results. Moreover, arsenic was found highly positively correlated with Pb (Table 4.9); the linear correlation between Pb and arsenic indicates simultaneous enrichment of those elements with the same pattern of dispersion. Same results were published by Govil et al. (2011). The concentration of copper in the water was due to the industrial effluents from those industries that used copper as raw materials, fertilizer and detergent industries and the natural sources also.

At the downstream station, the concentration was higher because of the interference of Kuantan harbour. Copper released from antifoulant paints of boats and sea ship contributed to the contamination. Furthermore, road run off due to tyre wear, corrosion of bushings, brake wires and radiators also contributed to the copper contaminations. All above results were supported by the findings of various researchers (Augusto and Gonzalez, 2011; Lassiter, 2010; Singare et al., 2011; USDHHS, 2004)

Co and Cd were highly and Ni was moderately loaded as stated in PC2 (Table 4.11). Concentrations of those three metals are high with mean values and standard deviations in samples from IZ1, IZ2 and IZ3, and are grouped in cluster 3. Ni was also present in samples from IZ2 and SB2, as found in cluster 4. A higher concentration of cobalt was due to mining activities, effluents from phosphate fertilizer industries and also sewage sludge associated with natural sources. Urban and agricultural run-off also contributed to the cobalt contamination. Similar investigation and results were common in industrial areas like Gebeng (Env.Canada, 2013; Hodge and Dominey, 2001; IPCS,

2006; Krishna et al., 2009; Nagpal, 2004; Singare et al., 2011). Source of cadmium was anthropogenic associated with natural causes. Anthropogenic sources included the effluent from the industrial and sewage treatment plants, fossil fuel combustion (mining activities) of Gebeng industrial estate and domestic wastes from residential area Seberang Balok. Banerjee and Gupta (2012); Ekpo et al. (2008); Hoo et al. (2005); Krishna et al. (2009); Pan et al. (2010); Singare et al. (2011); UNEP (2010); Yusuf (2001) also reported this type of results from their researches. Moreover, these three metals were found to be highly positively correlated with each other indicating that the linear relationship between those metals lead to similar trend of dispersion.

Cluster 4 was found closely related with PC3, which showed that Hg and Zn were found in samples from IZ2 and SB2 with higher concentrations. It also contained Ni that has already discussed. The highest concentration of Hg was observed in IZ2 followed by SB2. Station IZ2 was the densely populated industrial area where all kinds of industrial activities prevail. Therefore, industrial effluents from those industries were the possible potential sources of Hg. In case of SB2, there were some agricultural activities and homestead of kampong (residential area) Seberang Balok. Domestic wastes and agricultural runoff that flow to the river water contributed to the higher concentration of Hg. Similar results were also published by Zhang et al. (2011). However, the concentration of Zn was within the Malaysian threshold level (DOE, 2008). Ba concentrations were high with mean value and standard deviations (PC4) in the samples from DS, IZ2 and SA2 stations. Nevertheless, the concentration of Ba was within the recommended threshold level for Malaysian river water. However, the heavy metal concentrations in the other samples shown in cluster 1 have no significant variation. Low mean and standard deviation of those samples indicate that the contamination were mostly due to the natural process. Comparable results were published in previous similar researches (Pérez and Valiente, 2005; Yacoub et al., 2013).

4.5 CONCLUSION

Tunggak is a small river adjacent to the Gebeng industrial estate. A detailed physicochemical study along with heavy metal contamination of surface water of the

river and surrounding areas of Gebeng industrial area revealed that seasonal variation of different physicochemical parameters was observed for the whole area. As can be seen, BOD, COD, ammoniacal nitrogen and some metals like Ba, Cd, Co, Cr and Pb concentrations were comparatively higher in dry season. In the contrary, turbidity, TDS and TSS were higher in wet season. Temperature, pH and DO concentrations were similar throughout the year, although DO was very low at all stations. The water quality of the Tunggak River and surrounding areas were worst compared to the Malaysian standard even though some parameters were found to be at safe level. Based on the physicochemical and heavy metal contamination assessment the water of the river as well as the surrounding area was found to be unsuitable for use.

The source apportionment of physicochemical parameters of the study area revealed that physical parameters like temperature, pH, TDS, turbidity, TSS, EC and salinity were mainly from the natural sources associated with some anthropogenic activities, as hill cutting, deforestation and refilling for industrial expansion. Temperature and pH were mostly due to natural sources; though in some stations in industrial zone was due to industrial effluents. EC and salinity was primarily because of tidal interference. Source of BOD and COD was largely from industrial effluents accompanying domestic wastewater that contained high oxygen demanding organic matter. Ammonical-nitrogen was originated from both point and no-point sources. The primary source was the industrial and domestic wastewater associated with agricultural runoff. Like ammoniacal-nitrogen, nitrate-nitrogen, inorganic phosphorus also come from both the point and non-point sources. However, the sulphate concentration was within the safe level.

Source identification of heavy metals showed that the source of most metal contamination was mainly from industrial pollution. Gebeng industrial estate consisting of multifarious industries like metal, chemical & petrochemical, mining, food & beverage, palm oil, manufacturing & wooden industries, rare-earth plant, power industries (Appendix J). Metal industries usually use metallic elements as raw materials and produce metallic substances. These processes also produce metallic effluents as by-product that caused the metal pollution. Besides industrial pollution, natural sources of

metal were not negligible. Agricultural run-off, run-off from road dust, and fumes from vehicle exhaust pipes also contributed to the heavy metal contaminations in the area.

The physico-chemical assessment and evaluation of heavy metal contamination in this study disclosed the actual situation of the water quality of the Tunggak River as well as Gebeng industrial area. These results can be used as baseline information for taking any action plan for better management. The Source apportionment would suggest the managements to find out the real threat and to take proper actions. Based on the results, the authority could compel the companies to obey the existing law(s) of discharging industrial wastes to the river water and could impose new policy for the industries to ensure better management. However, physicochemical parameters assessment and determination of heavy metal contamination revealed that the water of Tunggak River and the surroundings of GIE were not suitable for aquatic life. Therefore, emphasis should be given to the proper water quality management to fix the problem, which can be specifically conducted using the information generated from the source apportionment of pollution.

CHAPTER 5

WATER QUALITY INDEX AND RIVER WATER CLASSIFICATION

5.1 INTRODUCTION

Water quality index (WQI) is a single number that expresses the overall water quality status of a location at a certain time (Hossain et al., 2013; Yogendra and Puttaiah, 2008). It is a tool for the assessment of water quality through physicochemical variable, heavy metals and coliform. In Malaysia, the Department of Environment (DOE) developed the Water Quality Index (WQI) to assess the water quality and to classify the river water. DOE-WQI is calculated based on the physicochemical parameters of the river as well as surface water.

This chapter discusses on the water quality index of the surface water of Gebeng industrial area including the Tunggak River. Water classification is done based on the DOE-WQI along with seasonal variation and the relation of water quality with the river water flow. The average results of the calculated WQI are demonstrated in Table 5.1. The monthly value DOE-WQI along with the corresponding water classes of all sampling stations are shown in Appendix I I-I V. The index was calculated based on sub-indices values of six parameters (Appendix C). The seasonal variation of water quality based on DOE-WQI is shown in Figure 5.1. A multiple linear regression analysis has been done to determine the contribution of the respective parameters to the water quality, and the results are shown in Table 5.2 River water flow variation (spatial and temporal) and the relation between flow and water quality are also described. The chapter also discusses on the critical analysis by comparing the DOE-WQI with other indices. Comparisons of WQI of the study area based on DOE-WQI and Canadian Council of Ministers of Environment (CCMEWQI) along with corresponding water classification has been done. Finally, CCMEWQI calculation scheme and river water

classification system of INWQS, Malaysia has been proposed to adopt for the calculation of the water quality index of Tunggak River.

5.2 WATER QUALITY INDEX AND WATER CLASSIFICATION

5.2.1 Department of Environment (DOE-WQI)

Based on the six physicochemical parameters, namely, DO, BOD, COD, SS, Ammoniacal nitrogen and pH, and their sub-indices value (Appendix C) the DOE-WQI are calculated and the results with their corresponding water class are shown in Table 5.1. The table shows that in all monitoring stations the water quality is found to be polluted (Class III) except for two stations at industrial area of Tunggak river (IZ3 and IZ4), which were under class IV (highly polluted). The overall water quality was also polluted. The previous work done by the Department of Environment showed that the quality of this river was slightly polluted with WQI value of 79, 77 and 68 in 2008, 2009 and 2010 respectively (DOE, 2009; DOE 2010).

Table 5.1: Water quality index of Tunggak River and corresponding water classes based on DOE-WQI

Monitoring Stations	Calculated DOE-WQI Value	Water Class	WQ Status
Down Stream (DS)	58.48	III	Polluted
Seberang Balok (SB1)	53.66	III	Polluted
Seberang Balok (SB2)	56.95	III	Polluted
Industrial Zone (IZ1)	62.14	III	Polluted
Industrial Zone (IZ2)	54.76	III	Polluted
Industrial Zone (IZ3)	46.69	IV	Highly Polluted
Industrial Zone (IZ4)	51.37	IV	Highly Polluted
Upper Stream (US)	55.30	III	Polluted
Swampy Area (SA1)	60.35	III	Polluted
Swampy Area (SA2)	60.82	III	Polluted
Overall	**55.99**	**III**	**Polluted**

Where, DOE-WQI value, ≥91.76 = Class I; 75.37- 91.75 = Class II; 51.68 – 75.36 Class III; 29.61 – 51.67 = Class IV and <29.61= Class V

The quality of the river water is deteriorating over the years. All stations especially the industrial zone received much effluents and wastewater from the industries and that wastewater was responsible for the deterioration of the water quality at industrial zone as well as at the lower stream stations.

5.2.2 Seasonal variation of water quality based on the DOE-WQI

DOE-WQI was also calculated on seasonal basis to find out the temporal variation, and the results are shown in figure 5.1. The figure suggests that the trend of the water quality of the area is almost similar throughout the year. But, the quality was relatively better in wet season, except for the industrial zone 4, which has been found to be highly polluted in the wet season, while the swampy area was found to be better than the other areas.

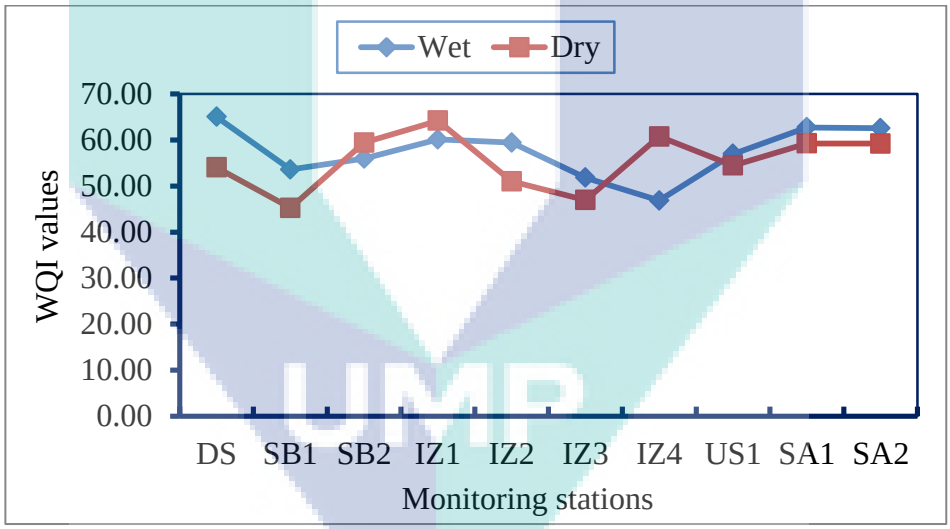


Figure 5.1: Seasonal variations of WQI values among the monitoring stations of the study areas

River water classification scheme was developed by INWQS with the expert opinion poll for the support of domestic water supply, fisheries and aquatic life, livestock drinking, recreation and agricultural uses (Zainudin, 2010). Based on the classification, the water of the study area falls under class III and IV. This result indicates that in the river water (except swampy area) of the study was in class III and IV, whereas the swampy area was in class III. During wet season, all stations except IZ4

and in the dry season, 5 stations (except SB1, IZ2 and IZ3) of the Tunggak River were under class III. Stations IZ4 in the wet season and SB1, IZ2 and IZ3 in the dry season were under class IV. Moreover, calculation of DOE-WQI of all stations shows that the water of downstream station was always under class III except in August, when it was under class IV. On the other hand, Seberang Balok (SB1) was under class III in February, March and May (Appendix I I). All industrial stations were under class IV in February 2012. In addition, the IZ3 was under class IV in March, July and August (Appendix I II-I IV). According to DOE (2008), this water (class IV) is not suitable for any purposes even after extensive treatment, except for irrigation. However, the water under class III can be used for water supply only after extensive treatment and for livestock drinking.

5.2.3 Contribution of water quality variables in water quality of the study area (The Multiple linear regression model)

The Multiple linear regression (MLR) analysis was done with SPSS 16.0 statistical software to identify the contribution of variables to the water quality of the study area. To detect the best predictors (significant variables) of water quality variation stepwise multiple linear regressions model was used (Hinton et al., 2004). Classical assumptions of linear regressions were checked before the interpretation of MLR model results; i.e. normal p-p plot of regression-standardised residuals were analysed (Figure 5.2a). The figure explains that all the observed values fall roughly along the straight line and indicates that the residuals are from the normally distributed population. Furthermore, a scatter plot of regression standardised predicted values, against observed values (Figure 5.2b) also shows the linear relationship between the dependent variable and the predictors, with the residuals variances being equal or constant.

Using the stepwise multiple linear regression model, four best predictor namely BOD_5, COD, NH_3-N and pH were detected. This means that the maximum water quality variation of Tunggak River was explained by those four predictor variables. Suspended solids also explained certain variation, but with DO, it was a minor contributor (Table 5.2). As can be seen, COD has made the strongest unique contribution in water quality variation with Beta coefficient value of -0.670. The second highest Beta value is for BOD_5 (-0.391) and NH_3-N is very close to BOD (-0.390). Among these four variables,

the lowest contributor was pH with a Beta value of 0.284. The negative sign of Beta value indicates that water quality is negatively correlated with those predictors (Nathans et al., 2012). The analysis of variance (ANOVA) was done and the ANOVA table (Table 5.3) shows the F-statistics value of 65.522 with 6 df and the corresponding p value of 0.003 which is highly significant. This test indicates that the estimated slope of regression model is not equal to zero; which confirmed the linear relationship between the predictors of the applied models.

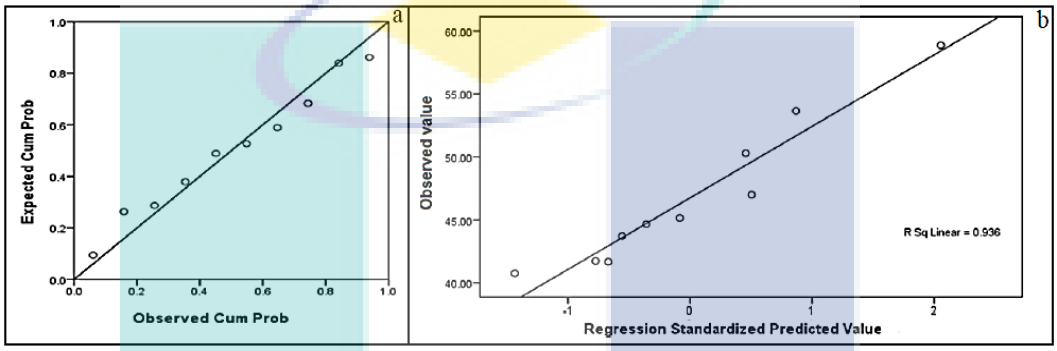


Figure: 5.2: a) Normal p-p plot of regression standardised residuals and b) Scatter plot of regression standardised predicted values against observed values

Table 5.2: Estimated regression coefficients of the multiple linear regression models

Models	Unstandardised Coefficients		Standardised Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	59.873	2.770		21.613	0.000
DO	0.103	0.739	0.011	0.139	0.898
BOD	-0.362	0.126	-0.391	-2.882	0.063
COD	-0.313	0.054	-0.670	-5.845	0.010
AN	-4.467	0.758	-0.390	-5.896	0.010
SS	-0.013	0.006	-0.168	-2.038	0.134
pH	1.774	0.620	0.284	2.862	0.064

Dependent Variable: WQI

Table 5.3: ANOVA of the multiple linear regression models

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	354.023	6	59.004	65.522	0.003
Residual	2.702	3	0.901		
Total	356.725	9			

Predictors: (Constant), pH, SS, AN, DO, COD, BOD
Dependent Variable: WQI

5.3 RIVER WATER FLOW AND WATER QUALITY

Water flow of Tunggak River was calculated from the hydrological data: speed of water, depth and width of the river. Seven stations were selected to collect the hydrological data. The flow of the river varied in terms of time and space. Spatial variation of the flow (among 7 stations) is shown in Figure 5.3. The figure shows that flow was highest at the downstream and decreased sharply at station Seberang Balok (SB2) and gradually decreased at the upper stream of the river. Highest flow in the downstream was due to the tidal interference of the South China Sea.

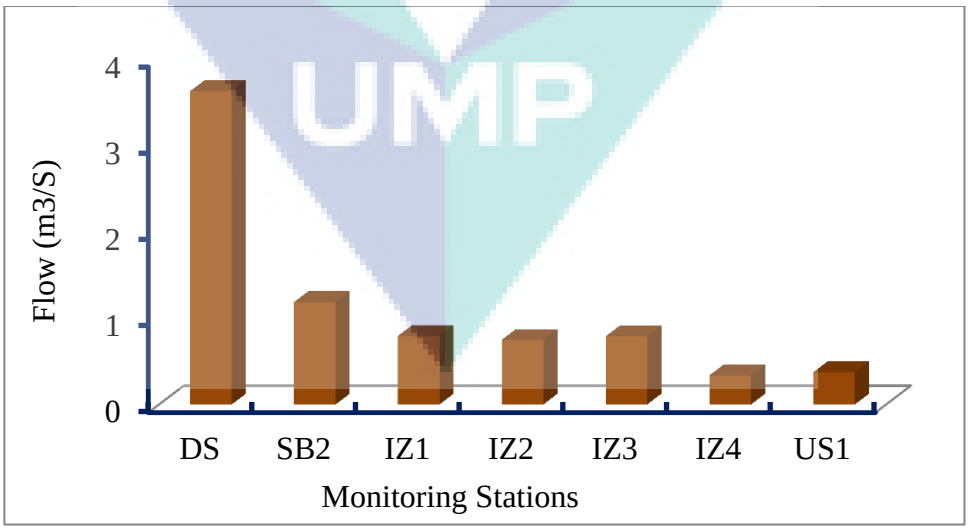


Figure 5.3: Average flow rate at the monitoring stations of the Tunggak river basin

The temporal variation of water flow is depicted in Figure 5.4. As can be seen, the trend of water flow was almost similar throughout the year in all stations, except for the downstream. A little fluctuation was observed in the wet season during September 2012 to January 2013. Regarding downstream station, it was due to the tidal interference from the South China Sea (Nasly et al., 2013).

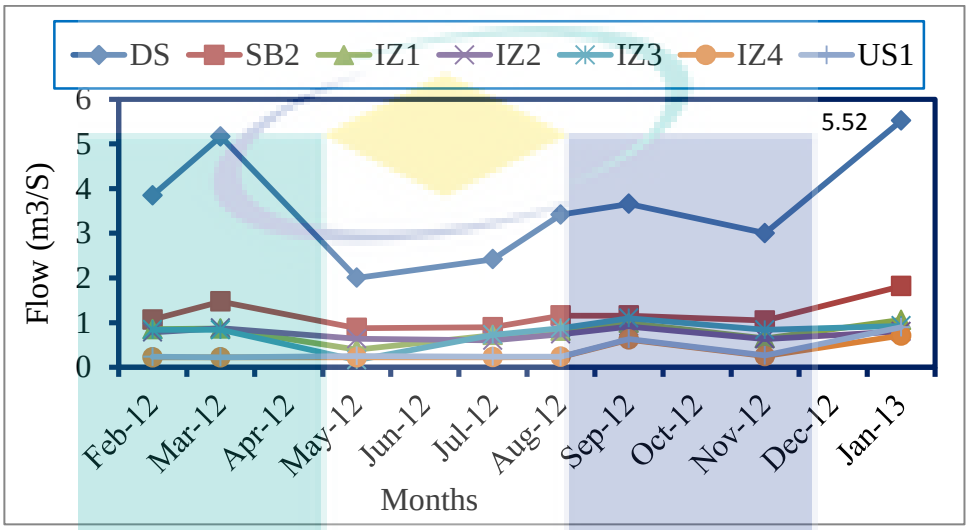


Figure 5.4: Monthly variations of average flow rate of Tunggak river basin

To identify the influence of water flow on water quality a comparative study was done, and the results are exhibited in Figure 5.5. In the figure, the columns indicate the average WQI and the red curve shows the average river flow of Tunggak River. The comparison shows a positive correlation between the water flow and quality. Excluding the downstream and upstream stations, the overall trend of the comparison is quite similar. As the downstream is a tidal station and the upstream receives less pollutant from bare land, the trend of these two stations was not similar compared with the others. However, the figure concludes that water quality might be better with the increase of water flow.

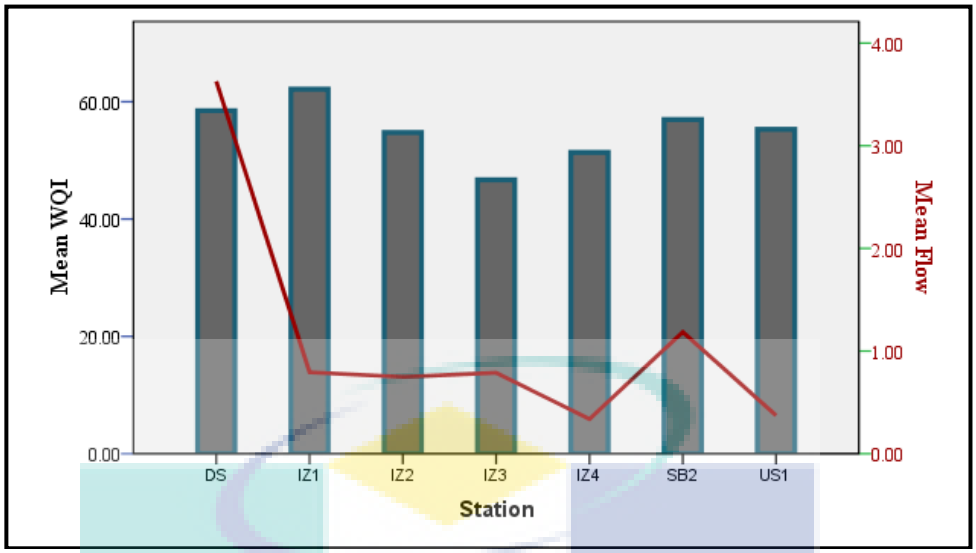


Figure 5.5: Trend of WQI of Tunggak River comparing with water flow

5.4 ADOPTING AN EXISTING WATER QUALITY INDEX FOR TUNGGAK RIVER

The Department of Environment, Malaysia has developed the DOE-WQI based on the six physicochemical parameters, namely, BOD, DO, COD, ammoniacal nitrogen, pH and SS. However, the water quality does not only depend on those six parameters but the number of parameters including physico-chemical, heavy metals and coliform. In the present study, based on the DOE-WQI, surface water of Gebeng area has been classified and stated above as in Table 5.1. According to the INWQS, this water can be used for water supply after extensive treatment and for livestock drinking, and irrigation (DOE, 2008). It may not be wise to recommend the water for the above-mentioned purposes without considering the heavy metal content. But, in DOE-WQI, there is no option of taking the heavy metals in consideration; as this index has a lot of limitation, such as consideration of less and only physicochemical parameters (Zainudin, 2010). With this issue in mind, this study intended to adopt an existing water quality index that consider more water quality parameters and eventually globally accepted. Revision or analysis of WQI is essential to adopt an existing WQI or to develop a new one because several studies have come out with new approaches and tools for developing other indices (Bharti and Katyal, 2012). In this regards, world's famous and widely used water quality indices along with DOE-WQI has been critically reviewed in Chapter 2. According to the review it is suggested that among all other water quality indices of the

world Canadian Council Ministers of Environment Water quality Index (CCME-WQI) would be better to adopt for Tunggak River as it considered as more as 400 water quality parameters and the water quality classification is similar with water quality classification by INWQS Malaysia. In spite of its superiority, this study compared it with DOE-WQI with the similar parameters and discussed in this section and finally a WQI has been proposed combining CCMEWQI with DOE-WQI water classification for the water quality of Tunggak river.

5.4.1 Comparison of DOE-WQI with CCMEWQI

For making comparison of DOE-WQI with CCMEWQI, an analysis was conducted and results are presented in Table 5.4. For this purpose, water quality index of the study area is calculated by using both indices and followed by water quality classification. CCMEWQI is estimated for two times; firstly by considering twenty two (22) water quality parameters (including heavy metals) and secondly by considering six (6) water quality parameters that were considered for DOE-WQI. The Table 5.4 states that according to the DOE-WQI the index values (based on six parameters) range from 62.14 – 46.69, which correspond with water class III (polluted) to class IV (highly polluted). On the contrary, the CCMEWQI values (based on 6 parameters) that ranged from 71.5- 38.7; correspond with water class III (fair) to class V (poor) was more or less similar to the DOE-WQI. Except one station, the water classes were also similar to the INWQS water quality classes (Table 5.4 column 6). At the same time, CCMEWQI estimated from twenty two (22) water quality parameters including nine heavy metals (Table 5.4 column 7) and corresponding water classes shows that the water of the area was categorised as class V and only one station was in class IV (Table 5.4 column 9). The water quality classification based on INWQS, Malaysia with the index values of DOE-WQI (Table 5.4 column 3) and CCMEWQI (considering 6 parameters) (Table 5.4 column 6) shows that except for the upper stream station (US), all stations have similar classes to the CCMEWQI values. However, the INWQS water quality classification with the index values of CCMEWQI that considered twenty-two parameters (Table 5.4 column 7) were not same as the previous one. Water classes based on six parameters (Table 5.4 column 3 & 6) can be used after treatment, whereas water classes (Table 5.4 column 9) cannot be used for any purpose. The two CCMEWQI values (considering six

and twenty-two parameters respectively) suggested that considering more parameters could ensure the real situation of the water quality of the study area.

Table 5.4: Comparison of DOE-WQI and CCME WQI for the water quality of Gebeng industrial area

Monitoring stations	DOE-WQI	INWQS Water Class[1]	*CCME-WQI	CCME Water Class[2]	INWQS Water Class[1]	**CCME-WQI	INWQS Water Class[1]
DS	58.48	III	71.5	III	III	14.4	V
SB1	53.66	III	66.0	III	III	21.6	V
SB2	56.95	III	65.5	III	III	23.7	V
IZ1	62.14	III	54.2	IV	III	34.2	IV
IZ2	54.76	III	66.2	III	III	25	V
IZ3	46.69	IV	41.6	V	IV	23.9	V
IZ4	51.37	IV	38.7	V	IV	23.8	V
US	55.3	III	43.2	V	IV	27.6	V
SA1	60.35	III	56.7	IV	III	29.3	V
SA2	60.82	III	54.3	IV	III	29	V

[1] DOE-WQI value, ≥91.76 = Class I; 75.37- 91.75 = Class II; 51.68 – 75.36 Class III; 29.61 – 51.67 = Class IV and <29.61= Class V;

[*]CCMEWQI value considering six physicochemical parameters;

[2]CCMEWQI value, 95-100= Excellent; 80-94= Good; 60-79= Fair; 45-59= Marginal and 0-44= Poor;

[**] CCMEWQI value considering twenty-two physicochemical parameters

Comparing the two results it can be concluded that consideration of additional variables (including heavy metals) for calculation of water quality index is more sustainable and dependable to make decision for any future planning for the surface water management. INWQS Malaysia has set up standard limit for more than 72 parameters that can be used easily for CCMEWQI calculation. Moreover, the two classifications (INWQS and CCMEWQI) of water quality are almost similar regarding grading system and basis of development. The grading system of CCMEWQI was developed based on the index value, and the grading of INWQS Malaysia was developed based on the standard/threshold limit of more than 72 water quality

parameters and then incorporated with the DOE-WQI (Zainudin, 2010). It was also supported by the expert opinion poll organised by DOE in 1985. By using the water classification of INWQS Malaysia with the CCMEWQI calculation scheme, it can provide a better result for the water user/ agencies, for water resources management, and for further research without any confusion; as it had considered more variables than any other indexing system.

Therefore, for the calculation of water quality index of Tunggak River, CCMEWQI can be adopted and river water classification can be done according to the INWQS Malaysia with the CCMEWQI values.

5.4.2 Water quality index for Tunggak River

From the above comparison, this study proposes the following water quality indexing system for calculating the water quality index of Tunggak River. This indexing system has two parts. The first part is the calculation part adopted from CCMEWQI and the second part is the river water classification that is adopted from the INWQS, Malaysia.

5.4.2.1 Calculation part

Water quality index of Tunggak River can be calculated as (adopted from CCMEWQI):

$$WQI_{TR} = 100 - \left(\frac{\sqrt{F_1^{\,2} + F_2^{\,2} + F_3^{\,2}}}{1.732} \right) \text{ ---------- (5.13)}$$

Where, $_{TR}$ referred to Tunggak River, F_1 is the number of parameters whose objective limits is not met, F_2 is the percentage of individual test that do not meet the objective and F_3 denotes the number of failed test values that do not meet their objectives. The factor of 1.732 arises from vector range. All these elements have been stated in chapter 2 (section 2.3.1.5).

5.4.2.2 River water classification

River water classification can be done by the following way (adopted from INWQS, Malaysia):

Class I *(WQI_{TR} =>91.76):* Conservation of natural environment, Water Supply I - Practically no treatment necessary, Fishery I - Very sensitive aquatic species.

Class II *(WQI_{TR}= 75.37- 91.75):* Water Supply II - Conventional treatment, Fishery II - Sensitive aquatic species, recreational use body contact.

Class III *(WQI_{TR}=51.68-75.36):* Water Supply III - Extensive treatment required, Fishery III - common, of economic value and tolerant species; livestock drinking.

Class IV *(WQI_{TR}=29.61-51.67):* Irrigation

Class V *(WQI_{TR}= < 29.61):* None of the above

5.5 CONCLUSION

Calculation of water quality index based on DOE-WQI and water classification according to the recommendation of INWQS Malaysia showed that the water of Tunggak River was categorised as class III (polluted), IV (highly polluted), and the swampy area as class III (polluted). As stated by the INWQS Malaysia, the water of that river was unsuitable for any use except some limited uses and irrigation (DOE, 2008). Temporal variation expressed that the WQI was lower in dry season compared to wet season indicated higher pollution in dry season and due to rain and better water flow slightly better in wet season. The water flow of the Tunggak River was higher at downstream stations and reasonably lower at upstream stations of Tunggak River. Seasonal distribution indicates that the flow was higher in wet season compared to dry season. Comparison figure (Figure 5.5) between WQI and water flow shows that the river water flow is positively correlated with water quality although the relation was not sharp at the upstream station where WQI was fairly higher. This was due the flow that was very low and less industrial interference.

The DOE-WQI is an important tool for water quality assessment calculated based on six physicochemical parameters. However, it does not consider more parameters including heavy metal contamination. Therefore, it is quite impossible to identify whether even the water with class I with heavy metal contamination is suitable

for any use. In this study, the water of the river was categorised as class III and IV that can be used for some limited purposes including irrigation. Nevertheless, the water was contaminated with some metals like Cd, Co, Pb, already discussed in the previous chapter. Therefore, it would not be wise to recommend this water for use. After a critical review and comparison of WQIs, CCMEWQI that considered more than 400 water quality parameters along with INWQS river water classification scheme, have been proposed to adopt for calculation of water quality index and water quality classification of Tunggak River. By using the water classification of INWQS Malaysia with the CCMEWQI, it can provide a better understanding for the water user/ agencies as well as for water resources management.

CHAPTER 6

HEAVY METAL CONTAMINATION OF SOIL

6.1 INTRODUCTION

Soil by its composition, contains heavy metals as natural components (Besada et. al., 2011). The heavy metal concentrations in soil largely depend on complex biological and geochemical cycles, which may be influenced by industrial activities, treatment of wastes, vehicles trafficking and agricultural practices (D'Emilio et al., 2013; Ramos-Miras et al., 2011; Smith, 2009). Again, soil can act as sink for metals contaminate coming from industrial activities, agricultural practices and deposition of particles emitted by vehicles exhaust (D'Emilio et al., 2013; Guo et al., 2012; Solgi et al., 2012; Xu et al., 2013). For the last couple of years, soils have been considered as an important part of environmental condition influencing human health (Chabukdhara and Nema, 2013). With the rapid development of industrialisation, metal contamination is becoming widely concerned all over the world because of their extended persistence and toxicity to many organisms, which threaten the ecosystems, food safety, water resources and also human health (Dheeba and Sampathkumar, 2012; Jan et al., 2011; Solgi et al., 2012). Increased inputs of metals due to industrialisation with inadequate waste management have led to large-scale contamination of soil as well as to the environment (Gowd et. al., 2010). A good number of metals, such as, Cd, Cu, Cr, Ni, Pb, and Zn have been widely used in the metal industries to produce alloys and steels (Li et al., 2008). These industries generate solid wastes, wastewater and waste air containing lots of metals that are returning to soil directly through dumping of wastes or various indirect ways, such as, dust fall, precipitation and others. Contaminated metals thus uptaken by the plant enter into food cycle; as metals uptake by plants is an avenue of their entry into the human food chain (Dheeba and Sampathkumar, 2012; Oyedele et al., 2006). Therefore, analysis of heavy metal concentrations in soils along with their

potential sources, specifically in rapidly growing industrial areas is critical to provide necessary information to the policymaker and environmentalist for taking proper action to reduce the pollution level (Chabukdhara and Nema, 2013; Solgi et al., 2012).

Gebeng is one of the biggest industrial city in peninsular Malaysia, having wide range of industries including metal, chemical and petrochemical, polypropylene, gas and power, food and beverage, manufacturing, rare-earth and mining industries (Nasly et al. 2013; Sujaul et al. 2013). These industries produce glasses, plastic containers, aluminium profiles, food processing, PVC pipes, furniture, paint, insecticide, fertilizer, disinfectant, herbicide, detergent, metal skeleton, car spare parts, electrical and electronics equipment, refrigerators and freezers, oven, ethanol, electroplating and so forth. Soil metal contamination is a potential threat in the city. Therefore, the present study is conducted to determine the level of contamination, evaluate the spatial distribution and for sources apportionment of heavy metals in soil at and around the Gebeng industrial estate. For this purpose, the study area was divided into three (3) zones; namely, residential cum semi-industrial Zone, industrial zone and swampy area. A total of thirty soil samples (nine from residential cum semi-industrial zone, twelve from industrial zone and nine from swampy area) were collected (Figure 6.1) and analysed to determine ten pre-selected heavy metals. Samples were collected for one time. Number of soil samples and sampling time was determined based on a series of literatures reviewed, such as, Ong et al. (2013);Jiang et al. (2013); Pajak and Jasik (2011); Shakeri et al. (2009); Al-Khashman (2004); Solgi et al. (2012); Möller et al. (2005); Hu et al. (2013); Rizo et al. (2011); Amouei et al. (2012): Yaylalı-Abanuz (2011): Chabukdhara and Nema (2013); Tiwari et al. (2011): Krishna and Govil (2007); Krami et al. (2013); Hani et al. (2014). ICP-MS spectrometry was used to determine heavy metal concentration. Detailed methodologies are already discussed in Chapter 3.

This chapter discusses on the physicochemical properties of soil at Gebeng industrial estate (Table 6.1), level of heavy metal contaminations and their spatial variations (Figures 6.1 to 6.10), pollution loading and source apportionment of metal contaminations of soil. Pollution load index and geo-accumulation index are calculated to evaluate the contamination level. The results revealed that the contaminations were higher in the industrial zone. Source apportionment was done with hierarchical cluster

analysis (HCA), Pearson correlation coefficient and principal component analysis (PCA). PCA and HCA concluded that the source of the contamination was mainly from the industrial effluents associated with natural causes.

Figure 6.1: Map of the study area indicating the soil sampling points

6.2 THE SOIL PHYSICOCHEMICAL PROPERTIES

The physicochemical properties of soil at Gebeng industrial areas are presented in Table 6.1. Mean values from each sampling site (from three replications) are given in the table. As can be seen, the range of soil pH at the industrial areas is in between 3.6 and 7.5, indicating that the soil of the area was highly acidic to slightly alkaline. Hence, the soil at most of the sampling sites, was acidic in nature. The soil of the area is mostly peat soil as the place was originally peat swamp forest where, low range of pH is its unique character (Grealish and Fitzpatrick, 2013; Huat et al., 2011; MARDI, 2009). The

pH in pit soil usually ranges between 3.0 and 4.5 (Chee and Peng, 1998). Despite pit soil, some sampling sites at residential cum semi-industrial area and at industrial zone have been found with relatively better pH.

Table 6.1: Physicochemical properties* of soil from ten different monitoring stations of the Gebeng industrial town

Studied Zone	Monitoring stations	Depth (cm)	pH	EC µS/cm	OM (%)
Residential cum semi-industrial Zone	1	0-20	3.6	16505.00	2.69
	2	0-20	6.5	406.08	2.10
	3	0-20	6.3	1389.00	5.32
Industrial Zone	4	0-20	6.3	1572.33	6.11
	5	0-20	6.0	606.88	6.60
	6	0-20	5.9	407.77	7.06
	7	0-20	5.2	744.78	11.25
	8	0-20	5.5	362.59	7.29
Swampy Area	9	0-20	5.4	114.42	3.47
	10	0-20	7.5	1047.67	2.02

*Concentrations are the mean values of three (3) replications

Electrical conductivity (EC) was measured and the results reveal that the concentration was higher at the sampling sites of residential cum semi-industrial areas (sampling sites 1, 3) and comparatively lower concentration was in the industrial zone except for sampling site 4 (Table 6.1). Higher concentration at sampling sites 1 and 3 might be due to saline water intrusion. Those two sites including site 2 are very near to the South China Sea, where tidal water enters two times daily (Sujaul et al., 2013). Saline water goes up to 3 km inland and this might be the cause of higher EC at industrial zone 1(station 4). Besides the sampling site, a number of metal industries that used and produced metallic elements and metal salts might be the cause of higher EC. Organic matter concentration was relatively higher at industrial zone compared to the other two areas. It might be largely due to the dumping of industrial effluents to the area. In spite of the higher organic matter, the pH was lower because of the organic matter that primarily came from chemical or metal industries.

6.3 SOIL HEAVY METAL CONCENTRATION

Heavy metal concentrations of collected soil samples were measured and the results are presented in Figures 6.2 to 6.11, to show the spatial distributions.

6.3.1 Arsenic (As)

Average arsenic (As) concentration in soil is presented in Figure 6.2. The average range of arsenic concentration at the area was 3.06 ppm to 58.07 ppm. As can be seen, there is a significant variation among the zones. The figure states that the higher concentrations were recorded at four (4) sampling sites, at the industrial area. But, soils at residential and swampy areas were found to have lower amount of arsenic compared to the industrial zone. However, the highest concentration was at industrial zone 2 (sampling site 5) and the lowest at swampy area. The arsenic contamination at industrial zone is beyond the standard limit for industrial areas according to the recommendation of the Ministry of Environment of Canada (MOE, 2011) and industrial waste resource guidelines (EPA, 2009). The higher concentration at industrial zone might be due to the industrial activities that produced effluents especially at the sampling site 5 that is adjacent to huge industries including mining activities (Appendix J). Similar results were reported by Rahman et al., (2012); Krishna and Govil (2007); Krishna et al. (2009b); Kabir et al. (2012).

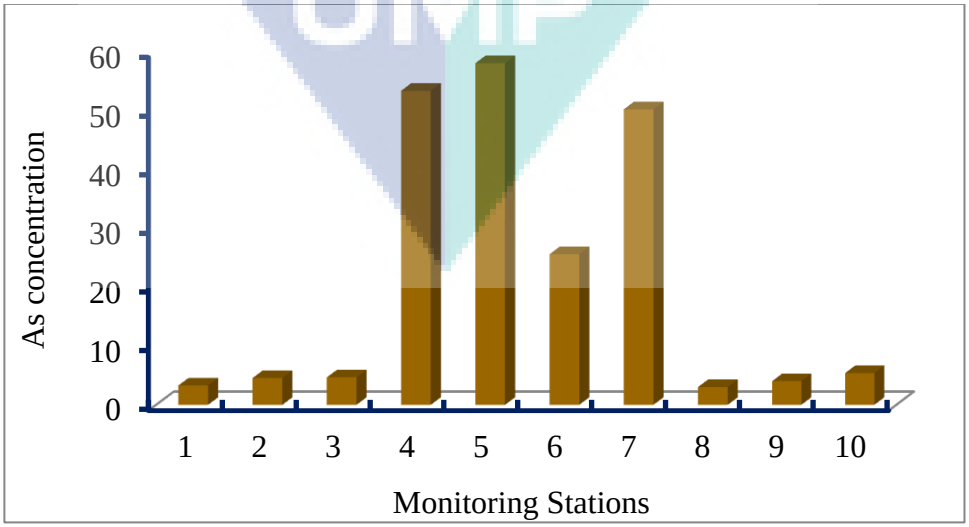


Figure 6.2: Average As concentration of soil samples from ten different sampling stations of Gebeng industrial town

6.3.2 Barium (Ba)

The concentrations of barium (Ba) in soil samples from the Gebeng industrial areas were analysed and the average values are presented in Figure 6.3. The figure states that there is a significant variation of barium among the sampling stations. The average range of barium was in between 8.71 ppm to 51.15 ppm. The highest concentration was recorded at industrial zone 1 (No 4 site) and the lowest, at Swampy area (no. 9). Based on zone distribution, the industrial zone contained comparatively more barium followed by residential area while the swampy area was found with relatively lower amount of barium. However, the concentration in soils of the study area was below the industrial recommended threshold level.

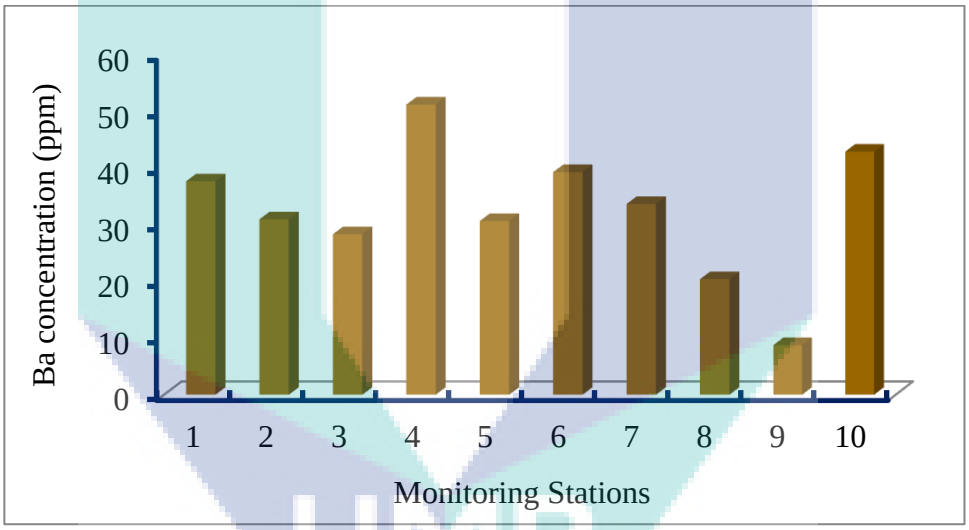


Figure 6.3: Average Ba concentration of soil samples from ten different sampling stations of Gebeng industrial town

6.3.3 Cadmium (Cd)

Cadmium concentration was calculated and the average levels are presented in Figure 6.4. The figure shows that cadmium concentration is higher at the industrial zone compared to any other zones of Gebeng industrial areas. The average range of contamination is in between 0.018 ppm to 0.442 ppm. The highest and lowest concentration were at industrial zone 2 (sampling site 5 and sampling site 2 respectively). Similar to arsenic the industrial zone has recorded highest cadmium

although the concentration at all stations are below the threshold level of most of the developed countries (EPA, 2009; Ian Martin et al., 2009; MOE, 2011; USDA, 2000).

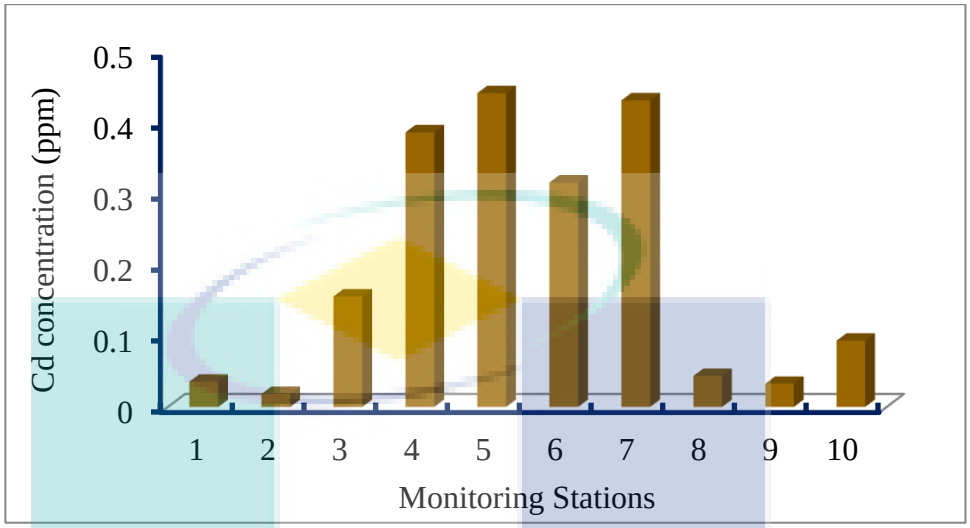


Figure 6.4: Average Cd concentration of soil samples from ten different sampling stations of Gebeng industrial town

6.3.4 Cobalt (Co)

The concentration of cobalt was measured and the average results are shown in Figure 6.5. The average concentration range of cobalt is in between 0.00 ppm to 809.07 ppm. Sampling sites 1 to 4 contained no cobalt, but the industrial zone had higher amount of Co. the highest concentration was in industrial zone 3 (sampling site 6) followed by industrial zone 2. According to threshold level of different countries, the two industrial sites were highly contaminated with cobalt although the other stations were distinctly below the threshold level. The cause of higher contamination at industrial zone might be due to dumping of industrial effluents. In source identification section (Section 6.5), details are described.

6.3.5 Chromium (Cr)

From all soil samples, chromium was analysed and the results are displayed in Figure 6.6 to show the spatial variations. The Figures shows significant variations among the sampling stations. The average range of Cr concentration was in between 7.34 ppm to 14.74 ppm. The highest value was obtained from sampling station 9

(swampy area) and the lowest, at sampling station 1. As can be seen, the concentration increased gradually from downstream to upstream (Figure 6.6). According to the threshold level of several countries, the concentrations at all sites were found to be toxic. The higher amount of chromium in soil might be due to industrial effluents associated with road dust, use of colour in some industries, and at the swampy area, the new extension works might be responsible for higher amount of Cr. Details about source apportionment are discussed in Section 6.5.

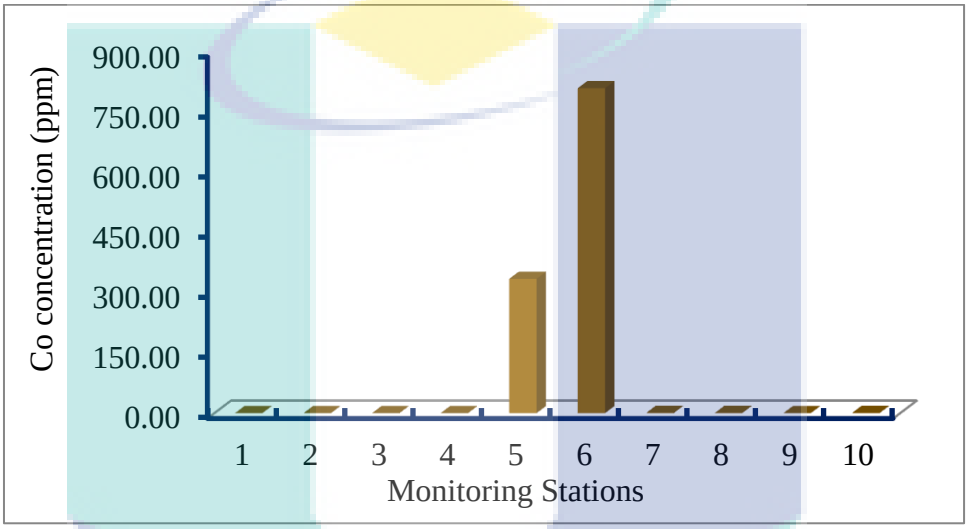


Figure 6.5: Average Co concentration of soil samples from ten different sampling stations of Gebeng industrial town

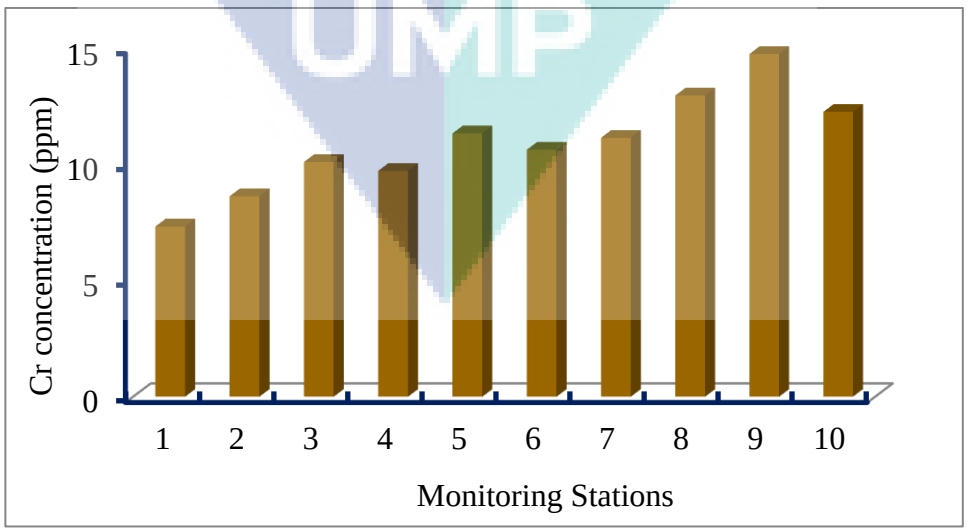


Figure 6.6: Average Cr concentration of soil samples from ten different sampling stations of Gebeng industrial town

6.3.6 Copper (Cu)

Copper concentration was measured and the results are presented in Figure 6.7. The Figure shows the spatial variation of copper concentration in soil samples among the sampling stations. It stated that the soil of the industrial zone of the Gebeng industrial town was found highly contaminated and the other zone were uncontaminated. The average range of Cu concentration at the area was 0.75 ppm to 30.63 ppm, which confirms the high variation in concentration level. The highest concentration was recorded at sampling site 7 (industrial zone 4) while the lowest at sampling site 1 (Figure 6.7). The higher amount of copper at industrial zone might be because of dumping of the industrial effluents from those industries that use copper as raw materials, fertilizer industries and obviously the natural sources (USDHHS, 2004).

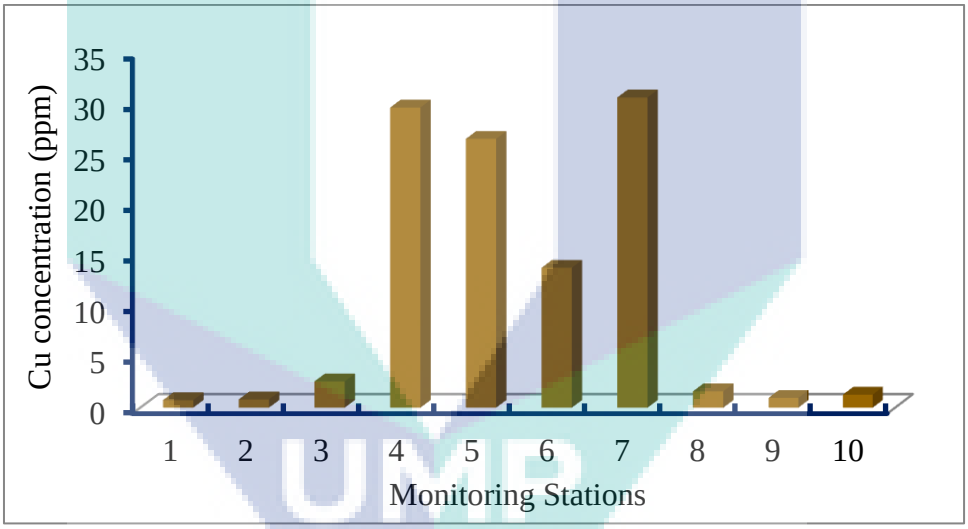


Figure 6.7: Average Cu concentration of soil samples from ten different sampling stations of Gebeng industrial town

6.3.7 Mercury (Hg)

The collected soil samples from ten sampling sites were analysed to determine mercury (Hg) concentration and the data obtained are presented in Figure 6.8 that displays the spatial variations among the sampling stations. Results indicates that the concentration of mercury was found at toxic level almost at all stations with the highest being recorded at industrial zone 2 (sampling site 5). The average range was 0.05 ppm to 7.45 ppm. Based on the threshold level of different countries, the Hg concentration

was beyond the threshold level at six (6) stations. Other stations (2 at residential areas and 2 at swampy areas) were within the threshold level which means that the soil of middle part (industrial and semi-industrial areas) was highly polluted with Hg concentration. The higher contamination at industrial zone might be due to the discharge of industrial wastewater from chemical industries and palm oil industries. The similar results were reported by Yaylal-Abanuz (2011).

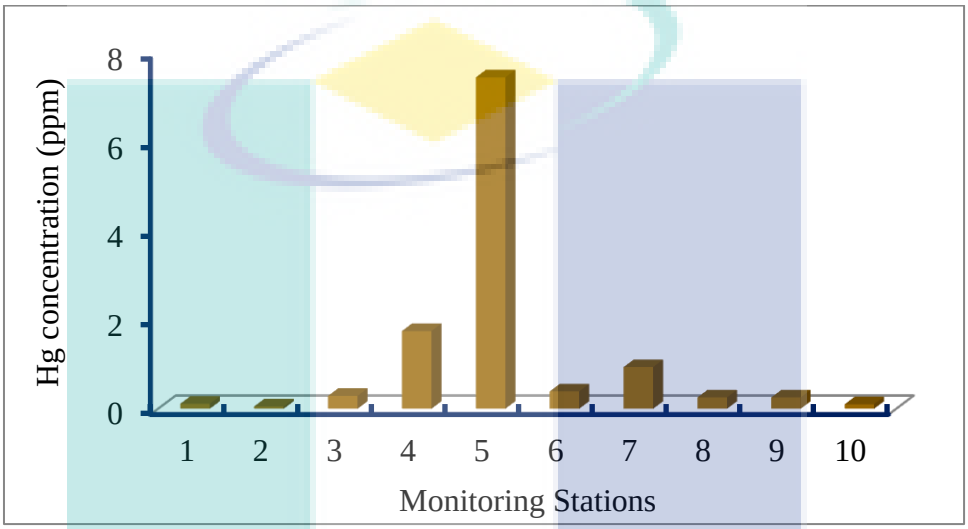


Figure 6.8: Average Hg concentration of soil samples from ten different sampling stations of Gebeng industrial town

6.3.8 Nickel (Ni)

Nickel concentration was determined and the average concentrations from all sampling points are shown in Figure 6.9. The figure states that nickel concentration increased with industrialisation, and decreased at the swampy areas. A chronologic normal curve shaped figure confirms that the concentrations were higher in industrial areas. The average range was 0.65 to 4.75 ppm. The highest concentration was at sampling station 5 (industrial 2) and the lowest was at sampling station 9 (swampy area). The concentration at industrial zone indicates that the industrial effluents from the specific industries that use nickel or nickel alloy were the possible causes of pollution. However, the concentration of nickel at all stations was below the threshold level of most developing countries (EPA, 2009; MOE, 2011).

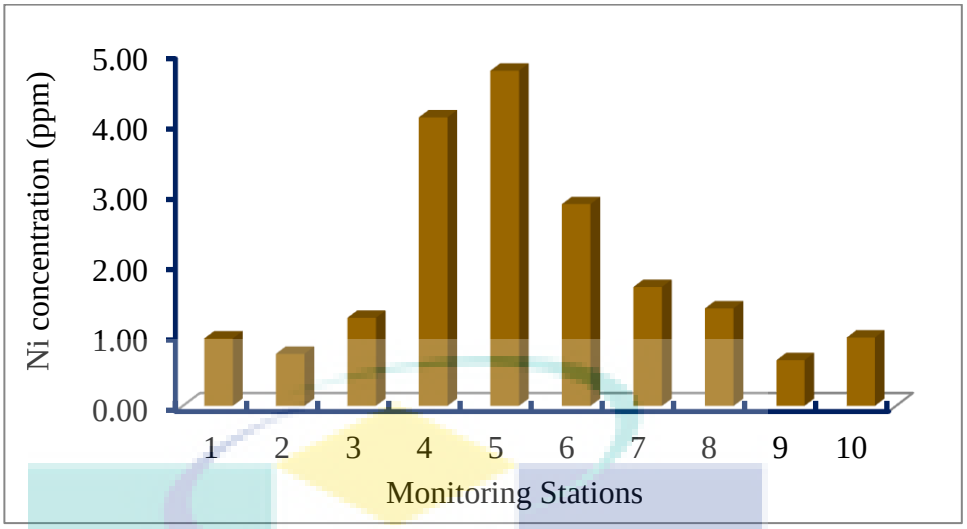


Figure 6.9: Average Ni concentration of soil samples from ten different sampling stations of Gebeng industrial town

6.3.9 Lead (Pb)

Lead is a non-essential element in soil that causes soil hazards even in lower concentration. The collected soil samples were analysed to measure the concentration of Pb and the results obtained are presented in Figure 6.10. The figure shows a significant variation among the sampling stations. The average range was in between 4.17 to 60.09 ppm. Similar to the other metals, higher concentration was found in the industrial zone, the highest being at sampling station 4 (industrial zone 1). Conversely, the lowest was recorded at sampling station 9 (swampy area). According to the threshold values of some countries, reading at station 4 was beyond the threshold level. It might be due to the industrial effluents associated with corrosion of lead pipes.

6.3.10 Zinc (Zn)

Zinc concentrations on soil samples were measured and the results are shown in Figure 6.11. The figure shows that average range of zinc concentration at the study area was 4.51 ppm to 50.87 ppm. The range in industrial area was 38.59 ppm to 50.87 ppm, indicating that zinc concentration was very low except for the industrial zone. The highest concentration was recorded at sampling station 4 while the lowest was at sampling station 3. Based on the zone distribution the residential and the swampy areas were found to have very low zinc compared to the industrial zone (Figure 6.11).

However, the concentration of zinc was within the threshold level of several countries (EPA, 2009; MOE, 2011).

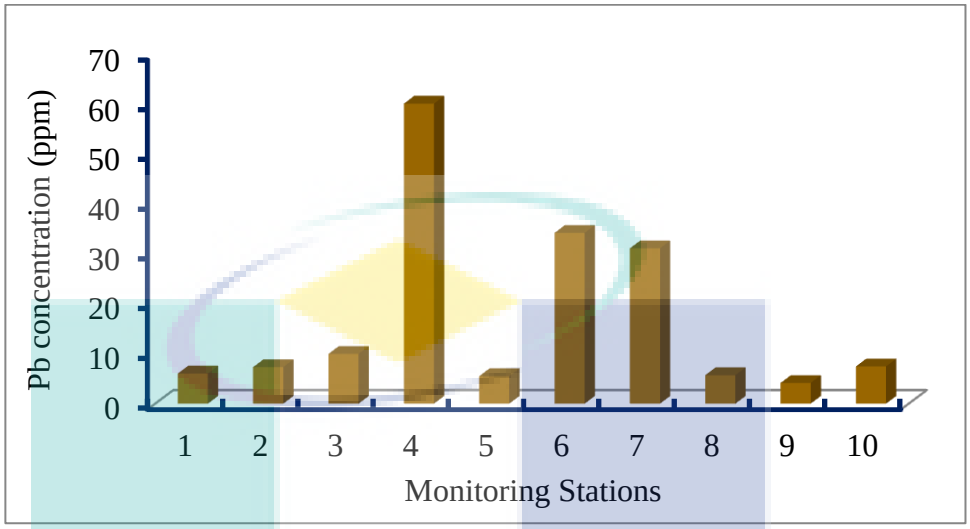


Figure 6.10: Average Pb concentration of soil samples from ten different sampling stations of Gebeng industrial town

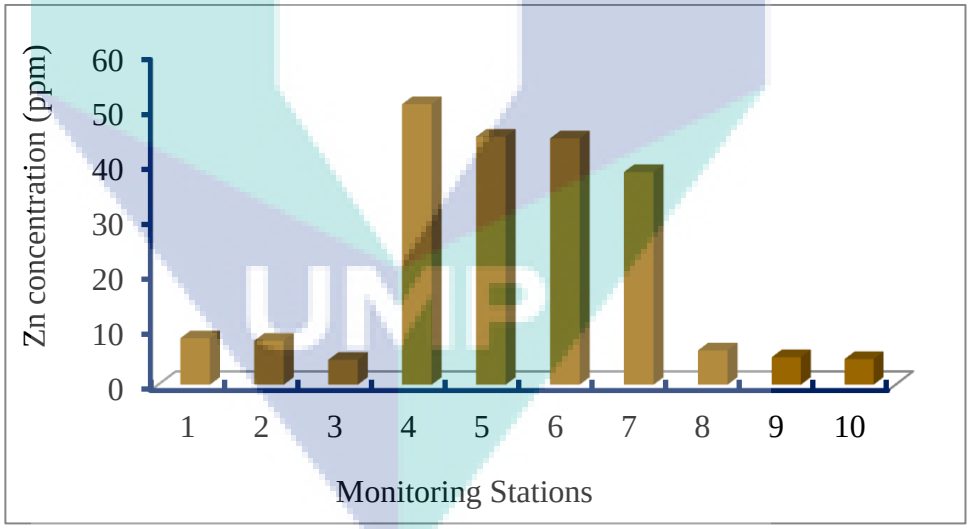


Figure 6.11: Average Zn concentration of soil samples from ten different sampling stations of Gebeng industrial town

6.4 POLLUTION LOADING

6.4.1 Geo-accumulation Index (Igeo) and degree of contamination

Geo-accumulation (Igeo) index allows the evaluation of contamination by correlating the obtained current concentration of metals with their pre-industrial concentrations, originally used for bottom sediments (Muller, 1969). It can also be used to assess the soil contamination. Muller (1969) proposed the following equation to compute the geo-accumulation index:

$$I_{geo} = \log_2 \frac{Cn}{1.5Bn} \quad \text{---------- (6.1)}$$

Where, *Cn* is the concentration of heavy metal in soil; *Bn* is the geo-chemical background value and 1.5 is the background matrix correction factor due to lithological variation. This factor (1.5) allows the analysis of the fluctuations that occurs naturally in the content of given element in the environment and also allows analysing the anthropogenic influence even if it is very small. In the present study, geo-accumulation index was calculated by using the modified equation by Loska et al. (2004); where, *Cn* is the observed concentration of heavy metal in soil samples and *Bn* is the geo-chemical background value in the Earth's crust (Taylor and McLennan, 1995). The *Igeo* scale constitutes seven grades, that is: *Igeo* ≤ 0 (grade 0), unpolluted; 0< *Igeo* ≤1 (grade 1), unpolluted to moderately polluted; 1 < *Igeo* ≤ 2 (grade 2), moderately polluted; 2< *Igeo* ≤3 (grade 3), moderately to strongly polluted; 3< *Igeo* ≤4 (grade 4), strongly polluted; 4< *Igeo* ≤5 (grade 5), strongly to very strongly polluted; *Igeo* > 5 (grade 6), very strongly polluted (Solgi et al., 2012). In the present study, the geo-accumulation index (*Igeo*) was calculated and the results are presented in Tables 6.2 and 6.3. Table 6.2 shows the minimum, maximum and mean values of *Igeo* from all soil samples, while Table 6.3 shows the zone wise *Igeo*.

Table 6.2: Geo-accumulation index for the soil samples in all zones of the study area

Statistical tools	Geo-accumulation Index									
	As	**Ba**	**Cd**	**Cr**	**Co**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**
Minimum	0.20	-4.91	-9.30	-2.02	-4.04	-4.33	-0.06	-4.07	-2.06	-5.99
Mean	2.25	-6.62	-6.62	-1.57	2.03	-1.24	2.96	-2.74	-0.56	-1.60
Maximum	3.63	-2.53	-5.20	-1.12	4.21	0.10	5.72	-1.46	0.83	-0.41

Table 6.3: Geo-accumulation index (*Igeo*) for the soil samples in the study area by zone

Sampling stations	Geo-accumulation Index									
	As	Ba	Cd	Cr	Co	Cu	Hg	Ni	Pb	Zn
Residential cum semi-industrial Zone	0.63	-3.24	-7.65	-1.80	-4.04	-3.29	0.93	-3.42	-1.34	-2.73
Industrial Zone	3.04	-3.06	-5.92	-1.59	2.95	-0.40	3.78	-2.19	0.09	-0.87
Swampy Area	0.62	-3.54	-7.86	-1.37	-3.92	-3.36	1.23	-3.40	-1.64	-3.00

The Table 6.2 states that the calculated geo-accumulation index of Ba, Cd, Cr, Ni and Zn have negative values (less than 0). This indicates that those metals concentrations are unpolluted. In cases of Cu and Pb, the minimum and mean concentrations are unpolluted while the maximum concentrations are unpolluted to moderately polluted. The mean values of *Igeo* for As, Co and Hg were 2.25, 2.03 and 2.96 respectively. It means that those metals are in the range of 2<Igeo≤ 3, which is moderately to strongly polluted. More specifically for As (0.2- 3.63), a total of 17 samples showed unpolluted to moderate pollution (0<*Igeo*≤1); two samples showed moderate pollution (1<*Igeo*≤2); five samples showed moderate to strong pollution (2<*Igeo*≤3) and six samples showed strong pollution (3<*Igeo*≤4) (Appendix K). For Co (- 4.04 – 4.21), twenty-four samples recorded unpolluted; five indicated strong pollution and one sample showed strongly to very strong pollution (4<*Igeo*≤5) (Appendix K). The contribution of Hg (-0.06 – 5.72) is as follows; three samples showed unpolluted; ten showed unpolluted to moderate pollution; seven samples resulted in moderate pollution; five resulted in moderately to strongly pollution; four showed strong pollution and one sample showed very strongly pollution (*I-geo* > 5) (Appendix K). In the case of Cu (-4.33 to 0.1), twenty-seven samples showed unpolluted and three samples exhibited unpolluted to moderate pollution. Similar to Cu, the contribution of Pb (-2.06-0.83) records twenty-three samples showing unpolluted and seven samples showed unpolluted to moderate pollution (Appendix K). Almost in all cases except for As and Hg, the contaminated samples are from the industrial zone; which indicated that, the contamination was due to the anthropogenic sources related to industrial activities. All

zones were found to be polluted with As and Hg and were recorded the highest in the industrial areas.

Table 6.3 displays the average geo-accumulation index values of metal based on zone distribution. As can be seen, *Igeo* values of As is 0.63 at residential areas, 3.04 at industrial areas and 0.62 at Swampy area. This means that the soils of residential and Swampy areas were unpolluted to moderately polluted and at industrial area it was strongly polluted. The *Igeo* values of Hg is found to be 0.93 at residential area, meanings that the soil of the region was unpolluted to moderately polluted. At industrial area, the *Igeo* value is 3.78. It confirms the soil of industrial area as strongly polluted whereas the value of 1.23 at Swampy area means it was moderately polluted. Other than these two metals, cobalt shows an index value of 2.95 at industrial area, indicating the soil of the area as moderately to strongly polluted with Co. However, the industrial zone was found contaminated with more metals than any other zones; which highlighted that the major cause of the contamination is industrial activities and their effluents get into the soil of the study area.

6.4.2 Estimation of Pollution Load Index (PLI) and level of pollution

The Pollution Load Index (PLI) is an empirical index that can be used to evaluate the level of heavy metal contamination of a soil in a comparative and simple way (Bentum et al., 2011). It is obtained as the concentration factor (CF). CF expresses the pollution caused by a single heavy metal. It is the ratio that results from dividing the obtained concentration of each metal by their background values (Equation 6.2). Tomlinson et al. (1980) proposed the PLI and developed the following equation to calculate the index:

$$CF = \frac{C_{metal}}{C_{background\ value}} \qquad \text{---------- (6.2)}$$

$$PLI = \sqrt[n]{(CF_1 \times CF_2 \times CF_3 \times ..... \times CF_n)} \qquad \text{---------- (6.3)}$$

Where, CF = contamination factor of each metal; C_{metal} = metal concentration obtained from sample; $C_{background\ value}$= geo-chemical background value of the metal and n = number of metals. The value of PLI > 1 indicates polluted and PLI < 1 denotes no pollution (Harikumar et al. 2009; Tomlinson et al., 1980). In this study, the

contamination factor (*CF*) of all metals was calculated and with those values pollution load index (PLI) was estimated to evaluate the levels of heavy metal pollution in the study area (Varol, 2011). The results are shown in Table 6.4.

Table 6.4: Pollution load index and contamination factor of heavy metals for soil samples

Sampling stations	Contamination factor										PLI
	As	Ba	Cd	Cr	Co	Cu	Hg	Ni	Pb	Zn	
Residential cum semi-industrial Zone	2.81	0.06	0.00	0.25	0.00	0.06	3.80	0.05	0.39	0.10	0.08
Industrial Zone	31.25	0.07	0.01	0.31	28.58	1.01	65.93	0.17	1.64	0.63	1.01
Swampy Area	2.80	0.04	0.00	0.38	0.03	0.05	5.15	0.05	0.29	0.08	0.123
Overall Average	14.18	0.06	0.002	0.31	11.4	0.44	29.06	0.10	0.86	0.304	0.54

As can be seen, the CF of As and Hg is greater than 1 in all zones indicating that, all zones were found to be polluted by these two metals. Contamination factor of Cu, Co and Pb is higher in industrial area; which confirms that, the soils of industrial area were contaminated with Cu, Co and Pb. For other metals, the CF is less than 1, thus considered unpolluted.

Based on the calculated CF values, PLI was estimated. It is found that the pollution load index, PLI > 1 in the soils of industrial areas which again confirmed that the soils of the area was found to be polluted, while the other two regions were found to be unpolluted (Table 6.4). This result indicates that, the pollution was due to the industrial activities in that area; which is supported by Banerjee and Gupta (2013) and Jordanova et al. (2013) with similar results in their studies.

6.5 SOURCE APPORTIONMENT OF HEAVY METAL CONTAMINATION

Source apportionment of heavy metal concentrations in soils, specifically in rapidly growing industrial areas is critical to provide necessary information to the concerned stakeholders like policymakers and environmentalists for taking proper

management policy to minimize the pollution level (Chabukdhara and Nema, 2013; Solgi et al., 2012). In the present study, source apportionment of soil heavy metal contamination was done and the results are presented in this section. To identify the potential sources, several statistical analyses have been performed. Hierarchical cluster analysis was done to classify the similar sampling stations, Pearson correlation coefficient analysis was executed to ascertain the relationship among the metals and physic-chemical parameters and finally Principal components analysis was done to identify the potential sources. Actually, Pearson correlation coefficient analysis, hierarchical cluster analysis and principal component analysis were employed to identify the sources of soil heavy metal contaminations at the study area. For better and easier understanding, a descriptive statistics was done and presented in Table 6.5.

6.5.1 Descriptive statistical analysis

A summary of descriptive statistics of heavy metal concentrations along with pH, electrical conductivity (EC) and organic matter (OM) are showed in Table 6.5. The Table describes mean and standard deviations of the metals, by zone and also an overall value. The highest mean value of pH (6.12) was recorded at swampy area, while the lowest (5.47) at residential cum semi-industrial zone. On the contrary, the highest mean value of EC (6100 µS/cm) was observed at residential area. OM that acts as buffering substance and the storehouse of metals was found to have higher in the industrial zone. The highest mean value of OM was recorded 7.76%, while the overall mean is 5.39% (Table 6.5).

As can be seen, among the metals, the highest mean concentration is observed for Co (285.82 ppm) at industrial zone while the lowest is also for Co at residential cum semi-industrial Zone (Table 6.5). The overall mean concentration is also higher in case of Co (114.42 ppm). The concentrations of As, Co and Hg was found to be contaminated compared to the standard value of most developed countries (Chen, 1998). Based on the zone distribution, at Residential area, the highest mean concentration is found for Ba (32.25 ppm) with a standard deviation of 4.81 and the lowest is in Co (0.000012 ppm). Regarding other metals, the concentrations are 4.22 ppm for As, 8.69 ppm for Cr, 7.83 ppm for Pb, while the other have least concentrations. However, the

concentrations of all metals were found to be within the standard total limit for soil contamination in developed countries (Chen, 1998). It is certain that industrial zone was characterised by more loading of heavy metals in contrast to the other zones (Table 6.5). Comparing the standard total concentration for soil contamination in developed countries, the obtained values of As, Co and Hg were observed as toxic (Chen, 1998) at the industrial zone.

Table 6.5: Mean and standard deviation of heavy metal concentration with physicochemical parameters of soil

Heavy Metals	Residential cum semi-industrial Zone	Industrial Zone	Swampy area	Overall
pH	5.47±1.59	5.84±0.48	6.12±1.22	5.81±1.13
EC	6100±9024	832.94±512	508.23±483	2316±5575
OM	3.37±1.71	7.76±2.36	4.26±2.72	5.39±3.25
As	4.22±0.77	46.88±14.43	4.19±1.20	21.27±25.35
Ba	32.25±4.81	38.64±9.08	23.96±17.35	32.32±15.07
Cd	0.07±0.08	0.39±0.06	0.06±0.03	0.20±0.21
Co	0.000012±0	285.82±382.55	0.30±0.21	114.42±261.78
Cr	8.69±1.38	10.71±0.72	13.32±1.28	10.89±2.51
Cu	1.39±1.06	25.18±7.72	1.30±0.32	10.88±14.24
Hg	0.15±0.12	2.64±3.26	0.21±0.09	1.16±3.34
Ni	0.98±0.26	3.35±1.36	1.00±0.37	1.93±1.53
Pb	7.83±2.02	32.79±22.30	5.80±1.67	17.21±19.65
Zn	6.97±2.15	44.77±5.01	5.29±0.83	21.59±20.78

However, the other metals were found to be below the contamination level. Similar to the residential area, swampy zone was also characterised with comparatively low concentrations of metals (Table 1). The highest value was in the case of barium (23.96 ppm) followed by Cr (13.32 ppm). Based on the mean values, this zone was also regarded as uncontaminated area.

6.5.2 Pearson correlation coefficient

Person correlation coefficient analysis was done to analyse the relationship among the metal concentrations and other variables that has been presented in Table 6.6.

Table 6.6: Pearson correlation coefficient matrix of soil heavy metals and physicochemical parameters

	pH	**EC**	**OM**	**As**	**Ba**	**Cd**	**Co**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**
pH	1												
EC	-0.580**	1											
OM	-0.082	-0.218	1										
As	-0.010	-0.183	0.411*	1									
Ba	0.241	0.139	0.148	0.201	1								
Cd	0.136	-0.203	0.464**	0.789**	0.256	1							
Co	0.058	-0.151	0.195	0.235	0.154	0.330	1						
Cr	0.185	-0.441*	0.185	-0.154	-0.419*	-0.138	-0.001	1					
Cu	-0.009	-0.175	0.612**	0.831**	0.345	0.865**	0.204	-0.038	1				
Hg	0.107	-0.084	0.288	0.280	0.063	0.565**	0.178	0.121	0.539**	1			
Ni	0.093	-0.166	0.372*	0.662**	0.359	0.699**	0.444*	-0.004	0.735**	0.718**	1		
Pb	0.035	-0.130	0.341	0.611**	0.385*	0.548**	0.142	-0.228	0.603**	-0.029	0.456*	1	
Zn	-0.016	-0.172	0.543**	0.742**	0.394*	0.811**	0.515**	-0.066	0.886**	0.555**	0.859**	0.642**	1

Significant level indicated as * for $p<0.05$ and ** for $p<0.01$

As can be seen, pH is negatively correlated significantly ($p < 0.01$) with EC and there is no significant relation with other variables and metals. Again, EC is found negatively correlated significantly ($p < 0.05$) with Cr; while, high significant positive correlation ($p < 0.01$) is found among OM, Cd, Cu and Zn, and significant correlation ($p < 0.05$) is observed among OM, As and Ni. It shows that Cd, Cu, Zn, As and Ni concentrations are largely dependent on organic matter concentration. Ping et al. (2005) and Gao et al. (1997) explained similar results in their research.

In the case of metals, high positive significant ($p < 0.01$) correlation is obtained among As, Cd, Cu, Ni, Pb and Zn; Cd and Hg; Co and Zn; Cu and Hg, and among Hg, Ni and Zn. In addition, positive significant correlation ($p < 0.05$) is found between Ba, Pb and Zn (Table 6.6). Ba is found negatively correlated with Cr. Positive significant correlation among the metals indicates that, the dispersion of metals concerned along with their sources of origin are similar and the cause might be the anthropogenic sources, such as, industrial activities. On the contrary, negative correlation indicates the different sources. Similar results were also reported by Chabukdhara and Nema (2013); Yang et al. (2011).

6.5.3 Hierarchical cluster analysis

PCA and the hierarchical cluster analysis (HCA) have been considered as the most sensible way for data mining from environmental quality assessment (Astel et al., 2008; Simeonova and Simeonov, 2006). Hierarchical Cluster analysis (HCA) has been used to evaluate similarity of monitoring stations with respect to the concentration of heavy metals in soils. HCA was carried out by means of Ward's method and as a measure of similarity, Euclidean distances were used, and finally the results obtained are represented in a Dendrogram. Cluster analysis of soil samples based on their metal concentrations has grouped 30 samples into three major and two minor clusters, as shown in Figure 6.12. The figure shows the dendrogram that is generated from the cluster analysis. A summary of the analysis is also shown in Table 6.7. As can be seen, cluster 3 (C3) and cluster 5 (C5), which are in the minority group, are dominated by two samples and one sample only from sampling sites 1 and sampling site 5 respectively. Sampling site 1 is located in residential areas, which is near mangrove vegetation and

South China Sea, while the sampling site 5 is located in the industrial zone. Cluster 1 is characterised by seven samples from sampling site 1, 2, 3 and 10; which are either near residential or swampy area. Cluster 2 is dominated by nine samples from sampling stations 3 (residential area), 8, 9 and 10 (swampy area). In addition, the cluster 4 consists of eleven samples from four stations including sampling sites 4, 5, 6 and 7; which are at the industrial areas.

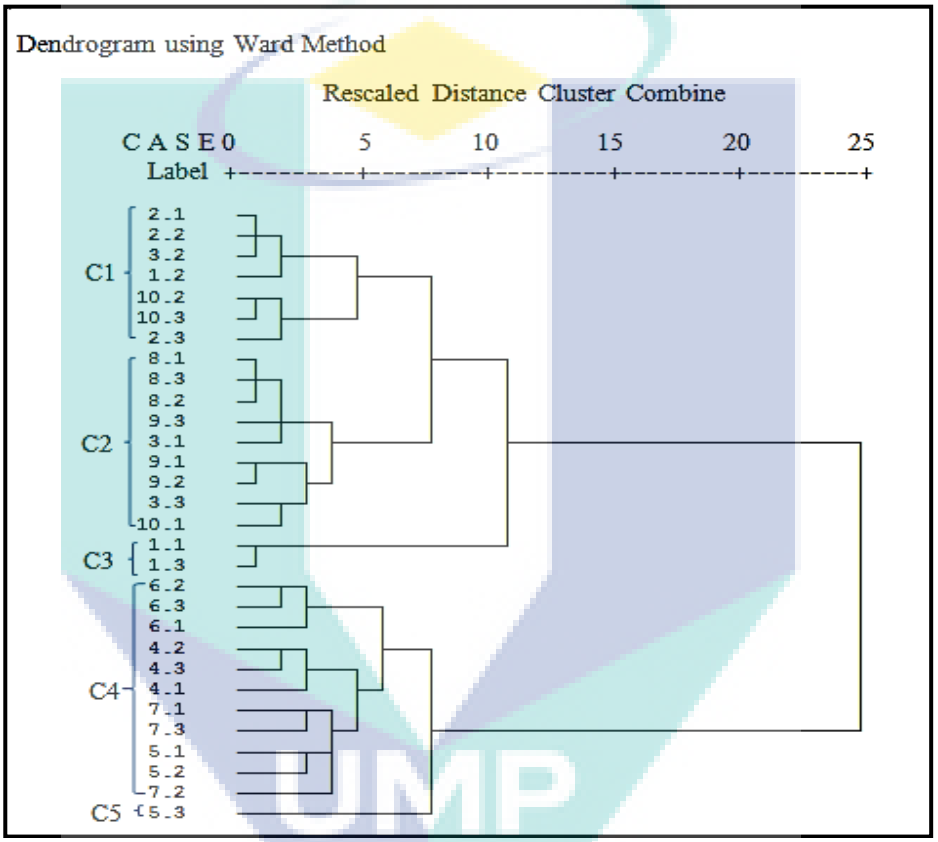


Figure 6.12: Dendrogram showing clustering of soil sampling station

Table 6.7: Summary of hierarchical cluster analysis

Cluster	Number of samples	Sampling stations
Cluster 1	7	1, 2, 3, 10
Cluster 2	9	3, 8, 9, 10
Cluster 3	2	1
Cluster 4	11	4, 5, 6, 7
Cluster 5	1	5

6.5.4 Principal Component Analysis (PCA)

PCA is an effective multivariate statistical technique to reduce data through transformation of the data into orthogonal variables that are the linear combinations of the original variables (Wang et al., 2007). As a central tool in chemo-metrics it extracts linear relationships among a set of diverse variables (Mustapha and Abdu, 2012; Onojake et al., 2011). Several researches have suggested that by using PCA source identification can be done with more accuracy (Chabukdhara and Nema, 2012; Xu et al., 2013). In this study, PCA was applied to identify the inside structures of heavy metals data on soil samples for identifying the source of metals. It was conducted using factor extraction after varimax rotation with Kaiser-normalisation with an Eigen value of >1. Before PCA, Kaisere-Meyere-Olkin (KMO) and Bartlett's test were performed to check the sampling adequacy. The rule of thumb is KMO value should be greater than 0.5 to precede a satisfactory PCA (Hinton et al., 2004). In the present study, KMO is found to be 0.571 (Table 6.8), indicating that the variables are correlated enough for PCA application. Likewise, the Bartlett test of sphericity significant level is 0.000 ($p < 0.01$). Hence, there are relationships between the variables, with those we can precede for PCA.

Table 6.8: KMO and Bartlett's Test for chemical parameters

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.571
Bartlett's Test of Sphericity	Approx. Chi-Square	303.924
	df	78
	Sig.	0.000

As can be seen, PCA with varimax rotation has extracted four principal components (PCs) based on Eigen value of >1. Four (4) factors altogether explained 77.33% of total variance (Table 6.9) of which PC1 is principal contributor that explained 31.64% of total variance and is positively loading with Cu, As, Pb, Zn, Cd, OM and Ni. According to the factor loading classification proposed by Liu et al. 2003, PC1 is strongly loading with Cu, As, Pb and Zn; whereas, moderately loading with OM, Cd and Ni. These metals are also positively correlated to each other (Table 6.6) and are grouped into cluster 4 (Figure 6.12).

Table 6.9: Rotated Component Matrix of the principal component analysis of heavy metals loadings in soils of Gebeng industrial area

Parameters	Principal Components				Communalities
	PC1	PC2	PC3	PC4	
Cu	**0.859**	0.412	0.062	-0.005	0.912
As	**0.841**	0.226	0.125	0.010	0.774
Pb	**0.801**	-0.122	0.371	0.120	0.809
Zn	**0.759**	**0.573**	0.157	0.022	0.930
Cd	**0.736**	0.492	0.127	0.087	0.807
OM	**0.683**	0.151	-0.270	-0.013	0.562
Ni	**0.533**	**0.749**	0.130	0.073	0.867
Hg	0.163	**0.880**	-0.171	-0.036	0.831
Co	0.127	**0.537**	0.120	0.134	0.337
Cr	-0.033	0.068	**-0.801**	0.338	0.761
Ba	0.197	0.190	**0.788**	0.172	0.725
pH	-0.114	0.129	0.143	**0.915**	0.886
EC	-0.246	-0.017	0.362	**-0.812**	0.851
Eigenvalue	4.113	2.510	1.744	1.687	
Total variance (%)	31.636	19.305	13.415	12.977	
Cumulative variance	31.636	50.941	64.355	77.333	

Extraction method: principal component analysis
Rotation method: varimax with Kaiser Normalisation

Correlation analysis indicated the similar sources of origin and the PCA results showed that those metals along with OM originated from anthropogenic sources like industrial effluents. The cluster analysis also supported the result indicating the contaminated area as the industrial zone that comprised of several metal industries (Appendix J). These industries utilise the metals and metal alloys concerned as raw materials or production materials. Moreover, the chemical industries often discharge wastewater containing nickel and other heavy metals. The wastewater and leachate from those metal and chemical industries been dumped to the adjacent soil was the cause of contamination at the soil of the area. Regarding arsenic contamination, it was due to mining activities accompanying with industrial effluents. Pb contamination was due to industrial effluents from metal as well as ceramic industries and also from the corrosion of lead pipes. Cu, Zn and Pb came also from vehicle fumes, as the sampling stations were near roads. Moreover, in case of every metal contamination anthropogenic causes were associated with natural source of pollution. Similar investigations and

outcomes were published by several researchers (Ansari and Malik, 2007; Banerjee and Gupta, 2013; Liu et al., 2009; Pandhija et al., 2013; Thuong et al., 2013; Varol, 2011; Zhou et al., 2007). PC2 was strongly loading with Hg and moderately loading with Ni, Zn and Co that explained 19.31% of total variance (Table 6.9). Strong loading denotes the anthropogenic sources like industrial wastewater from power plants, industrial broiler, petroleum refineries, leachates and agricultural runoff as the possible source of Hg. These results were similar to the investigation and findings of Luo et al., (2009) and Yaylal-Abanuz (2011).

PC3 has explained 13.42% of total variance and found strongly positive loading with Ba, and strong negative loading with Cr; which is grouped into cluster 1. The Pearson correlation coefficient also denotes that those two metals are significantly negatively correlated with each other (Table 6.6). Strong positive loading of Ba and strong negative loading of Cr indicate that the sources of those metals are not similar.

However, those two metals were found uncontaminated at the study area. PC4, which explained 12.98% of total variance, was strongly positive loading with pH and negative strong loading with EC. Similar to the PC3 it also indicates that, the source of these two elements was not common. Strong loading of EC was due to natural sources like the saline water intrusion at residential areas and the correlation between these two variables was the possible cause of low pH loading.

6.6 CONCLUSION

Soil heavy metal contamination in and around industrial town is a common problem throughout the world. Gebeng is one of the biggest industrial estates in peninsular Malaysia was also found contaminated with soil heavy metals. The physicochemical parameters that were correlated to the heavy metals showed that the lower part of the area especially the sampling stations near to the South China Sea were more loading with EC but lower pH. The geo-accumulation index revealed that the concentration of As, Co and Hg was found contaminating at the area. As and Hg were contaminating all areas while the Co was at industrial zone. Pb was also found contaminating the industrial areas. Similar to geo-accumulation index, PLI also indicated that As and Hg were highly polluting the industrial zone followed by other

zones, whereas Co, Pb and Ni were also found polluting the study area. Overall PLI value was more than one (1) at industrial zone, which indicated that the soil of the area was polluted.

Source apportionment was done to identify the potential sources of heavy metal and the results revealed that most of the metals in soil were due to the anthropogenic causes as industrial activities and effluents dumped into the soil. The investigation also pointed out that the industries that used the metal concerned as raw materials or product metals or metal alloys were the potential sources. Furthermore, road dust, vehicle fumes and natural sources also contributed to the metal contamination of soil at the industrial area Gebeng. Although, it is a common problem in some industrial areas, to protect the environment it should be minimised and controls should be taken to minimise the problem. Proper industrial waste management and prohibition of dumping the effluent without treatment can definitely mitigate the soil heavy metal contamination problem at the area.

CHAPTER 7

WATER QUALITY MODELLING

7.1 INTRODUCTION

A water quality model is an important tool to predict water quality trends. It was first introduced early in the 20th century when Streeter and Phelps (1925) produced the first significant model of dissolved oxygen and organic carbon in rivers. In the early 1960s, the Streeter-Phelps model was extended to decay rates that differentiated spatially and with temperature simultaneously, heat exchange models, the coupling of hydrodynamic models and nonlinear differentials using Monod kinetics was introduced (Orlob, 1992). The US EPA funded a model in the early 1970s, which was named QUAL2 that could simulate river systems at both steady or unsteady flow and it also allowed for nitrogen oxygen demand (McIntyre, 2004). The full recognition and utility of water quality models at government as well as commercial level came in between 1980 and 2000. Menu-driven user interfaces including improved graphics have made water quality models more marketable and concurrently, the number of modelling tools for a variety of specific applications was available. Such as, Brown and Barnwell (1987) who developed QUAL2E, Ambrose et al. (1993) produced WASP5, Ivanov et al. (1996) made DESERT, Whitehead et al. (1997) developed QUASAR, Runkel (1998) produced OTIS, U.K. Environmental agency (UKEA, 2001) developed SIMCAT, DHI made MIKE11 in 2000 (DHI, 2008), Shanahan et al. (2001) produced RWQM1 and Cole and Wells (2000) developed CEQUAL-W2. In spite of the common elements in all models, every model had their specific features aimed at developing the state of the art of water quality modelling.

Among the water quality models, QUAL2E was the widely used mathematical model for river and stream water quality to evaluate the conventional pollutant impact

(Brown and Barnwell, 1987; Drolc and Končan, 1996; Kannel et al., 2007). But still it had some limitations which were later modified by Park and Lee (2002) and they developed QUAL2K, 2000. It included the addition of new water quality interactions. It was further improved by Chapra and Pelletier (2003) with the name QUAL2K, 2003. By modifying the QUAL2K, 2003, Pelletier et al. (2006) developed QUAL2Kw, which is the modernised version of QUAL2E (Kannel et al., 2007). QUAL2Kw has many new features, including Software Environment and Interface, Model segmentation, Carbonaceous BOD speciation and others (Pelletier and Chapra, 2008). It can be used for both small and big river water quality modelling (Bottino et al., 2010). As a tool for water quality management of small river basin, Oliveira et al. (2012) used this QUAL2Kw in Portugal. In Malaysia, QUAL2K model was used by Zainudin et al. (2010) for Sungai Tebrau and found as an outstanding tool in managing the river basin.

Regarding the present study, Tunggak River in Kuantan Malaysia, is a small river having no tributary. It is being polluted due to the vicinity of industrial estate Gebeng. Gebeng industrial areas discharge their wastewater to the river flow causing heavy pollution. It acts as an important factor to contribute DO reduction as well as increasing of other water quality parameters in the river water. In this study, QUAL2Kw model was calibrated and validated by the observed data and discussed in this chapter. This chapter also describes on the root mean square error (RMSE) of the calibrated and validated model. A sensitivity analysis was done to identify the model parameters that have the most influence on the model outputs and the results are also shown here. Finally, a strategy for water quality control with pollution load modification and flow augmentation has been discussed. As can be seen, the model results represented the data quite well and concluded that QUAL2Kw model can be used for the water quality management in Tunggak River.

7.2 MODEL CALIBRATION AND VALIDATION

7.2.1 Input data

The input data of water quality parameters were flow, temperature, conductivity (EC), pH, DO, BOD, COD (as generic constituent), ammoniacal nitrogen, nitrate nitrogen, inorganic phosphorus and inorganic suspended solid (ISS). The data were

collected for one time in one day of each month both in wet and dry seasons. The average data for the dry season and wet season were used as the input data. The measured dry season data are presented in Table 7.1 and wet season data are shown in Table 7.2. Regarding phytoplankton and pathogen, these data were not measured. The bottom plants were assumed 40%. The sediment/hyporheic zone thickness was assumed 10 cm. The water qualities for the point and diffuse source of pollutions were other input to the model.

7.2.2 System parameters

The system parameters required by QUAL2Kw for calibration are shown in Table 7.3. These parameters were obtained from a number of studies and literatures including Environment Protection Agency (EPA) guidance document (Bowie et al., 1985), user manual of QUAL2Kw (Pelletier and Chapra, 2008) and documentation for the enhanced stream water quality model QUAL2E and QUAL2E-UNCAS (Brown and Barnwell, 1987). Internal calculation method was used to calculate re-aeration rate; which was also applied by Zhang et al. (2012). Exponential model was chosen for oxygen inhibition of CBOD oxidation, nitrification and phyto-respiration and for oxygen enhance of de-nitrification and bottom algae respiration. The range of CBOD oxidation rate was assumed as 0–5, which was also used by Oliveira et al. (2012); Cho and Ha (2010) and Camargo et al. (2010) for small rivers. The other parameters were set as default value in QUAL2Kw.

7.2.3 Model implementation

Model calibration was run with the measured data of dry season. To avoid instability in the model calibration, the calculation step was set at 5.625 min (Kannel et al., 2007; Zhang et al., 2012). Euler's method was set for the solution of integration; Newton-Raphson method was used for pH modelling. The sediment diagnosis simulation was done for level I option. To perform goodness of fit different weighting factors were given to different parameters. The weight 50 was given for DO as it was the most influential parameter (Camargo et al., 2010; Kannel et al., 2007). Weight 2 was given for temperature, pH, CBOD and COD and for other parameters 1 was given as weighting factor.

Table 7.1: Water quality measurement at monitoring stations along Tunggak River on dry season (March-August)

Station	Distance (km)	Water flow(m^3/S)	Water temp.(^{0}C)	pH	EC (µS/cm)	DO (mg/L)	ISS (mg/L)	Inorganic P (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)	BOD (mg/L)	COD (mg/L)
US	0.00	0.713	31.9	7.1	778.167	4.14	3.700	0.069	1.241	0.139	27.863	75.667
EC	1.27	0.239	30.6	7.1	777.110	5.63	23.400	0.181	1.241	0.139	27.863	75.667
BPL	1.17	0.226	31.9	7.6	1130.917	2.48	22.125	0.901	1.759	1.049	20.225	37.417
Ast	0.87	0.650	30.4	7.5	1022.25	3.49	7.663	0.931	1.433	1.158	21.525	41.417
MF	0.90	0.714	30.6	7.6	864.917	4.98	5.275	0.780	1.562	0.744	20.892	37.333
TBM	0.85	0.700	32.5	7.4	1087.417	3.92	8.299	0.861	2.321	0.254	20.721	32.667
SB	0.85	1.101	33.3	7.1	5852.917	3.47	11.288	1.083	2.162	0.238	16.596	35.167
LS	1.60	3.250	30.2	6.6	11970.25	2.77	19.388	0.607	1.598	0.081	8.3	25.975

Table 7.2: Water quality measurement at monitoring stations along Tunggak River on wet season (September-February)

Station	Distance (km)	Water flow(m^3/S)	Water temp.(^{0}C)	pH	EC (µS/cm)	DO (mg/L)	ISS (mg/L)	Inorg.P (mg/L)	NH_3N (mg/L)	NO_3N (mg/L)	BOD (mg/L)	COD (mg/L)
US	0.00	0.713	30.6	6.8	272.833	5.63	11.100	0/181	1.116	0.130	26.329	43.500
EC	1.27	0.508	31.3	6.8	525.500	4.886	11.100	0.125	1.178	0.116	27.096	59.583
BPL	1.17	0.451	31.6	7.4	1168.125	2.824	5.425	0.683	1.547	1.039	21.407	54.417
Ast	0.87	0.927	30.5	7.1	988.875	3.745	8.100	0.760	1.443	1.008	21.556	50
MF	0.90	0.783	30.5	7.3	915.708	4.793	2.825	0.667	1.615	0.776	18.881	37.833
TBM	0.85	0.888	31.0	7.2	1153.125	3.907	3.900	0.894	2.118	0.442	18.729	36.0417
SB	0.85	1.271	31.0	7.2	4445.375	3.234	3.000	1.003	2.279	0.374	16.394	38.708
LS	1.60	4.006	29.4	6.5	14073.54	3.259	6.850	0.500	1.459	0.106	8.544	37.904

Table 7.3: Calibrated parameters for the Tunggak River

Parameters	Values	Units	Auto-calibration	Min. value	Max. value
Carbon	40	gC	No	30	50
Nitrogen	7.2	gN	No	3	9
Phosphorus	1	gP	No	0	4.2
Dry weight	100	gD	No	100	100
Chlorophyll	1	gA	No	0.4	2
ISS settling velocity	0.01	m/day	Yes	0	2
O2 reaeration model	Internal		No		
Slow CBOD hydrolysis rate	2.7636	day−1	Yes	0	5
Slow CBOD oxidation rate	0.213085	day−1	Yes	0	0.5
Fast CBOD oxidation rate	3.0658	day−1	Yes	0	5
Organic N hydrolysis	2.27565	day−1	Yes	0	5
Organic N settling velocity	1.67572	m/day	Yes	0	2
Ammonium nitrification	0.1505	day−1	Yes	0	10
Nitrate denitrification	0.98572	day−1	Yes	0	2
Sed. denitrification transfer coefficient	0.09598	m/day	Yes	0	1
Organic P hydrolysis	2.112	day−1	Yes	0	5
Organic P settling velocity	0.72152	m/day	Yes	0	2
Inorganic P settling velocity	1.38792	m/day	Yes	0	2
Sed. P oxygen attenuation half sat constant	1.81956	mgO_2/L	Yes	0	2
Bottom plant					
Growth model	zero-order				
Max Growth rate	72.631	$mgA/m^2/day$	Yes	0	100
First-order model carrying capacity	100	mgA/m^2	No	50	200
Basal Respiration rate	0.48434	day−1	Yes	0	0.5
Excretion rate	0.47967	day−1	Yes	0	0.5
Death rate	0.062045	day−1	Yes	0	0.5
External nitrogen half sat constant	193.179	ugN/L	Yes	0	300
External phosphorus half sat constant	31.623	ugN/L	Yes	0	100
Inorganic carbon half sat constant	1.13E-04	moles/L	Yes	1.30E	1.30E
Light model	Half saturation				
Light constant	24.59071	langleys/day	Yes	1	100
Ammonia preference	61.74442	ugN/L	Yes	1	100
Subsistence quota for nitrogen	61.87110	mgN/gD	Yes	0.072	72
Subsistence quota for phosphorus	6.3753283	mgP/gD	Yes	0.01	10
Max. uptake rate for nitrogen	1303.12	mgN/gD/d	Yes	350	1500
Max. uptake rate for phosphorus	79.1345	mgP/gD/d	Yes	50	200
Internal nitrogen half sat ratio	3.7176325		Yes	1.05	5
Internal phosphorus half sat ratio	3.260499		Yes	1.05	5
Detritus dissolution rate	1.4653	day^{-1}	Yes	0	5
Detritus settling velocity	0.94975	m/day	Yes	0	5
COD decay rate	0.8	day^{-1}	Yes	0.8	0.8
COD settling velocity	1	m/day	Yes	1	1

Model was run for a population size of 100 with 50 generations in the evolution (model runs in a population). According to Pelletier et al. (2006) a population size of 100 performs better than smaller numbers and as nearly as a population size of 500.

7.2.4 Calibration and validation results

Figure 7.1 shows the calibration and Figure 7.2 shows the validation results of modelling respectively. Figure 7.1 denotes that, the calibration result of all parameters were in accordance with the observed values although very little difference was observed which was negligible. The studied river water qualities are hard to reach the minimum DO requirement in all reaches of the river (Figure 7.1). The low DO concentration that is below 3.0 mg/L in all reaches, gives an indication of entering wastewater from different point sources through wastewater drains and channels from the industrial area. Those wastewater added high organic and inorganic materials that have resulted in low DO (Sujaul et al., 2013). The concentrations of CBOD and COD are higher and beyond the standard level in all reaches. These two parameters decrease steadily up to 3.0 km from the upstream boundary (Figure 7.1). This is because the amount of industrial wastewater has increased with the distance due to the density of industries in the mid region of the river (just after the upstream boundary) (Nasly et al., 2013). The concentration of ammoniacal-N has increased steadily up to 4 km but sharply decreased after 6 km from upstream. On the contrary, inorganic phosphorus increased sharply up to 3.3 km whereas the inorganic suspended solids were similar up to 2.5 km and then decreased sharply followed by steady upturn after 4 km from upstream.

With some exception, the outcomes of the model calibration were in good agreement with the observed data. Table 7.4 shows the root mean square errors (RMSE) between the simulated and observed values of water quality parameters in the calibration (dry season) and validation (wet season). The table also shows the difference of RMSE from calibration to validation (%). Calibration and validation have similar RMSE value, if the difference is less than 20%, it indicates the good matching between the observed and predicted values (Camargo et al., 2010). During calibration, the RMSE of temperature, pH, DO, CBOD, COD, NH4-N, PO4-P and ISS are observed

to be 2.67, 0.69, 1.55, 34.58, 37.93, 0.51, 0.44 and 21.18%, respectively; and in the validation, the RMSE for temperature, pH, DO, CBDO, COD, NH4-N, PO4-P and ISS are observed to be 3.07, 0.56, 1.20, 33.10, 32.48, 0.56, 0.39 and 7.51% respectively (Table 7.4). On the basis of the difference of RMSE (%) temperature, pH, CBOD, COD NH4-N and PO4-P have very good match between observed and predicted values. The large difference indicated that the environmental conditions especially for those parameters were different between the two periods (Camargo et al., 2010).

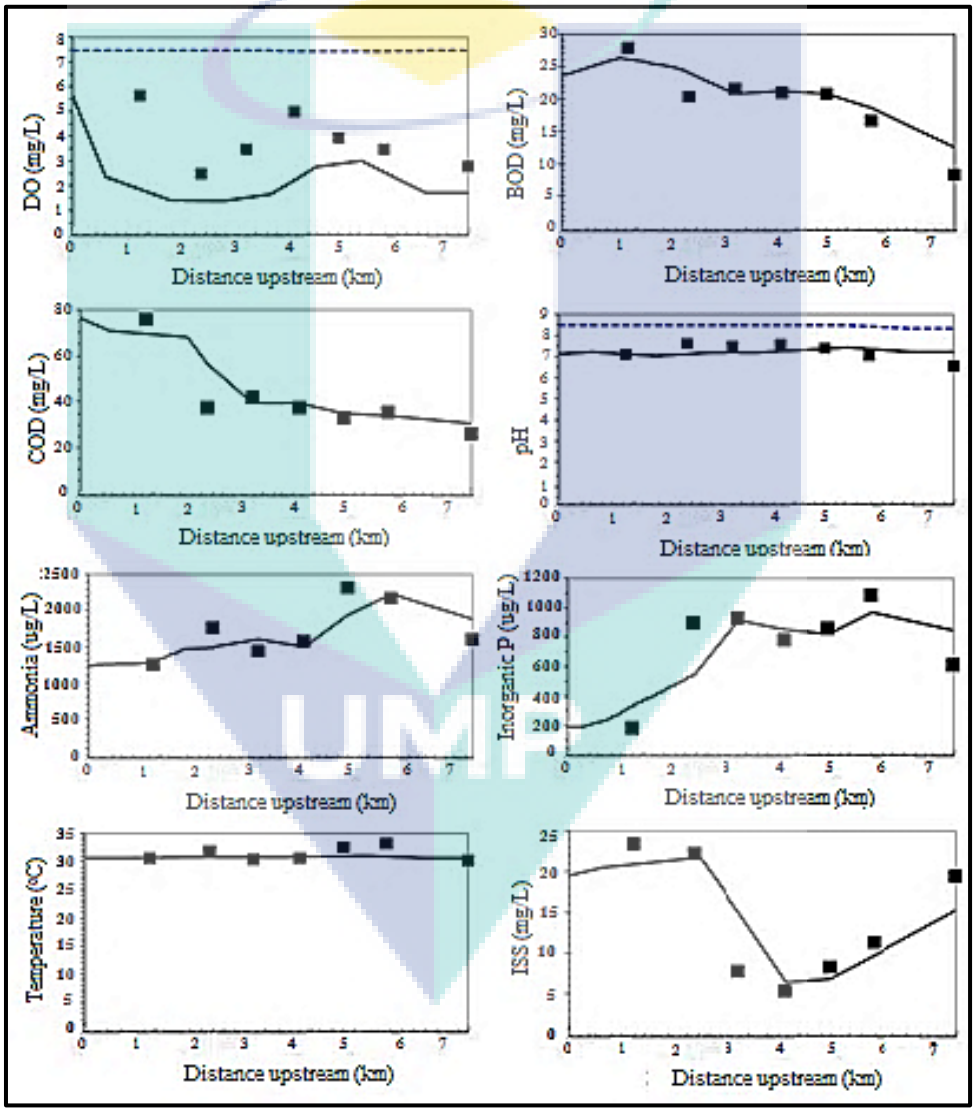


Figure 7.1: Model calibration of water qualities in Tunggak River for dry season's data (where ■ indicates observed data and ——— indicates simulation curve)

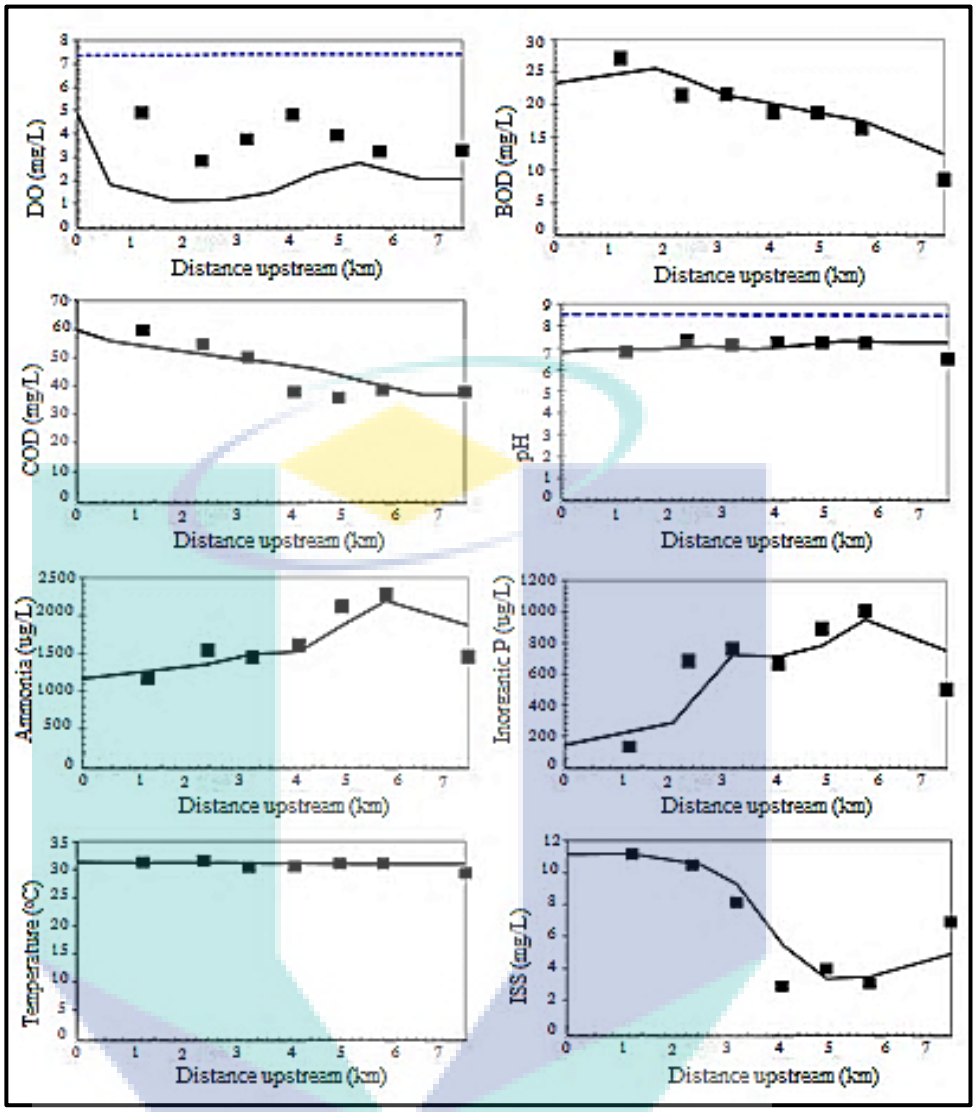


Figure 7.2: Model validation of water qualities in Tunggak River for wet season's data (where ■ indicates observed data and ——— indicates simulation curve)

In spite of some errors in this modelling, which are inevitable due to time variation of sample collection, the simulation results were quite good and acceptable to achieve modest management goals. Nevertheless, more accuracy could be attained through adding various input variables including bottom algae, sediment oxygen demand, organic nitrogen, total and organic phosphorus and so on. in monitoring program. More sophisticated 2-D or 3-D models can be applied to achieve the best management.

Table 7.4: Root mean squared errors (RSME) between the predicted vs. observed values of water quality parameters

SL No.	Parameters	RMSE (%)		Difference (%)
		Calibration	Validation	
1.	Temperature	2.57	3.07	19.5
2.	pH	0.69	0.56	18.8
3.	DO	1.55	1.20	22.6
4.	CBOD	34.58	33.10	4.3
5.	COD	37.93	28.48	14.4
6.	NH3-N	0.51	0.56	9.8
7.	Inorganic Phosphorus	0.44	0.39	11.4
8.	ISS	21.18	7.51	64.5

7.2.5 Sensitivity analysis

To evaluate the model robustness and error associated with variation of important model parameters, sensitivity analysis is a crucial part of QUAL2Kw river water quality model (Oliveira et al., 2012). In the present study, sensitivity analysis was done to identify the model parameters that had most influence on the model outputs in the dry season. For seven model parameters, the analysis was performed keeping all the parameters but one constant, that one being increased or decreased by 20% and the variation was observed in four water quality parameters: DO, BOD, COD and NH_3-N. It was done by varying one parameter at a time and the summary of the analysis are shown in Table 7.5. The analysis was done considering the dry season as a baseline. The results revealed that the model was highly sensitive to Manning coefficient; COD decay rate; bottom plants maximum growth rate and ammonium nitrification rate. Similar results for Manning equation, bottom plants maximum growth rate and nitrification were investigated and published by Kannel et al., (2007) and Oliveira et al., (2012).

Table 7.5: Results of sensitivity analysis for the data of Tunggak River

Parameters	Variation (%)	% Change in			
		DO	BOD	COD	NH_3-N
Manning Coefficient	+20	-1.63	-1.34	-1.91	-1.43
	-20	2.98	1.46	2.15	1.85
Fast CBOD oxidation rate	+20	-1.04	-13.11	0.00	-2.88
	-20	1.34	12.45	0.00	2.74
ISS settling velocity	+20	-1.03	-3.11	0.00	-1.02
	-20	-0.98	3.12	0.00	.1.00
Ammonium nitrification rate	+20	-20.00	9.46	0.01	-27.41
	-20	9.61	-4.56	-0.01	13.55
Nitrate denitrification rate	+20	0.12	-0.10	0.00	-0.10
	-20	-0.01	0.01	0.00	0.12
COD decay rate	+20	-13.31	14.45	-3.15	-1.78
	-20	15.89	-11.43	3.35	4.39
Bottom plants maximum growth rate	+20	7.17	1.24	7.26	1.01
	-20	-13.29	-2.39	-6.07	-1.56

7.3 SCENARIO ANALYSIS

In order to identify what strategies should be adopted to protect water quality in the study area, the calibrated model was applied to develop several management scenarios by examining different strategies during pre-monsoon period to maintain the targeted water quality criteria considering I) pollution load modification; II) river water flow augmentation and III) local oxygenation.

7.3.1 Examining different water quality control strategies

The water quality parameters of Tunggak River were evaluated with pollution loads modification and flow augmentation to meet the desired quality criteria of water for survival of aquatic lives. The minimum DO at or above 4 mg/L is needed for fisheries while the maximum CBOD, ammoniacal nitrogen and P are essential at or

below 6 mg/L, 0.9 mg/L and 0.1 mg/L respectively, and pH range between 6.5 to 8.5 is needed according to the recommendation of INWQS Malaysia for Malaysian river water (class III water). In this aspect, the pH was within the limit. To improve the situation, the strategy of cleaning the Tunggak River as well as imposing the Environmental Quality (Industrial Effluent) Regulations, 2009, Malaysia to conform the discharge limits for industrial effluents into river flow, would be a possible solution. Malaysia has set 20 mg/L as tolerant limit for BOD to discharge into water flow (MNRE, 2009). This is not maintained in Gebeng area as the water in the area was polluted more than the allowable limit. To propose the potential water quality control strategy, pollution load modification, flow alteration and local oxygenation were examined with various limits of BOD, ammoniacal nitrogen and inorganic phosphorus to get the required level of water quality along the Tunggak River with enforcing the rules for discharging industrial effluents according to the Environmental Quality (Industrial Effluent) Regulations 2009, Malaysia.

Simulation was performed in different combination of the BOD with ammoniacal nitrogen, phosphorus and flow augmentation. Water flow was increased 1.0 m^3/s and was applied for simulation with all combinations of BOD. DO concentrations after simulation with various combinations are shown in Figures 7.3 to 7.5.

7.3.1.1 Modification of pollution loadings

During trial, ammoniacal nitrogen and phosphorus concentrations were fixed at 2.00 mg/L and 0.2 mg/L respectively to limit the simulated concentrations of ammoniacal nitrogen and phosphorus at 0.9 and 0.1 mg/L respectively. Fixing four trial values of BOD for point sources, pollution load modification was done where the four values were 20, 30, 40 and 50 mg/L BOD. Figure 7.3 showed the DO profile after simulation with BOD and nitrogen, phosphorus (NP) limit. It revealed that all profile did not fulfilled the required minimum DO level after load modification, only 20 mg/L BOD with (+) NP limit met the minimum requirement at some stations (Figure 7.3).

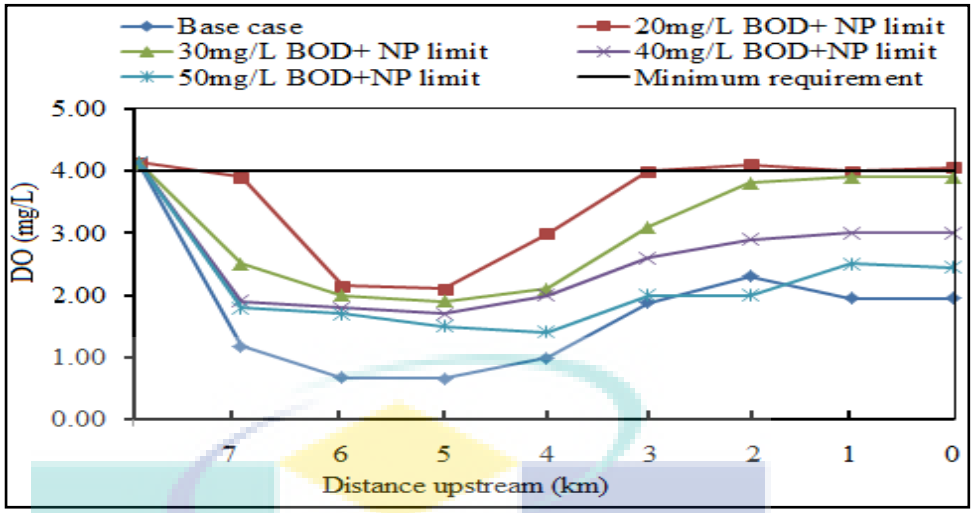


Figure 7.3: Concentration of DO after simulation with different amount of BOD and NP limits.

7.3.1.2 Flow augmentation

Increasing 1 m^3/s flow rate in addition of existing flow, simulation was done and the results are presented in Figure 7.4. It reveals that if 1 m^3/s flow augmentation is possible, the minimum requirement of DO can be met for some stations (Figure 7.4) and the required ammoniacal nitrogen and phosphorus concentration can be fulfilled in 20 mg/L BOD combination (Table 7.6). Nevertheless, at the mid-zone of the river that is in the vicinity of the industrial estate, DO concentration was below the minimum required level. It can be seen that the flow augmentation had a minor contribution to the DO concentration.

7.3.1.3 Local oxygenation

Active oxygenation using a series of weirs happens when a flow over them produces strong oxygenation through air contact. Evaluations were done with imposing 1, 2 and 3 weirs at critical locations of the river chronologically, after which evaluation with three (3) weirs along with different BOD and NP combination, and flow augmentation was found better for required water quality. Results of simulations with various combinations are shown in Figure 7.5. The Figure shows that the combination of 20 mg/L BOD+ NP limit + 1 m^3/S flow augmentation and three weirs can fulfil the minimum required DO at all stations.

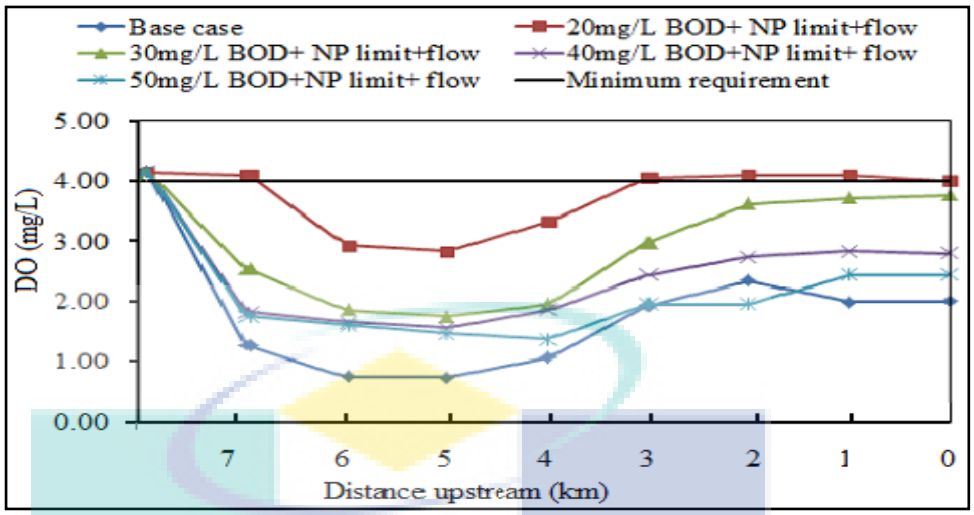


Figure 7.4: Concentration of DO after simulation with different amount of BOD, NP limits and increasing $1m^3/s$ river water flow.

30 mg/L BOD combination could meet the minimum DO level at most of the stations. However, other combinations failed to fulfil the requirement. Actually, building the weir at river obstruct the water flow and thus flow pass the weir with higher energy and momentum to produce better mixing of fresh air that resulted in local oxygenation to increase DO level. Similar evaluation and results were reported by Campolo et al. (2002) and Kannel et al. (2007). The simulation results for other parameters from the same combinations are presented in Table 7.6.

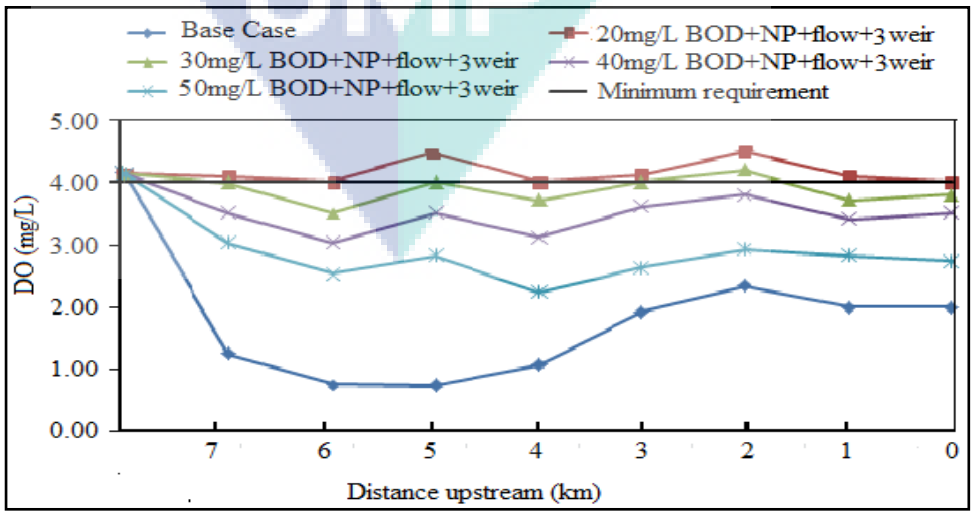


Figure 7.5: Concentration of DO after simulation with different amount of BOD, NP limit, $1m^3/s$ water flow augmentation and weirs at 3, 4 and 5 km.

Table 7.6: Different water quality control strategies to protect the water quality of Tunggak River

Combination	Results of water quality mg/L)			
	DO (min)	BOD (max)	NH3-N (max)	Phosphorus (max)
Base data (dry season data)	0.7	55.7	1.24	0.67
20 mg/L BOD+ NP limit*	2.1	12.1	1.04	0.24
20 mg/L BOD+ NP limit+ 1 m^3/S flow amplification	2.8	9.2	0.92	0.10
20 mg/L BOD+ NP limit+ 1 m^3/S flow amplification+ 3 weirs[1]	**4.0**	**6.03**	**0.93**	**0.11**
30 mg/L BOD+ NP limit	1.9	14.3	1.03	0.25
30 mg/L BOD+ NP limit+ 1 m^3/S flow amplification	1.7	12.0	0.92	0.10
30 mg/L BOD+ NP limit+ 1 m^3/S flow amplification+ 3 weirs[1]	3.5	9.9	1.05	0.11
40 mg/L BOD+ NP limit	1.7	16.7	1.01	0.24
40 mg/L BOD+ NP limit+ 1 m^3/S flow amplification	1.5	13.0	0.91	0.10
40 mg/L BOD+ NP limit+ 1 m^3/S flow amplification+ 3 weirs[1]	3.1	10.6	0.93	0.11
50 mg/L BOD+ NP limit	1.4	19.6	0.99	0.27
50 mg/L BOD+ NP limit+ 1 m^3/S flow amplification	1.3	16.8	0.89	0.11
50 mg/L BOD+ NP limit+ 1 m^3/S flow amplification+ 3 weirs[1]	2.2	14.7	1.06	0.11

*NP denotes nitrogen and phosphorus;
[1]1st weir was 1.0 meter height at 4km second and 3rd were 1.5 meter height and at 5 and 6 km.

7.3.2 Potential water quality control strategy

The above examinations of water quality control strategies suggest that to confirm to the minimum required DO concentration and the maximum required level of ammoniacal nitrogen and phosphorus in the Tunggak river pollution load modification with 20 mg/L BOD, flow augmentation and imposing three weirs at critical locations can be applied. Actually, the industrial estate of Gebeng has not adhered to the rules of the Environmental Quality (Industrial Effluent) Regulations 2009 Malaysia, when it discharges more than 6 kg BOD/day into the Tunggak River. However, according to the existing water quality criteria, estimated BOD discharge per day in the river was over 165 kg per day. This amount is injected into the river flow through point sources. The load modification, flow augmentation and local oxygenation imposing three weirs would conform to the strict execution of the Environmental Quality (Industrial Effluent) Regulations 2009, Malaysia. Discharging 20 mg/L BOD with flow augmentation and imposing weirs could help to fix the pollution problem of water at Tunggak River.

7.3.3 Implementation of the proposed water quality control strategy

For the implementation of the proposed water quality control strategy, the concern authority should take proper action plan. The following suggestion may be applied for preparing the action plan:

- Industries should compel to obey the Environmental Quality (Industrial Effluent) Regulations 2009, Malaysia, which ensure maximum discharge amount of industrial pollutant;
- For flow augmentation, industries should use the required water (for industrial use and dilution of wastewater as prescribed by the Environmental Quality (Industrial Effluent) Regulations 2009, Malaysia) from other source than Tunggak River and should discharge the used and diluted water into Tunggak River. For this purpose, water can be supplied from Pahang river and Balok river; and
- The concerned authority should construct the weirs for local oxygenation as suggested by the potential proposed strategy at the three (3) critical locations.

7.4 CONCLUSION

River and stream water quality model QUAL2Kw was calibrated using the data of the dry season of 2012 and confirmed by the wet season's (2012-13) data. RMSE showed a good match between observed and predicted value of maximum parameters, except for ISS. The model was applied to simulate various water quality parameters. The result shows that the water quality parameters did not differ greatly from dry season to wet season. RMSE noted that the ISS differed significantly and it was due to run-off from heavy shower. The sensitivity analysis showed significant sensitivity of the model changing over different model parameters. However, the model QUAL2Kw adequately represented the field data of Tunggak River and the modelled data (Simulation) expressed that the DO concentration was very low. To increase the amount of DO, some improvement measures based on the simulated results need to be undertaken. An evaluation was done to fix water quality control strategy as to confirm to the minimum level of DO and maximum threshold level of ammoniacal nitrogen and phosphorus. The results investigated one strategy that can ensure the minimum quality of water for aquatic lives. Proper execution of the Environmental Quality (Industrial Effluent) Regulations 2009, Malaysia along with proposed water quality control strategy, the water quality improvement of Tunggak River can be in place. Finally, the QUAL2Kw model performed very well in simulating the water quality parameters and it was found more sensitive to the change of model parameters.

CHAPTER 8

CONCLUSION AND RECOMMENDATIONS

8.1 CONCLUSIONS

8.1.1 Water Quality and DOE-Water Quality Index

The rapid industrialisation in Gebeng is a major threat to the water quality of Tunggak River as well as the surrounding surface water of the Gebeng industrial area. Detailed physicochemical study along with heavy metal content of surface water revealed that there was a significant variation regarding seasonality and spatiality. A total of 24 (14 physicochemical and 10 heavy metals) water quality parameters were determined from February 2012 to January 2013. Four (4) physicochemical parameters and five (5) heavy metals were comparatively higher in dry season and three parameters showed almost similar trend. On the other hand, almost all parameters were relatively higher in the industrial zone with some exceptions. Of all parameters, nine (9) physicochemical parameters including DO, BOD, COD and ammoniacal nitrogen, and six (6) heavy metals concentration exceeded the INQWS Malaysia recommended threshold level, which made the water of Tunggak River and surrounding areas worst, even though some parameters were found to be at safe levels. According to the DOE-WQI, the river water was under class III (polluted) and IV (highly polluted) and the swampy area was under class III (polluted). The study indicated that the water of the river that was under class III could be used for water supply and some common species of fish only after extensive treatment and water under class IV could not be used for any purpose except irrigation. Nevertheless, DOE-WQI calculation only considered six (6) physicochemical parameters, without consideration of the number of other water quality parameters, such as, heavy metals and faecal coliform. On the other hand, in the

calculation of CCMEWQI system, it gave due consideration up to 400 water quality parameters. Considering that fact, a new WQI system has been proposed in this study by combining the DOE-WQI and CCMEWQI to assess and classify the river water quality of Tunggak River using all measured parameters.

The source of pollution identified in the study revealed that the point sources including the industrial effluents that contributed to the major pollutant were associated with the urban and domestic wastewater. The source of a number of physicochemical parameters was natural, associated with some anthropogenic activities, such as, hill cutting, deforestation and refilling for industrial expansion. Lower DO, and higher BOD, COD, ammoniacal nitrogen and phosphorus were due to the industrial activities, although a portion of ammoniacal nitrogen had come from non-point sources. Similarly, the sources of most heavy metals were the effluents from the industries that used metal or metal alloys. Beside the industrial pollution, the agricultural run-off, road-dust, exhausts vehicle fumes associated with natural sources also contribute to the heavy metal contamination.

8.1.2 Heavy Metal Contamination of Soil

Soil heavy metal contamination in and around the industrial area of Gebeng is the eventual result of rapid industrialisation at the area. A total of ten (10) selected heavy metals were analysed from 30 soil samples. The calculated geo-accumulation index revealed that four metals were found with toxic concentration of which, Arsenic (As) and Mercury (Hg) were polluting the whole area, while Cobalt and Lead (Pb) were polluting the industrial zone. Similarly, pollution load index PLI indicated that As and Hg were highly polluting, and Co, Pb and Ni were found polluting the industrial zone. The overall PLI value of more than 1.0 at the industrial zone indicated that the soil of the area was heavily polluted.

The results of source apportionment of heavy metal contamination revealed that the main causes of heavy metal contamination were the anthropogenic sources, such as industrial activities that produced and discharged wastewater into the soil. The industries (including chemical and metals) that used or produced respective metal or

metal alloys also generated metal effluent as by-products of wastes, were the possible sources of those contaminants. Sources of mercury were the wastewater from power plants and other industrial wastewater. Human induced causes also included road dust, vehicle fumes and mining activities. However, the contribution of natural sources to the heavy metal contamination and pollution in soil were not negligible.

8.1.3 Water Quality Modelling

QUAL2Kw water quality model was calibrated and validated with the data of dry and wet seasons respectively. The results showed that, the water quality parameters did not differ greatly from dry season to wet season. RMSE showed good match between observed and predicted value of all parameters except for ISS as the value of ISS differed significantly. The model was applied to simulate various water quality constituents. The model showed significant sensitivity to the change, over different model parameters. However, the model QUAL2Kw adequately represented the field data of Tunggak River.

The modelled data (simulation) from the QUAL2Kw modelling indicated that, the DO concentration was very low and due to the increase amount of wastewater, it would not be fixed without taking improved management based on the simulated results. Water quality control strategies were evaluated with pollution load modification, flow augmentation and imposing weirs in the river flow. The results investigated the strategy that combined pollution load modification with 20 mg/L BOD, flow augmentation and imposing three (3) weirs at critical locations would be applied to ensure better water quality for aquatic lives. It was noteworthy that the Environmental Quality (Industrial Effluent) Regulations 2009 that has proposed the discharging rate of BOD 20 mg/L and 6 kg/ day be used for the above-mentioned strategy. Therefore, proper execution of the Environmental Quality (Industrial Effluent) Regulations 2009, Malaysia along with the suggested strategy for the Tunggak River can be revived to ensure better quality and value of life for its water and its inhabitants.

However, this research contributes two major outcomes for the concerned stakeholder and for future research. It proposes a new approach of calculating water

quality index by adopting CCMEWQI for calculation and INWQS (DOE) classification system for water quality classification of the Tunggak River and it proposes a water quality control strategy to revive and control the water quality of the river by performing the QUAL2Kw water quality model.

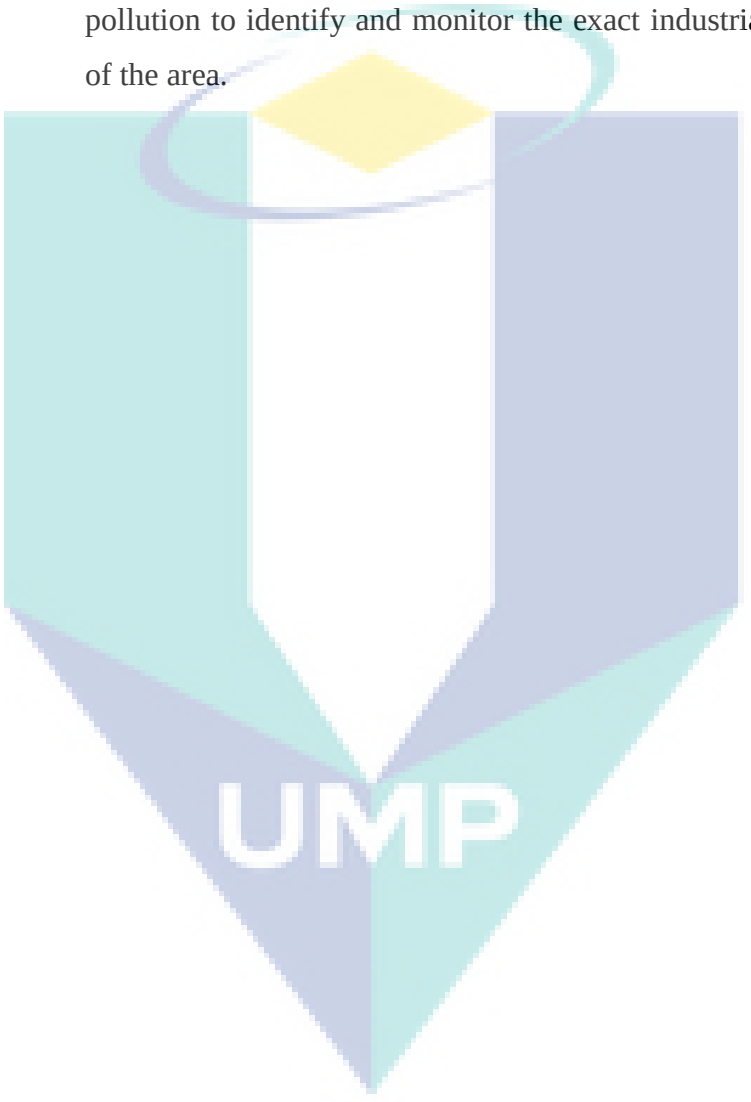
8.2 RECOMMENDATIONS

Gebeng industrial area is an emerging important area in peninsular Malaysia. Newly established rare-earth plant makes the city geo-politically important. Water as well as soil pollution started in the area since the inception of the industrial estate. However, to revive the environmental condition especially to protect the water quality and soil of the area the following recommendations may be applied:

1. The entire catchment area of Tunggak River including the industrial estate should bring under some form of unique management. Ideally, a bioregional approach should be adopted to protect the aquatic ecosystem and the remaining peat swamp forested catchment areas. To achieve this, it is necessary that a detailed useful plan for the area be drawn up and managed effectively.
2. Rapid industrialisation in the area promotes water and soil pollution that will be increases by the day. It is necessary to ensure a regular monitoring scheme. The present monitoring of DOE should be expanded to the whole catchment. A systematic catchment protection strategy in the form of a monitoring and evaluation system should be established in order to assess the water pollution, pollution source, pollution control strategies and catchment management. Therefore, it will be easy to take any necessary step to mitigate any emerging problem.
3. The industries should be compelled to obey the Environmental Quality (Industrial Effluent) Regulations 2009 strictly. The monitoring programme of DOE should include the matter in its monitoring schedule.
4. The water quality control strategy proposed by this study should be applied and further research should be conducted on the issues to improve the strategy.

5. This study is the first in-depth long-term study of the area that needs verification. Therefore, it is recommended that;

    a) A study should be conducted to integrate the hydrology and physicochemical variables in relation to the environmental health to sustain river ecosystem equilibrium;
    b) Integrated research should be conducted on air, water and soil pollution to identify and monitor the exact industrial pollution status of the area.



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APPENDIX A

INTERIM NATIONAL WATER QUALITY STANDARDS (INWQS) FOR MALAYSIA

Parameters	Unit	Water Classes					
		I	IIA	IIB	III	IV	V
Ammonical nitrogen	mg/L	0.1	0.3	0.3	0.9	2.7	> 2.7
BOD	mg/L	1	3	3	6	12	> 12
COD	mg/L	10	25	25	50	100	> 100
DO	mg/L	7	5-7	5-7	3-5	< 3	< 1
pH		6.5-8.5	6-9	6-9	5-9	5-9	-
Colour	TCU	15	150	150	-	-	-
Electrical conductivity*	umhos/cm	1000	1000	-	-	6000	-
Floatables		N	N	N	-	-	-
Odour		N	N	N	-	-	-
Salinity	(%)	0.5	1	-	-	2	-
Taste		N	N	N	-	-	-
Total Dissolved Solid	mg/L	500	1000	-	-	4000	-
Total Suspended Solid	mg/L	25	50	50	150	300	300
Temperature	℃	-	Normal +2 ℃	-	Normal +2 ℃	-	-
Turbidity	NTU	5	50	50	-	-	-
Faecal Coliform**	counts/100mL	10	100	400	5000 (20000)a	5000 (20000)a	-
Total Coliform	counts/100mL	100	5000	5000	50000	50000	<50000

Notes

N denotes: No visible floatable materials or debris; or
No objectionable odor; or
No objectionable taste

*denotes: Related parameters, only one recommended for use

**denotes: Geometric mean

a indicates: maximum not to be exceeded

Source: DOE (2008)

INTERIM NATIONAL WATER QUALITY STANDARDS (INWQS) FOR MALAYSIA

Parameters	Unit	Water Classes				
		I	IIA/IIB	III[#]	IV	V
Al	mg/L	N	-	(0.06	0.5	L
As	mg/L		0.05	0.4 (0.05)	0.1	
Ba	mg/L		1	-		
Cd	mg/L	A	0.01	0.01* (0.001)	0.01	E
Cr (IV)	mg/L		0.05	1.4 (0.05)	0.1	
Cr (III)	mg/L		-	2.5		
Cu	mg/L	T	0.02			V
Hardness	mg/L		250			
Ca	mg/L		-			
Mg	mg/L	U	-			E
Na	mg/L		-		3 SAR	
K	mg/L		-			
Fe	mg/L	R	1	1	1 (Leaf) 5 (Others)	L
Pb	mg/L		0.05	0.02* (0.01)	5	
Mn	mg/L	A	0.1	0.1	0.2	S
Hg	mg/L		0.001	0.004 (0.0001)	0.002	
Ni	mg/L		0.05	0.9*	0.2	
Se	mg/L	L	0.01	0.25 (0.04)	0.02	
Ag	mg/L		0.05	0.0002		
Sn	mg/L		-	0.004		A
U	Mg/L		-			
Zn	mg/L		5	0.4*	2	
B	mg/L	L	1	(3.4)	0.8	
Cl	mg/L		200		80	B
Cl2	mg/L		-	(0.02)		
CN	mg/L	E	0.02	0.06 (0.02)		
F	mg/L		1.5	10	1	O
NO2	mg/L		0.4	0.4 (0.03)	1	
NO3	mg/L	V	7		5	
P	mg/L		0.2	0.1		V
Silica	mg/L		50			
SO4	mg/L	E	250			
S	mg/L		0.05	(0.001)		E
CO2	mg/L		-			
Ra-226	Bg/L	L	-			
Sr-90	µg/L		0.05			
						IV

Source:(WEPA, 2008)

INTERIM NATIONAL WATER QUALITY STANDARDS (INWQS) FOR MALAYSIA

WATER CLASSES AND USES

Classes	Uses
Class I	Conservation of natural environment Water Supply I - Practically no treatment necessary Fishery I - Very sensitive aquatic species.
Class IA	Water Supply II - Conventional treatment. Fishery II - Sensitive aquatic species
Class IIB	Recreational use body contact
Class III	Water Supply III - Extensive treatment required. Fishery III - Common, of economic value and tolerant species; livestock drinking
Class IV	Irrigation
Class V	None of the above

Source: DOE (2008)

APPENDIX B

ACCEPTABLE CONDITIONS FOR DISCHARGE OF INDUSTRIAL EFFLUENT OR MIXED EFFLUENT OF STANDARDS A

SL No.	Parameter	Unit	Standard A
1.	Temperature	^{o}C	40
2.	pH Value	–	6.0-9.0
3.	BOD_5 at 20 °C	mg/L	20
4.	COD	mg/L	80
5.	COD (Fermentation and distillery industry)	mg/L	400
6.	Suspended Solids	mg/L	50
7.	Mercury	mg/L	0.005
8.	Cadmium	mg/L	0.01
9.	Chromium, Hexavalent	mg/L	0.05
10.	Chromium, Trivalent	mg/L	0.20
11.	Arsenic	mg/L	0.05
12.	Lead	mg/L	0.10
13.	Copper	mg/L	0.20
14.	Nickel	mg/L	0.20
15.	Zinc	mg/L	2.0
16.	Boron	mg/L	1.0
17.	Barium	mg/L	1.0
18.	Sulphide	mg/L	0.50
19.	Ammoniacal Nitrogen	mg/L	10

Source: Environmental Quality (Industrial Effluent) Regulation 2009, Ministry of Natural Resources and the Environment, Malaysia

APPENDIX C

LIST OF BEST -FIT EQUATIONS FOR THE ESTIMATION OF VARIOUS SUB-INDEX VALUES OF DOE-WQI

Parameters	Equations		SI Value (ranges)
Dissolved Oxygen (DO) (%DO)	SIDO	= 0	For $x \leq 8$
		= 100	For $x \geq 92$
		= - 0.395 + 0.03 x2 – 0.0002 x3	For $8 < x < 92$
Biochemical Oxygen Demand (BOD)(mg/L)	SIBOD	= 100.4 – 4.23 x	For $x \leq 5$
		= 108 e0.055x – 0.1 x	For $x > 5$
Chemical Oxygen Demand (COD)(mg/L)	SICOD	= - 1.33 x + 99.1	For $x \leq 20$
		= 103 e0.0157x – 0.04 x	For $x > 20$
Ammonical-nitrogen (AN)(mg/L)	SIAN	= 100.5 – 105 x	For $x \leq 0.3$
		= 94 e0.573x – 5 | x – 2 |	For $0.3 < x < 4$
		= 0	For $x \geq 4$
Suspended Solids (SS) (mg/L)	SISS	= 97.5 e0.00676x +0.05 x	For $x \leq 100$
		= 71 e0.0061x – 0.015 x	For $100 < x < 1000$
		= 0	For $x \geq 1000$
pH	SIPH	= 17.2 – 17.2 x + 5.02 x2	For $x < 5.5$
		= - 242 + 95.5 x – 6.67 x2	For $5.5 \leq x < 7$
		= - 181 + 82.4 x – 6.05 x2	For $7 \leq x < 8.75$
		= 536 – 77 x + 2.76 x2	For $x \geq 8.75$
WQI = 0.22 x SIDO + 0.19 x SIBOD + 0.16 x SICOD + 0.15 x SIAN + 0.16 x SISS + 0.12 x SIPH			

Note:
x = concentration of respective parameter (in mg/L except pH)
Source: Department of Environment, Malaysia, 1986

APPENDIX D

DOE-WATER QUALITY INDEX CLASSIFICATION

Parameters	Unit	Water Classes				
		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 - 7	5 - 6	< 5	> 5
Total Suspended Solid	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

Source: (WEPA, 2008)

APPENDIX E

MONTHLY AVERAGE TEMPERATURE (°C) AND PRECIPITATION (MM) OF GEBENG (KUANTAN), MALAYSIA DURING THE PERIOD OF FEBRUARY 2012-JANUARY 2013

Months	Average Temperature (°C)			Total Precipitation (mm)
	Mean	Maximum	Minimum	
February 2012	27.81	31.93	23.69	531
March 2012	27.66	31.81	23.52	382
April 2012	27.73	31.77	23.7	544
May 2012	27.95	31.84	24.06	586
June 2012	28.02	32.07	23.97	557
July 2012	26.92	30.48	23.35	1438
August 2012	27.03	30.84	23.23	1732
September 2012	27.28	31.13	23.43	1533
October 2012	27.79	31.58	24.00	1465
November 2012	27.38	31.03	23.73	788
December 2012	27.56	31.29	23.84	921
January 2013	27.84	31.81	23.87	113

Source: Malaysian Meteorological Department, Kuantan

APPENDIX F

LOCATION OF SOIL SAMPLING POINTS WITH THEIR GEOGRAPHICAL COORDINATES

Sampling zone	Station number	Sampling points	Geographical coordinates	Location
Residential cum semi-industrial Zone	1	1.	3°56'35"N & 103°22'32"E	Adjacent to the mangrove vegetation; near water sampling station 1 (DS)
		2.	3°56'45"N & 103°22'34"E	
		3.	3°56'48"N & 103°22'32"E	
	2	1.	3°57'00"N & 103°22'49"E	At the Kampung Seberang Balok (KSB)
		2.	3°57'07"N & 103°22'47"E	At the agricultural area near KSB
		3.	3°57'38"N & 103°23'15"E	In the middle of KSB
	3	1.	3°57'41"N & 103°23'13"E	Near the northern area of KSB; besides road
		2.	3°57'51"N & 103°23'24"E	At the southern side of Kampung Berahi
		3.	3°57'49"N & 103°23'18"E	At the southern side of Kampung Berahi
Industrial Zones	4	1.	3°57'57"N & 103°23'23"E	Adjacent to the Mieco furniture
		2.	3°58'12"N & 103°23'24"E	Adjacent to Asturi metal industry
		3.	3°58'11"N & 103°23'22"E	Near Hope mining
	5	1.	3°58'14"N & 103°23'21"E	Besides KNM metal industry
		2.	3°58'32"N & 103°23'18"E	Besides Cargil Palm products
		3.	3°58'31"N & 103°23'15"E	Besides MTBE
	6	1.	3°58'35"N & 103°23'19"E	Near to BP chemicals
		2.	3°58'57"N & 103°23'15"E	Adjacent to the BP chemical
		3.	3°59'12"N & 103°23'18"E	Near to the SHE Sdn. Bhd.

LOCATION OF SOIL SAMPLING POINTS WITH THEIR GEOGRAPHICAL COORDINATES

Sampling zone	Station number	Sampling points	Geographical coordinates	Location
Industrial Zones	7	1.	3°59'13"N & 103°23'16"E	Adjacent to the Eastman chemical industry
		2.	3°59'17"N & 103°23'16"E	Near to the upstream station
		3.	3°59'29"N & 103°23'43"E	Near to the Flexsys Chemical Sdn Bhd
Swampy Area	8	1.	3°59'23"N & 103°24'04"E	Near to the peat swamp forest
		2.	3°59'28"N & 103°24'12"E	
		3.	3°59'30"N & 103°24'14"E	
	9	1.	3°59'33"N & 103°24'34"E	Near to the peat swamp forest and at the tail of new phase of GIE
		2.	3°59'37"N & 103°24'40"E	
		3.	3°59'39"N & 103°24'36"E	
	10	1.	3°59'40"N & 103°24'46"E	Near to the port road and at the tail of the new phase of GIE
		2.	3°59'43"N & 103°24'41"E	
		3.	3°59'45"N & 103°24'47"E	

APPENDIX GI

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 1(DS)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Temperature (°C)	Mean	29.71	28.00	29.00	28.11	29.87	31.78	31.14	27.28
	SD	0.41	0.33	0.19	0.04	0.05	0.21	0.15	2.05
pH	Mean	6.69	5.83	6.72	6.33	6.18	6.8	6.65	6.99
	SD	0.32	0.15	0.05	0.27	0.06	0.09	0.06	0.55
Conductivity (µS/cm)	Mean	17450.00	18580.00	10330.00	14286.87	19870.00	5327.33	25223.33	1521
	SD	2448.49	7362.36	1005.83	649.33	173.49	54.50	126.62	34.70
Salinity (%)	Mean	9.07	7.99	5.54	9.71	10.63	2.50	15.19	0.73
	SD	1.42	0.29	0.41	3.50	0.07	0.05	0.17	0.22
TDS (mg/L)	Mean	9140.00	23133.33	41300.00	44766.67	72713.33	17693.33	102033.33	3710.00
	SD	99.50	1011.60	1473.09	4461.32	2171.30	667.11	4308.52	445.31
Turbidity (NTU)	Mean	22.17	11.15	9.52	13.35	20.09	55.57	38.63	563.67
	SD	0.29	3.41	1.20	1.47	7.66	6.72	2.59	166.57
TSS (mg/L)	Mean	36.00	58.33	20.67	7.67	24.67	35.67	23.33	310.67
	SD	1.00	14.74	6.11	1.53	3.51	3.21	3.79	37.90

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS OF WATER QUALITY OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 1(DS)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
DO mg/L)	Mean	2.96	2.97	2.06	2.64	2.02	3.04	3.39	6.32
	SD	0.35	0.56	0.45	0.91	0.10	0.07	0.33	0.06
BOD (mg/L)	Mean	7.83	3.23	11.90	8.90	12.90	7.30	6.05	10.23
	SD	2.46	0.29	0.95	0.23	0.17	1.91	0.55	2.06
COD (mg/L)	Mean	20.23	34.67	29.33	40.67	114.67	21.67	22.33	19.67
	SD	1.03	1.76	15.31	2.52	1.15	3.06	1.53	2.08
NH3-N (mg/L)	Mean	1.82	0.67	2.38	1.93	1.88	1.20	0.27	1.53
	SD	0.01	0.03	0.09	0.21	0.34	0.18	0.06	0.09
Nitrate-N (mg/L)	Mean	0.07	0.02	0.22	0.16	0.09	0.12	0.15	0.01
	SD	0.00	0.01	0.01	0.06	0.01	0.04	0.02	0.00
Phosphate (mg/L)	Mean	0.58	0.09	0.77	1.08	0.47	0.51	0.37	0.14
	SD	0.01	0.02	0.02	0.06	0.12	0.23	0.11	0.08
Sulphate (mg/L)	Mean	590.00	1160.00	383.33	423.33	666.67	196.67	1213.33	49.67
	SD	10.00	60.00	150.11	35.12	151.44	5.77	70.24	13.61

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS OF WATER QUALITY OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 1(DS)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Arsenic (ppm)	Mean	0.0096	0.0149	0.0127	0.0133	0.0256	0.0249	0.0194	0.0144
	SD	0.0082	0.0037	0.0032	0.0059	0.0032	0.0063	0.0095	0.0119
Barium (ppm)	Mean	0.0278	0.0303	0.0303	0.0938	0.0346	0.0219	0.0219	0.0525
	SD	0.0138	0.0001	0.0118	0.0054	0.0082	0.0029	0.0012	0.0105
Cadmium (ppm)	Mean	0.0111	0.0291	0.0302	0.0303	0.0018	0.0163	0.0111	0.0116
	SD	0.0087	0.0021	0.0002	0.0011	0.0009	0.0053	0.0010	0.0171
Chromium (ppm)	Mean	0.0347	0.0115	0.0079	0.0132	0.0412	0.0022	0.0046	0.1244
	SD	0.0574	0.0116	0.0028	0.0092	0.0232	0.0036	0.0024	0.0365
Cobalt (ppm)	Mean	0.0337	0.0926	0.0733	0.1161	0.0765	0.0171	0.0218	0.0294
	SD	0.0185	0.0139	0.0108	0.0065	0.0027	0.0027	0.0125	0.0188
Copper (ppm)	Mean	0.1185	0.4496	0.2028	0.1721	0.2126	0.1602	0.1331	0.1113
	SD	0.0251	0.1426	0.0171	0.0352	0.0150	0.0163	0.0111	0.0170
Mercury (ppb)	Mean	0.0726	0.0858	0.0844	0.0974	0.0907	0.0852	0.0755	0.0737
	SD	0.0094	0.0269	0.0040	0.0261	0.0264	0.0174	0.0145	0.0095
Nickel (ppm)	Mean	0.0491	0.0467	0.0600	0.0633	0.0620	0.0478	0.0604	0.0594
	SD	0.0081	0.0208	0.0265	0.0153	0.0072	0.0067	0.0095	0.0029
Lead (ppm)	Mean	0.0497	0.5415	0.1479	0.1292	0.0014	0.0794	0.0836	0.0795
	SD	0.0528	0.0525	0.0660	0.0050	0.0015	0.0680	0.0618	0.0411
Zinc (ppm)	Mean	1.1102	1.0718	1.1300	1.2753	1.2667	1.2721	1.2016	1.1379
	SD	0.0278	0.6478	0.2274	0.3072	0.1525	0.2203	0.0869	0.0906

APPENDIX GII

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 2(SB1)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Temperature (°C)	Mean	29.08	28.02	31.43	29.94	34.81	34.84	33.51	26.92
	SD	0.10	0.05	0.15	0.05	0.04	0.04	0.15	0.16
pH	Mean	7.57	6.92	7.27	7.77	7.11	7.35	6.68	6.45
	SD	0.20	0.13	0.11	0.17	0.18	0.10	0.06	0.17
Conductivity (µS/cm)	Mean	13440.33	8350.00	1270.00	1937.67	2643.00	786.67	6784.00	351.33
	SD	196.57	650.00	204.21	85.24	197.55	52.77	175.01	42.52
Salinity (%)	Mean	7.10	4.27	0.54	0.88	1.13	0.39	4.13	0.22
	SD	0.12	0.39	0.05	0.05	0.10	0.02	0.12	0.15
TDS (mg/L)	Mean	7240.00	5260.00	3486.67	6273.33	7253.33	2323.33	2187.67	907.00
	SD	29.51	140.00	353.03	96.09	671.14	560.92	285.58	132.25
Turbidity (NTU)	Mean	22.65	12.78	14.55	14.18	15.50	24.70	32.03	546.67
	SD	2.05	2.68	4.79	0.65	2.33	1.20	3.20	7.23
TSS (mg/L)	Mean	37.67	44.67	10.33	4.67	8.33	14.00	13.00	168.33
	SD	2.52	23.76	3.79	2.08	1.15	3.61	2.65	65.36

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS OF WATER QUALITY OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 2(SB1)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
DO mg/L)	Mean	1.25	1.91	3.54	1.60	3.18	6.26	2.84	5.30
	SD	0.18	0.26	0.14	0.16	0.11	0.09	0.88	0.01
BOD (mg/L)	Mean	15.33	6.37	35.73	24.42	19.05	8.77	12.53	8.95
	SD	0.28	0.28	0.15	0.64	0.74	0.08	0.90	0.22
COD (mg/L)	Mean	26.33	34.00	65.33	55.67	37.00	10.33	66.00	15.00
	SD	5.51	4.36	3.06	2.31	5.00	3.51	11.79	5.20
NH3-N (mg/L)	Mean	2.37	2.88	2.19	3.43	2.21	1.58	2.37	1.20
	SD	0.01	0.16	0.19	0.57	0.15	0.07	0.15	0.10
Nitrate-N (mg/L)	Mean	0.11	0.34	0.42	0.34	0.38	0.25	1.07	0.09
	SD	0.01	0.01	0.02	0.03	0.07	0.02	0.29	0.02
Phosphate (mg/L)	Mean	2.06	0.64	0.61	1.28	0.56	0.74	1.75	0.38
	SD	0.01	0.04	0.03	0.03	0.10	0.40	0.03	0.39
Sulphate (mg/L)	Mean	60.33	316.67	57.33	59.00	296.67	49.00	226.67	22.67
	SD	1.15	2.89	6.03	1.00	332.01	5.29	55.08	12.50

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 2(SB1)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Arsenic (ppm)	Mean	0.0088	0.0087	0.0088	0.0089	0.0074	0.0085	0.0073	0.0086
	SD	0.0025	0.0033	0.0010	0.0019	0.0025	0.0023	0.0023	0.0023
Barium (ppm)	Mean	0.0203	0.0000	0.0291	0.0829	0.0339	0.0215	0.0194	0.0297
	SD	0.0022	0.0000	0.0028	0.0034	0.0054	0.0032	0.0049	0.0069
Cadmium (ppm)	Mean	0.0185	0.0266	0.0256	0.0295	0.0040	0.0092	0.0083	0.0206
	SD	0.0062	0.0031	0.0011	0.0016	0.0011	0.0065	0.0063	0.0137
Chromium (ppm)	Mean	0.0055	0.0007	0.0012	0.0013	0.0393	0.0006	0.0018	0.0356
	SD	0.0090	0.0002	0.0003	0.0004	0.0307	0.0004	0.0025	0.0199
Cobalt (ppm)	Mean	0.0261	0.2243	0.1148	0.1803	0.0734	0.0248	0.0197	0.0193
	SD	0.0186	0.0051	0.0131	0.0010	0.0391	0.0216	0.0237	0.0230
Copper (ppm)	Mean	0.0244	0.0099	0.0300	0.0373	0.0290	0.0260	0.0267	0.0209
	SD	0.0072	0.0002	0.0022	0.0102	0.0112	0.0137	0.0095	0.0060
Mercury (ppb)	Mean	0.0787	0.0813	0.0883	0.0911	0.0916	0.0816	0.0783	0.0683
	SD	0.0087	0.0177	0.0044	0.0100	0.0097	0.0120	0.0125	0.0056
Nickel (ppm)	Mean	0.0503	0.0564	0.0503	0.0590	0.0643	0.0568	0.0607	0.0521
	SD	0.0065	0.0118	0.0055	0.0052	0.0083	0.0139	0.0090	0.0168
Lead (ppm)	Mean	0.0467	0.4956	0.0292	0.1215	0.0073	0.0524	0.0558	0.0514
	SD	0.0202	0.0079	0.0016	0.0013	0.0032	0.0600	0.0670	0.0361
Zinc (ppm)	Mean	0.8517	0.9441	0.9416	1.0261	1.0482	1.0226	0.8850	0.8267
	SD	0.1258	0.1961	0.1090	0.1720	0.1045	0.0876	0.0278	0.1198

APPENDIX GIII

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 3(SB2)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Temperature (°C)	Mean	29.68	29.03	31.81	31.58	33.15	32.76	32.64	27.40
	SD	0.19	0.03	0.88	0.42	0.10	0.21	0.41	0.46
pH	Mean	7.90	7.48	7.48	7.60	7.18	7.42	6.69	6.67
	SD	0.43	0.20	0.10	0.15	0.24	0.22	0.19	0.07
Conductivity (µS/cm)	Mean	1860.00	1272.33	1046.67	1499.00	1049.00	521.67	1805.67	170.67
	SD	55.68	25.15	158.85	177.55	54.34	17.39	397.81	2.08
Salinity (%)	Mean	0.85	0.58	0.46	0.66	0.39	0.25	1.52	0.08
	SD	0.02	0.01	0.08	0.06	0.11	0.01	0.29	0.00
TDS (mg/L)	Mean	868.67	665.67	2503.33	4426.67	3060.00	1507.67	4313.33	505.00
	SD	0.58	16.01	245.83	400.79	310.97	57.74	210.32	5.20
Turbidity (NTU)	Mean	13.81	13.59	14.59	14.65	20.56	21.47	29.80	234.33
	SD	0.08	6.16	7.16	1.03	7.50	8.12	1.30	14.84
TSS (mg/L)	Mean	11.00	17.33	5.33	8.00	9.33	20.33	14.33	135.67
	SD	1.00	2.31	1.53	5.29	4.93	1.53	7.64	64.53

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS OF WATER QUALITY OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 3(SB2)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
DO mg/L)	Mean	1.52	2.55	6.21	4.25	1.94	6.06	3.45	5.97
	SD	0.25	1.60	0.61	0.18	1.14	0.56	0.41	0.12
BOD (mg/L)	Mean	29.22	8.65	36.40	23.32	25.52	7.67	10.45	8.62
	SD	2.00	0.20	0.92	3.04	3.78	0.71	1.03	0.03
COD (mg/L)	Mean	36.67	17.33	66.00	60.33	47.33	6.33	43.67	10.67
	SD	2.31	3.79	5.29	8.74	8.08	3.06	0.58	3.79
NH3-N (mg/L)	Mean	3.27	3.83	1.24	2.80	1.97	1.47	1.43	0.94
	SD	0.06	0.26	0.45	0.89	0.75	0.30	0.22	0.11
Nitrate-N (mg/L)	Mean	0.01	0.45	0.44	0.39	0.15	0.21	1.77	0.12
	SD	0.01	0.00	0.01	0.27	0.02	0.01	0.47	0.05
Phosphate (mg/L)	Mean	1.73	1.06	0.79	0.85	0.74	0.44	1.41	0.12
	SD	0.01	0.04	0.58	0.09	0.44	0.11	0.08	0.01
Sulphate (mg/L)	Mean	66.00	21.00	45.00	126.67	41.67	46.00	51.00	11.00
	SD	1.00	1.00	14.80	11.55	1.53	6.08	1.73	0.00

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 3 (SB2)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Arsenic (ppm)	Mean	0.0063	0.0065	0.0066	0.0070	0.0071	0.0067	0.0070	0.0070
	SD	0.0005	0.0010	0.0013	0.0017	0.0013	0.0012	0.0017	0.0017
Barium (ppm)	Mean	0.0281	0.0000	0.0282	0.0900	0.0372	0.0262	0.0244	0.0282
	SD	0.0025	0.0000	0.0078	0.0056	0.0057	0.0037	0.0017	0.0032
Cadmium (ppm)	Mean	0.0048	0.0000	0.0100	0.0129	0.0019	0.0026	0.0061	0.0053
	SD	0.0019	0.0000	0.0001	0.0006	0.0016	0.0008	0.0052	0.0068
Chromium (ppm)	Mean	0.0035	0.0007	0.0009	0.0010	0.0101	0.0006	0.0020	0.0145
	SD	0.0057	0.0001	0.0003	0.0003	0.0077	0.0004	0.0011	0.0076
Cobalt (ppm)	Mean	0.1533	0.1740	0.2005	0.2337	0.2036	0.1359	0.1251	0.1170
	SD	0.0510	0.0095	0.0524	0.0314	0.0070	0.0071	0.0147	0.0831
Copper (ppm)	Mean	0.0184	0.0052	0.0146	0.0172	0.0391	0.0511	0.0184	0.0182
	SD	0.0123	0.0036	0.0041	0.0062	0.0550	0.0471	0.0193	0.0185
Mercury (ppb)	Mean	0.0663	0.0793	0.0782	0.0923	0.0772	0.0754	0.0649	0.0651
	SD	0.0240	0.0179	0.0139	0.0438	0.0217	0.0209	0.0175	0.0107
Nickel (ppm)	Mean	0.0693	0.0753	0.0757	0.0807	0.0827	0.0640	0.0827	0.0783
	SD	0.0115	0.0175	0.0140	0.0045	0.0065	0.0106	0.0065	0.0040
Lead (ppm)	Mean	0.0414	0.4827	0.0099	0.1106	0.0003	0.0390	0.0765	0.0372
	SD	0.0669	0.0103	0.0081	0.0081	0.0003	0.0621	0.0663	0.0637
Zinc (ppm)	Mean	0.3332	0.3431	0.3754	0.3978	0.4587	0.4310	0.4065	0.2976
	SD	0.0973	0.5528	0.4385	0.0151	0.4522	0.3294	0.0983	0.1013

APPENDIX GIV

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 4 (IZ1)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Temperature (°C)	Mean	32.40	31.07	31.03	31.77	30.67	31.28	28.75	27.43
	SD	0.24	0.14	0.03	0.04	0.08	0.04	0.03	0.21
pH	Mean	8.21	7.68	7.71	7.63	7.99	7.02	6.41	6.75
	SD	0.27	0.17	0.10	0.24	0.30	0.06	0.35	0.04
Conductivity (µS/cm)	Mean	1300.00	1127.00	886.67	1748.00	785.33	427.33	938.67	146.00
	SD	36.06	7.55	5.77	7.00	253.21	92.09	36.02	9.54
Salinity (%)	Mean	0.55	0.49	0.39	0.77	0.34	0.22	0.32	0.05
	SD	0.01	0.00	0.01	0.01	0.12	0.01	0.27	0.03
TDS (mg/L)	Mean	600.33	625.67	2490.00	5233.33	2696.67	1484.67	3300.00	474.00
	SD	2.52	169.17	43.59	85.05	11.55	3.51	260.58	19.31
Turbidity (NTU)	Mean	17.22	11.06	8.73	10.94	18.53	20.37	30.23	163.67
	SD	0.05	0.87	0.63	0.60	0.63	6.83	1.90	20.11
TSS (mg/L)	Mean	16.67	12.33	4.67	6.67	10.00	9.00	12.00	69.33
	SD	4.04	0.58	1.53	2.31	2.65	11.27	4.00	3.51

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS OF WATER QUALITY OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 4(IZ1)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
DO mg/L)	Mean	1.96	3.45	7.00	5.38	4.89	5.70	3.93	6.03
	SD	0.41	0.68	0.10	0.03	0.83	0.02	0.22	0.12
BOD (mg/L)	Mean	28.07	9.30	37.42	20.63	27.50	7.37	11.98	8.78
	SD	0.61	0.25	0.08	0.40	1.74	0.58	0.54	0.33
COD (mg/L)	Mean	46.67	24.00	66.67	50.33	48.33	8.67	46.00	12.00
	SD	4.51	3.00	1.53	0.58	4.16	3.51	9.64	3.46
NH3-N (mg/L)	Mean	1.22	3.15	1.12	2.29	1.81	1.19	1.38	0.76
	SD	0.01	0.10	0.04	0.04	0.01	0.04	0.05	0.05
Nitrate-N (mg/L)	Mean	0.01	2.30	0.50	0.36	0.15	0.22	2.50	0.17
	SD	0.00	0.53	0.01	0.03	0.05	0.01	0.17	0.03
Phosphate (mg/L)	Mean	1.20	0.57	0.30	0.43	0.15	0.67	1.88	0.14
	SD	0.01	0.02	0.01	0.02	0.03	0.46	0.08	0.05
Sulphate (mg/L)	Mean	69.33	21.33	42.67	243.33	36.00	41.33	43.00	9.33
	SD	0.58	1.53	11.85	15.28	4.58	0.58	1.00	0.58

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 4 (IZ1)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Arsenic (ppm)	Mean	0.0075	0.0062	0.0067	0.0073	0.0075	0.0071	0.0079	0.0079
	SD	0.0007	0.0002	0.0015	0.0010	0.0013	0.0011	0.0007	0.0007
Barium (ppm)	Mean	0.0249	0.0000	0.0236	0.1036	0.0431	0.0301	0.0300	0.0215
	SD	0.0058	0.0000	0.0034	0.0126	0.0087	0.0062	0.0025	0.0038
Cadmium (ppm)	Mean	0.0044	0.0197	0.0209	0.0292	0.0010	0.0016	0.0035	0.0010
	SD	0.0043	0.0010	0.0011	0.0008	0.0010	0.0003	0.0051	0.0010
Chromium (ppm)	Mean	0.0054	0.0025	0.0049	0.0064	0.0790	0.0023	0.0345	0.0174
	SD	0.0033	0.0005	0.0016	0.0009	0.0179	0.0027	0.0538	0.0147
Cobalt (ppm)	Mean	0.3916	0.2502	0.1733	0.3201	0.4731	0.4090	0.4303	0.4022
	SD	0.0387	0.0059	0.0602	0.0227	0.0436	0.0441	0.0176	0.0242
Copper (ppm)	Mean	0.0087	0.0124	0.0202	0.0206	0.0133	0.0093	0.0100	0.0097
	SD	0.0025	0.0055	0.0014	0.0097	0.0093	0.0042	0.0036	0.0040
Mercury (ppb)	Mean	0.0462	0.0483	0.0486	0.0491	0.0508	0.0461	0.0455	0.0452
	SD	0.0045	0.0033	0.0018	0.0071	0.0044	0.0044	0.0046	0.0053
Nickel (ppm)	Mean	0.0629	0.0797	0.0737	0.0780	0.0783	0.0630	0.0912	0.0860
	SD	0.0168	0.0168	0.0219	0.0135	0.0110	0.0400	0.0191	0.0104
Lead (ppm)	Mean	0.0376	0.4801	0.0076	0.1346	0.0008	0.0546	0.0495	0.0323
	SD	0.0509	0.0136	0.0076	0.0121	0.0001	0.0802	0.0843	0.0548
Zinc (ppm)	Mean	0.5472	0.4778	0.5144	0.5951	0.8478	0.6575	0.6542	0.4209
	SD	0.3215	0.3996	0.3642	0.3462	0.2274	0.3157	0.2628	0.4492

APPENDIX GV

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 5 (IZ2)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Temperature (°C)	Mean	33.01	31.01	30.57	30.97	30.84	30.46	29.26	27.86
	SD	0.08	0.08	0.20	0.10	0.12	0.18	0.07	0.21
pH	Mean	8.86	7.06	7.50	7.37	8.11	5.95	7.04	6.50
	SD	0.08	0.13	0.11	0.07	0.28	0.29	0.03	0.05
Conductivity (µS/cm)	Mean	1600.00	1409.00	853.33	1835.00	955.00	502.33	829.67	226.67
	SD	26.46	26.21	20.82	65.00	19.52	2.08	58.05	1.53
Salinity (%)	Mean	0.69	0.61	0.38	0.82	0.41	0.24	0.40	0.10
	SD	0.01	0.02	0.01	0.03	0.02	0.00	0.04	0.01
TDS (mg/L)	Mean	745.33	655.00	2256.67	4903.33	2736.67	1562.33	2476.00	686.33
	SD	2.52	15.39	213.62	230.94	32.15	13.43	544.23	17.04
Turbidity (NTU)	Mean	34.40	12.47	9.83	132.00	22.75	24.33	20.18	215.50
	SD	0.10	1.05	1.29	59.10	4.25	1.72	2.53	130.46
TSS (mg/L)	Mean	17.67	19.67	19.00	65.67	11.33	18.67	12.33	40.00
	SD	0.58	2.89	6.08	1.53	4.51	2.52	7.51	8.72

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS OF WATER QUALITY OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 5 (IZ2)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
DO mg/L)	Mean	2.37	3.87	4.09	2.93	1.23	6.13	3.43	5.70
	SD	0.64	0.06	0.02	0.09	0.42	0.10	0.50	0.01
BOD (mg/L)	Mean	28.05	10.22	36.67	25.98	36.97	7.30	16.10	11.17
	SD	0.58	0.40	0.20	0.55	0.23	1.43	1.40	0.58
COD (mg/L)	Mean	53.67	23.33	66.67	73.00	103.67	16.33	41.33	22.00
	SD	2.08	0.58	10.41	16.64	6.66	8.50	7.77	2.65
NH3-N (mg/L)	Mean	1.29	3.05	0.87	2.10	1.37	1.06	1.28	0.52
	SD	0.01	0.30	0.20	0.11	0.03	0.05	0.53	0.08
Nitrate-N (mg/L)	Mean	0.01	4.07	0.38	0.30	0.01	0.26	2.87	0.18
	SD	0.01	0.75	0.01	0.06	0.00	0.06	0.72	0.06
Phosphate (mg/L)	Mean	1.49	0.37	0.28	1.10	0.21	0.49	1.93	0.22
	SD	0.05	0.03	0.05	0.26	0.02	0.25	0.42	0.21
Sulphate (mg/L)	Mean	37.67	60.00	47.33	300.00	38.67	44.33	35.33	37.33
	SD	0.58	3.00	4.62	17.32	1.15	1.15	9.61	3.79

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 5 (IZ2)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Arsenic (ppm)	Mean	0.0056	0.0057	0.0054	0.0036	0.0029	0.0036	0.0076	0.0053
	SD	0.0010	0.0009	0.0009	0.0036	0.0050	0.0036	0.0009	0.0046
Barium (ppm)	Mean	0.0229	0.0000	0.0503	0.1116	0.0344	0.0242	0.0259	0.0247
	SD	0.0062	0.0000	0.0378	0.0119	0.0081	0.0036	0.0057	0.0147
Cadmium (ppm)	Mean	0.0169	0.0280	0.0284	0.0285	0.0003	0.0009	0.0133	0.0180
	SD	0.0026	0.0013	0.0014	0.0027	0.0005	0.0001	0.0126	0.0156
Chromium (ppm)	Mean	0.0017	0.0102	0.0123	0.0134	0.0312	0.0026	0.0076	0.0053
	SD	0.0013	0.0085	0.0013	0.0037	0.0003	0.0029	0.0056	0.0064
Cobalt (ppm)	Mean	0.5608	0.6191	0.3571	0.2944	0.5738	0.4205	0.4381	0.4169
	SD	0.0319	0.0532	0.0560	0.0242	0.0235	0.1456	0.1661	0.1859
Copper (ppm)	Mean	0.0117	0.0219	0.0268	0.0361	0.0126	0.0122	0.0129	0.0146
	SD	0.0038	0.0113	0.0060	0.0089	0.0030	0.0034	0.0033	0.0045
Mercury (ppb)	Mean	0.1724	0.1945	0.2137	0.2104	0.2111	0.2021	0.1895	0.1748
	SD	0.0117	0.0235	0.0820	0.0778	0.0783	0.0695	0.0791	0.0456
Nickel (ppm)	Mean	0.0769	0.0919	0.0893	0.0893	0.0897	0.0643	0.0731	0.0571
	SD	0.0260	0.0064	0.0015	0.0025	0.0064	0.0391	0.0323	0.0387
Lead (ppm)	Mean	0.0391	0.4937	0.0096	0.1287	0.0007	0.0466	0.0875	0.0419
	SD	0.0485	0.0141	0.0077	0.0039	0.0006	0.0677	0.0751	0.0715
Zinc (ppm)	Mean	0.7823	1.9435	1.3665	1.6718	1.3998	1.0578	1.0554	0.7148
	SD	0.5084	1.3446	0.5393	0.3497	0.5023	0.1204	0.0933	0.5164

APPENDIX GVI

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 6 (IZ3)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Temperature (°C)	Mean	34.12	31.64	31.46	37.39	31.89	28.40	30.02	28.05
	SD	0.02	0.01	0.01	1.14	0.01	0.01	0.07	0.25
pH	Mean	8.67	7.36	7.82	7.38	8.04	6.66	7.34	6.52
	SD	0.39	0.12	0.07	0.11	0.05	0.10	0.10	0.10
Conductivity (µS/cm)	Mean	1730.00	1435.00	1130.00	2478.33	831.67	387.00	1124.67	228.67
	SD	12.49	13.11	0.00	7.64	331.11	155.20	3.51	7.51
Salinity (%)	Mean	0.73	0.63	0.49	1.11	0.35	0.15	0.50	0.09
	SD	0.00	0.01	0.00	0.00	0.14	0.13	0.00	0.01
TDS (mg/L)	Mean	776.67	652.33	3143.33	7533.33	3580.00	1750.33	3236.67	81800.00
	SD	0.58	3.51	5.77	66.58	17.32	1.53	11.55	5230.68
Turbidity (NTU)	Mean	28.15	13.82	9.55	16.09	30.57	26.50	34.53	1489.67
	SD	0.63	2.47	0.53	4.82	3.72	1.00	6.25	50.30
TSS (mg/L)	Mean	16.33	16.67	5.33	18.33	14.67	22.33	17.00	479.33
	SD	0.58	0.58	3.06	5.13	2.89	4.93	11.36	34.27

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS OF WATER QUALITY OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 6 (IZ3)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
DO mg/L)	Mean	1.61	3.02	2.37	1.70	0.75	5.01	2.44	5.69
	SD	0.05	0.23	0.06	0.06	0.06	0.21	0.18	0.09
BOD (mg/L)	Mean	27.47	9.05	35.27	34.25	37.22	8.80	10.08	9.12
	SD	1.58	1.18	0.25	0.95	0.35	0.26	0.41	0.26
COD (mg/L)	Mean	54.67	34.00	47.67	87.00	137.00	12.00	49.67	13.33
	SD	0.58	1.73	2.31	1.73	4.36	6.24	15.04	5.03
NH3-N (mg/L)	Mean	0.88	3.33	0.32	1.82	1.51	0.86	1.15	2.50
	SD	0.01	0.03	0.01	0.01	0.01	0.10	0.05	0.26
Nitrate-N (mg/L)	Mean	0.00	2.77	1.37	1.33	0.01	0.31	2.47	0.06
	SD	0.01	0.95	0.15	0.06	0.00	0.04	0.67	0.04
Phosphate (mg/L)	Mean	1.03	0.65	0.17	0.47	0.28	0.12	2.73	0.02
	SD	0.01	0.05	0.02	0.05	0.08	0.01	0.45	0.01
Sulphate (mg/L)	Mean	38.33	18.33	53.00	423.33	30.67	48.33	49.67	18.33
	SD	0.58	1.53	0.00	5.77	3.21	2.52	8.08	7.23

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 6 (IZ3)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Arsenic (ppm)	Mean	0.0113	0.0099	0.0102	0.0118	0.0099	0.0099	0.0068	0.0106
	SD	0.0083	0.0010	0.0011	0.0066	0.0092	0.0092	0.0024	0.0086
Barium (ppm)	Mean	0.0150	0.0031	0.0256	0.0976	0.0274	0.0145	0.0130	0.0201
	SD	0.0065	0.0053	0.0095	0.0009	0.0023	0.0032	0.0027	0.0044
Cadmium (ppm)	Mean	0.1095	0.2867	0.2972	0.3003	0.0023	0.0048	0.0048	0.0914
	SD	0.0145	0.0283	0.0151	0.0268	0.0016	0.0034	0.0043	0.1541
Chromium (ppm)	Mean	0.0035	0.0007	0.0008	0.0008	0.0183	0.0006	0.0040	0.0034
	SD	0.0049	0.0001	0.0002	0.0002	0.0068	0.0003	0.0045	0.0049
Cobalt (ppm)	Mean	0.7181	0.6716	0.7561	0.7168	0.8837	0.8249	0.8329	0.6620
	SD	0.0787	0.0263	0.1274	0.0479	0.0447	0.0451	0.3478	0.4953
Copper (ppm)	Mean	0.0120	0.0299	0.0307	0.0310	0.0153	0.0133	0.0153	0.0114
	SD	0.0016	0.0002	0.0009	0.0075	0.0042	0.0034	0.0042	0.0013
Mercury (ppb)	Mean	0.0618	0.0596	0.0622	0.0661	0.0660	0.0645	0.0599	0.0606
	SD	0.0027	0.0046	0.0051	0.0024	0.0024	0.0020	0.0012	0.0037
Nickel (ppm)	Mean	0.0827	0.0780	0.0827	0.0840	0.0853	0.0800	0.0853	0.0840
	SD	0.0045	0.0101	0.0047	0.0066	0.0067	0.0026	0.0067	0.0066
Lead (ppm)	Mean	0.0306	0.2323	0.0244	0.1209	0.0010	0.0453	0.0405	0.0350
	SD	0.0009	0.0122	0.0164	0.0039	0.0008	0.0693	0.0691	0.0500
Zinc (ppm)	Mean	0.7915	0.8404	0.8544	0.8519	0.9210	0.7956	0.7881	0.7466
	SD	0.0990	0.4224	0.4254	0.0503	0.0668	0.1114	0.1044	0.2532

APPENDIX GVII

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 7 (IZ4)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Temperature (°C)	Mean	33.24	34.33	32.66	33.43	28.09	30.72	30.34	27.62
	SD	0.06	1.01	0.01	0.08	0.07	0.01	0.03	0.12
pH	Mean	7.95	7.36	7.04	7.15	6.08	6.84	7.15	6.10
	SD	0.58	0.62	0.50	0.35	0.95	0.63	0.39	0.36
Conductivity (µS/cm)	Mean	1203.00	932.33	930.00	513.33	214.67	78.67	284.67	47.33
	SD	11.27	8.14	20.00	6.81	4.04	0.58	1.53	0.58
Salinity (%)	Mean	0.51	0.17	0.40	0.21	0.09	0.04	0.12	0.02
	SD	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00
TDS (mg/L)	Mean	521.67	208.67	2260.00	1347.00	603.33	228.67	817.00	129.63
	SD	7.51	4.93	26.46	19.16	8.74	0.58	11.79	1.40
Turbidity (NTU)	Mean	11.76	7.88	6.36	8.51	5.62	18.78	780.33	32.07
	SD	0.59	1.24	0.36	2.30	0.21	1.01	58.94	12.50
TSS (mg/L)	Mean	15.67	13.67	10.00	9.67	9.33	5.33	2123.67	10.00
	SD	4.16	3.21	1.73	1.53	0.58	2.08	45.61	11.27

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS OF WATER QUALITY OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 7 (IZ4)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
DO mg/L)	Mean	2.84	3.72	5.90	4.95	5.71	6.03	6.03	4.11
	SD	0.03	0.26	0.10	0.31	0.16	0.06	0.18	0.12
BOD (mg/L)	Mean	32.53	33.22	37.88	38.30	37.90	7.62	21.50	7.82
	SD	0.28	0.40	0.20	0.05	0.35	0.35	1.71	1.10
COD (mg/L)	Mean	69.67	103.00	103.33	106.00	38.00	4.00	26.00	26.67
	SD	10.02	16.82	7.51	7.00	6.08	3.61	3.46	0.58
NH3-N (mg/L)	Mean	1.75	0.94	1.70	1.60	0.97	0.81	1.08	0.58
	SD	0.01	0.07	0.03	0.02	0.02	0.07	0.16	0.01
Nitrate-N (mg/L)	Mean	0.41	0.02	0.13	0.00	0.18	0.05	0.14	0.00
	SD	0.01	0.01	0.05	0.00	0.01	0.01	0.09	0.00
Phosphate (mg/L)	Mean	0.08	0.06	0.09	0.08	0.06	0.07	0.51	0.05
	SD	0.00	0.01	0.01	0.02	0.05	0.01	0.78	0.01
Sulphate (mg/L)	Mean	334.67	176.67	280.00	673.33	49.33	15.00	51.00	1.00
	SD	4.51	6.51	1.00	5.77	1.15	0.00	6.93	0.00

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 7 (IZ4)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Arsenic (ppm)	Mean	0.3200	0.0085	0.0082	0.0089	0.0068	0.0075	0.5301	0.3653
	SD	0.2767	0.0016	0.0011	0.0011	0.0037	0.0016	0.0573	0.2007
Barium (ppm)	Mean	0.0072	0.0092	0.0196	0.0657	0.0280	0.0145	0.1087	0.0083
	SD	0.0005	0.0154	0.0064	0.0009	0.0080	0.0039	0.0353	0.0049
Cadmium (ppm)	Mean	0.0262	0.0270	0.0273	0.0284	0.0048	0.0127	0.0127	0.0200
	SD	0.0217	0.0017	0.0009	0.0004	0.0012	0.0021	0.0010	0.0142
Chromium (ppm)	Mean	0.0940	0.0395	0.0330	0.0389	0.0248	0.0075	0.1095	0.0974
	SD	0.1444	0.0622	0.0141	0.0048	0.0300	0.0082	0.1311	0.1415
Cobalt (ppm)	Mean	0.0092	0.0076	0.0074	0.0183	0.0015	0.0239	0.0160	0.0155
	SD	0.0127	0.0056	0.0059	0.0004	0.0003	0.0000	0.0122	0.0118
Copper (ppm)	Mean	0.2047	0.4496	0.4886	0.5064	0.0070	0.0040	0.2827	0.1955
	SD	0.1028	0.1426	0.3076	0.0679	0.0047	0.0056	0.0492	0.1606
Mercury (ppb)	Mean	0.0682	0.0593	0.0597	0.0601	0.0623	0.0540	0.0669	0.0640
	SD	0.0097	0.0032	0.0014	0.0171	0.0164	0.0073	0.0084	0.0028
Nickel (ppm)	Mean	0.0717	0.0657	0.0637	0.0643	0.0690	0.0667	0.0736	0.0663
	SD	0.0033	0.0120	0.0086	0.0040	0.0020	0.0065	0.0361	0.0057
Lead (ppm)	Mean	0.2233	0.2349	0.4711	0.1190	0.0012	0.0791	1.1504	0.0772
	SD	0.1077	0.0118	0.1059	0.0078	0.0004	0.0677	0.1859	0.0654
Zinc (ppm)	Mean	0.5798	1.0003	1.0372	1.0712	0.9405	0.8256	0.6292	0.6112
	SD	0.2067	0.5560	0.2550	0.1307	0.0150	0.1344	0.3157	0.3975

APPENDIX GVIII

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 8 (US1)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Temperature (°C)	Mean	33.08	33.43	33.56	33.73	28.78	28.53	29.18	26.65
	SD	0.15	0.83	0.46	0.05	0.04	0.19	0.11	0.38
pH	Mean	5.18	4.73	4.70	5.26	4.45	4.67	4.85	5.04
	SD	0.22	0.09	0.08	0.08	0.23	0.70	0.16	0.66
Conductivity (µS/cm)	Mean	52.67	57.67	48.33	220.00	118.33	54.00	57.00	34.67
	SD	2.89	0.58	0.58	13.00	3.51	0.00	1.00	0.58
Salinity (%)	Mean	0.02	0.02	0.02	0.09	0.05	0.02	0.02	0.01
	SD	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
TDS (mg/L)	Mean	19.80	23.77	112.57	553.33	310.67	151.07	108.53	92.90
	SD	0.20	0.91	0.91	82.21	6.66	2.10	64.98	0.30
Turbidity (NTU)	Mean	6.34	6.85	5.12	18.37	25.73	23.00	19.72	36.77
	SD	0.31	2.81	0.74	3.86	11.82	0.36	13.27	19.51
TSS (mg/L)	Mean	10.00	13.67	12.00	10.00	18.33	5.67	26.33	3.00
	SD	1.00	3.21	6.24	3.00	8.14	2.08	16.26	1.00

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS OF WATER QUALITY OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 8 (US1)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
DO mg/L)	Mean	3.87	2.89	2.48	2.04	5.59	3.32	1.36	3.40
	SD	0.35	0.12	0.22	0.16	0.12	0.35	0.37	0.65
BOD (mg/L)	Mean	11.58	1.60	15.95	20.47	13.75	5.23	8.00	6.17
	SD	1.56	0.39	0.26	3.67	0.44	0.48	0.61	0.16
COD (mg/L)	Mean	28.67	24.33	24.67	63.33	34.00	8.00	65.67	31.33
	SD	0.58	3.21	1.53	12.70	2.00	6.08	4.04	2.31
NH3-N (mg/L)	Mean	1.71	1.32	1.44	2.15	1.73	0.65	1.87	0.65
	SD	0.01	0.31	0.01	0.11	0.04	0.07	0.03	0.01
Nitrate-N (mg/L)	Mean	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
	SD	0.01	0.01	0.00	0.00	0.00	0.02	0.00	0.00
Phosphate (mg/L)	Mean	0.02	0.03	0.02	0.04	0.03	0.04	0.03	0.09
	SD	0.00	0.01	0.01	0.02	0.01	0.00	0.03	0.04
Sulphate (mg/L)	Mean	6.33	3.67	0.00	46.33	31.00	8.67	10.67	0.00
	SD	0.58	1.53	0.00	5.69	4.58	0.58	0.58	0.00

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 8 (US1)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Arsenic (ppm)	Mean	0.0035	0.0038	0.0030	0.0030	0.0041	0.0040	0.0033	0.0034
	SD	0.0009	0.0020	0.0012	0.0019	0.0035	0.0036	0.0014	0.0024
Barium (ppm)	Mean	0.0043	0.0039	0.0072	0.0711	0.0239	0.0136	0.0065	0.0070
	SD	0.0031	0.0064	0.0041	0.0145	0.0064	0.0036	0.0044	0.0029
Cadmium (ppm)	Mean	0.0179	0.0333	0.0333	0.0328	0.0021	0.0208	0.0125	0.0125
	SD	0.0158	0.0011	0.0013	0.0013	0.0021	0.0003	0.0171	0.0171
Chromium (ppm)	Mean	0.0323	0.0575	0.0277	0.0297	0.0523	0.0125	0.0234	0.0233
	SD	0.0177	0.0276	0.0068	0.0095	0.0030	0.0016	0.0181	0.0182
Cobalt (ppm)	Mean	0.0091	0.0083	0.0051	0.0195	0.0012	0.0166	0.0094	0.0078
	SD	0.0068	0.0094	0.0069	0.0014	0.0001	0.0056	0.0071	0.0060
Copper (ppm)	Mean	0.0018	0.0017	0.0018	0.0017	0.0000	0.0012	0.0013	0.0017
	SD	0.0001	0.0001	0.0001	0.0000	0.0000	0.0010	0.0008	0.0001
Mercury (ppb)	Mean	0.0487	0.0503	0.0487	0.0561	0.0537	0.0495	0.0472	0.0448
	SD	0.0032	0.0035	0.0032	0.0079	0.0102	0.0042	0.0050	0.0046
Nickel (ppm)	Mean	0.0233	0.0364	0.0340	0.0303	0.0337	0.0293	0.0488	0.0363
	SD	0.0155	0.0067	0.0061	0.0090	0.0095	0.0182	0.0441	0.0050
Lead (ppm)	Mean	0.0623	0.2305	0.0088	0.1204	0.0000	0.0088	0.0772	0.0428
	SD	0.0572	0.0109	0.0033	0.0016	0.0000	0.0034	0.0654	0.0668
Zinc (ppm)	Mean	0.5878	0.8810	0.9377	0.8999	0.8234	0.7763	0.6852	0.6733
	SD	0.2014	0.6108	0.4290	0.2157	0.1500	0.1217	0.3176	0.0565

APPENDIX GIX

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 9 (SA1)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Temperature (°C)	Mean	27.33	26.26	26.74	26.73	26.38	25.42	27.23	26.54
	SD	0.13	0.11	0.11	0.06	0.52	0.07	1.14	0.11
pH	Mean	6.02	4.25	5.65	4.28	4.49	7.74	4.44	4.62
	SD	0.60	0.02	0.93	0.06	0.03	0.07	0.22	0.15
Conductivity (µS/cm)	Mean	20.67	26.67	18.67	17.00	32.00	25.67	18.67	17.00
	SD	1.15	0.58	0.58	1.00	1.00	1.15	1.15	5.20
Salinity (%)	Mean	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TDS (mg/L)	Mean	7.73	8.57	42.90	42.63	62.27	50.57	48.07	52.03
	SD	0.06	0.15	1.31	5.25	1.36	0.60	6.57	0.70
Turbidity (NTU)	Mean	3.17	4.57	2.00	17.97	11.73	3.13	15.56	27.77
	SD	0.13	2.15	0.61	7.51	2.71	0.57	8.57	7.48
TSS (mg/L)	Mean	2.33	17.00	9.00	9.33	19.67	6.33	11.67	12.67
	SD	0.58	16.46	2.65	2.08	3.79	5.77	5.13	1.53

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS OF WATER QUALITY OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 9 (SA1)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
DO mg/L)	Mean	2.17	2.50	1.49	1.54	0.85	1.59	1.76	2.73
	SD	0.21	0.49	0.50	0.59	0.37	0.31	0.47	0.04
BOD (mg/L)	Mean	7.38	0.88	10.38	4.87	10.80	5.90	8.32	6.37
	SD	0.55	0.68	0.14	0.10	0.17	0.36	1.42	0.30
COD (mg/L)	Mean	2.67	15.33	13.33	57.00	38.00	13.67	36.67	21.67
	SD	1.15	1.15	7.77	20.66	4.36	4.04	10.97	2.52
NH3-N (mg/L)	Mean	0.16	0.33	0.05	0.45	0.60	0.42	0.18	0.35
	SD	0.01	0.04	0.08	0.13	0.02	0.07	0.05	0.03
Nitrate-N (mg/L)	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Phosphate (mg/L)	Mean	0.01	0.06	0.05	0.03	0.04	0.03	1.16	0.06
	SD	0.00	0.04	0.04	0.02	0.03	0.01	1.55	0.02
Sulphate (mg/L)	Mean	2.67	1.33	0.00	0.00	0.00	0.00	0.00	0.00
	SD	0.58	0.58	0.00	0.00	0.01	0.00	0.00	0.00

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 9 (SA1)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Arsenic (ppm)	Mean	0.0035	0.0044	0.0044	0.0051	0.0046	0.0031	0.0031	0.0035
	SD	0.0007	0.0024	0.0027	0.0021	0.0032	0.0017	0.0017	0.0018
Barium (ppm)	Mean	0.0225	0.0000	0.0101	0.0665	0.0377	0.0403	0.0187	0.0573
	SD	0.0006	0.0000	0.0054	0.0136	0.0269	0.0167	0.0060	0.0452
Cadmium (ppm)	Mean	0.0197	0.0235	0.0259	0.0285	0.0008	0.0016	0.0088	0.0205
	SD	0.0029	0.0009	0.0036	0.0018	0.0003	0.0002	0.0080	0.0004
Chromium (ppm)	Mean	0.0081	0.0321	0.0320	0.0328	0.0644	0.0108	0.0243	0.0152
	SD	0.0059	0.0268	0.0020	0.0041	0.0129	0.0025	0.0225	0.0106
Cobalt (ppm)	Mean	0.0010	0.0920	0.0859	0.0188	0.0000	0.0099	0.0033	0.0023
	SD	0.0001	0.0030	0.1182	0.0006	0.0000	0.0131	0.0020	0.0023
Copper (ppm)	Mean	0.0017	0.0017	0.0017	0.0018	0.0010	0.0017	0.0015	0.0014
	SD	0.0001	0.0000	0.0000	0.0001	0.0007	0.0001	0.0005	0.0005
Mercury (ppb)	Mean	0.0576	0.0489	0.0465	0.0552	0.0619	0.0586	0.0541	0.0458
	SD	0.0270	0.0069	0.0144	0.0391	0.0278	0.0240	0.0119	0.0113
Nickel (ppm)	Mean	0.0309	0.0140	0.0100	0.0127	0.0107	0.0358	0.0341	0.0137
	SD	0.0345	0.0078	0.0017	0.0072	0.0025	0.0307	0.0326	0.0064
Lead (ppm)	Mean	0.0496	0.4896	0.0130	0.1199	0.0046	0.0062	0.0799	0.0631
	SD	0.0581	0.0036	0.0125	0.0029	0.0032	0.0010	0.0684	0.0503
Zinc (ppm)	Mean	0.2501	0.1400	0.1358	0.1360	0.2225	0.2253	0.2085	0.1516
	SD	0.0106	0.0323	0.0129	0.0094	0.0357	0.0392	0.0530	0.0906

APPENDIX GX

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 10 (SA2)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Temperature (°C)	Mean	31.70	31.19	30.65	29.99	27.75	26.84	28.10	28.58
	SD	0.06	0.12	0.11	0.04	0.02	0.03	0.02	0.18
pH	Mean	6.18	5.54	5.18	5.40	5.13	6.19	5.19	5.04
	SD	0.24	0.36	0.23	0.26	0.19	0.01	0.25	0.15
Conductivity (µS/cm)	Mean	717.33	782.67	900.00	738.33	941.00	744.00	882.33	548.33
	SD	3.79	5.13	60.83	5.51	1.00	25.36	3.79	30.11
Salinity (%)	Mean	0.30	0.33	0.41	0.33	0.44	0.36	0.40	0.25
	SD	0.01	0.01	0.05	0.01	0.00	0.01	0.01	0.01
TDS (mg/L)	Mean	334.67	374.00	2603.33	2270.00	2920.00	2446.67	2666.67	1608.67
	SD	1.53	7.81	283.08	125.30	30.00	107.86	15.28	14.64
Turbidity (NTU)	Mean	11.99	8.23	7.90	15.53	9.47	24.77	8.64	47.70
	SD	0.25	0.53	1.66	12.73	1.03	7.64	0.70	14.77
TSS (mg/L)	Mean	13.67	7.00	6.00	8.67	3.33	13.00	6.33	18.33
	SD	1.53	2.00	4.00	3.51	2.08	4.00	4.73	4.73

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS OF WATER QUALITY OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 10 (SA2)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
DO mg/L)	Mean	2.82	2.50	2.58	1.69	2.45	5.16	2.76	4.56
	SD	0.17	0.16	0.18	0.59	0.44	0.19	0.71	0.11
BOD (mg/L)	Mean	16.02	2.45	18.13	6.08	10.23	6.63	7.50	6.48
	SD	0.46	0.22	0.28	0.13	0.73	0.46	0.36	0.25
COD (mg/L)	Mean	10.67	8.33	20.00	17.33	14.33	10.33	24.33	7.00
	SD	1.53	1.53	18.25	9.07	2.52	3.06	0.58	2.65
NH3-N (mg/L)	Mean	2.37	2.06	1.91	3.27	2.06	1.00	2.33	0.71
	SD	0.01	0.16	0.18	0.15	0.02	0.07	0.15	0.00
Nitrate-N (mg/L)	Mean	0.24	0.21	0.22	0.09	0.09	0.08	0.20	0.05
	SD	0.01	0.03	0.06	0.01	0.02	0.02	0.01	0.02
Phosphate (mg/L)	Mean	12.23	0.10	0.38	35.47	0.17	0.34	0.25	0.07
	SD	0.06	0.03	0.06	1.50	0.01	0.09	0.12	0.03
Sulphate (mg/L)	Mean	48.67	33.33	53.67	35.33	66.00	66.67	39.33	73.33
	SD	0.58	3.51	13.43	4.04	24.25	20.82	8.33	5.77

MEAN AND STANDARD DEVIATION (SD) OF PHYSICOCHEMICAL PARAMETERS AND HEAVY METALS OF TUNGGAK RIVER AND SURROUNDING SURFACE WATER OF GEBENG AT STATION 10 (SA2)

Parameters (unit)	Statistical Tools	2012							2013
		February	March	May	July	August	September	November	January
Arsenic (ppm)	Mean	0.0021	0.0020	0.0021	0.0053	0.0021	0.0019	0.0018	0.0014
	SD	0.0009	0.0010	0.0010	0.0067	0.0009	0.0010	0.0012	0.0006
Barium (ppm)	Mean	0.0453	0.0366	0.0689	0.0882	0.0749	0.0575	0.0496	0.0508
	SD	0.0074	0.0034	0.0066	0.0107	0.0133	0.0173	0.0142	0.0381
Cadmium (ppm)	Mean	0.0043	0.0317	0.0326	0.0316	0.0020	0.0022	0.0074	0.0020
	SD	0.0042	0.0006	0.0014	0.0016	0.0010	0.0010	0.0039	0.0009
Chromium (ppm)	Mean	0.0137	0.0452	0.0350	0.0483	0.0019	0.0007	0.0009	0.0010
	SD	0.0222	0.0051	0.0176	0.0095	0.0005	0.0002	0.0004	0.0003
Cobalt (ppm)	Mean	0.0085	0.0083	0.0096	0.0216	0.0000	0.0203	0.0063	0.0090
	SD	0.0126	0.0061	0.0082	0.0020	0.0000	0.0056	0.0067	0.0129
Copper (ppm)	Mean	0.0024	0.0019	0.0023	0.0043	0.0010	0.0017	0.0023	0.0023
	SD	0.0013	0.0002	0.0006	0.0026	0.0002	0.0007	0.0014	0.0014
Mercury (ppb)	Mean	0.0251	0.0376	0.0384	0.0371	0.0417	0.0312	0.0356	0.0319
	SD	0.0113	0.0081	0.0069	0.0218	0.0093	0.0192	0.0208	0.0197
Nickel (ppm)	Mean	0.0540	0.0523	0.0610	0.0670	0.0654	0.0540	0.0654	0.0526
	SD	0.0192	0.0178	0.0095	0.0041	0.0088	0.0192	0.0088	0.0274
Lead (ppm)	Mean	0.0826	0.2283	0.0020	0.1234	0.0000	0.0020	0.0826	0.0824
	SD	0.0712	0.0052	0.0014	0.0035	0.0000	0.0014	0.0712	0.0715
Zinc (ppm)	Mean	1.5150	1.0003	1.1336	1.1429	1.4003	1.3121	1.1079	0.7667
	SD	0.3588	0.8692	0.2570	0.1625	0.3895	0.3552	0.0124	0.8278

APPENDIX H

PEARSON CORRELATION COEFFICIENT (R) AMONG THE WATER QUALITY PARAMETERS AT THE STUDY AREAS

	Temp.	pH	EC	Salinity	Turbid.	TDS	SS	DO	BOD	COD	NH_3-N	NO_3-N	SO_4^{2-}	PO_4^{3-}
Temp.	1													
pH	0.425**	1												
EC	-0.018	0.062	1											
Salinity	-0.020	0.051	0.974**	1										
Turbidity	-0.184**	0.041	-0.087	-0.083	1									
TDS	-0.048	0.004	0.701**	0.731**	0.357**	1								
SS	-0.055	0.063	-0.045	-0.046	0.617**	0.068	1							
DO	0.011	0.113	-0.188**	-0.186**	0.338**	-0.026	0.244**	1						
BOD	0.496**	0.562**	-0.159*	-0.168**	-0.092	-0.141*	0.015	0.022	1					
COD	0.418**	0.331**	0.082	0.071	-0.170**	0.052	-0.093	-0.221**	0.717**	1				
NH_3-N	0.299**	0.262**	0.071	0.062	0.026	0.040	-0.038	-0.145*	0.104	0.115	1			
NO_3-N	0.159*	0.227**	-0.058	-0.054	-0.093	-0.080	-0.061	0.007	-0.015	0.031	0.272**	1		
SO_4^{2-}	0.152*	0.085	0.811**	0.787**	-0.092	0.613**	-0.039	-0.062	0.023	0.234**	0.005	-0.068	1	
PO_4^{3-}	0.113	0.186**	0.084	0.091	-0.096	-0.026	-0.041	-0.237**	-0.008	-0.014	0.372**	0.257**	-0.048	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

APPENDIX I I

DISTRIBUTION OF DOE-WQI AND CLASSIFICATION OF SURFACE WATER AT STATION 1-2 (DS-SB1)

Month	DO		BOD		COD		SS		pH		NH_3-N		WQI	Water Class
	(%)	SIDO	(mg/L)	SIBOD	(mg/L)	SICOD	(mg/L)	SISS	Value	SIPH	(mg/L)	SIAN		
Station 1 (DS)														
February/12	40.95	36	7.83	69	20.23	74	36.00	78	6.69	98	1.82	32	62.18	III
March	48.88	48	3.23	87	34.67	58	58.33	69	5.83	88	0.67	57	66.54	III
May	27.66	18	11.90	55	29.33	64	20.67	86	6.72	99	2.38	22	53.55	III
July	35.71	29	8.90	65	40.67	53	7.67	93	6.33	95	1.93	31	58.08	III
August	28.22	19	12.90	52	114.67	12	14.67	89	6.18	93	1.88	31	46.19	IV
September	41.98	38	7.30	72	21.67	72	35.67	78	6.80	99	1.20	43	64.37	III
November	49.68	49	6.05	77	22.33	72	23.33	84	6.65	98	0.27	73	73.02	III
January/13	80.57	90	10.23	60	19.67	73	310.67	39	6.99	100	1.53	37	66.55	III
Station 2 (SB1)														
February/12	16.97	7	15.33	45	26.33	67	37.67	77	7.57	96	2.37	22	48.13	IV
March	24.95	10	6.37	75	34.00	59	44.67	74	6.92	17	2.88	14	41.96	IV
May	48.13	14	35.73	12	65.33	34	10.33	91	7.27	98	2.19	26	41.18	IV
July	21.20	93	24.42	26	55.67	41	4.67	95	7.77	94	3.43	6	59.30	III
August	45.84	61	19.05	36	37.00	56	8.33	93	7.11	99	2.21	26	59.85	III
September	90.03	18	8.77	66	10.33	85	14.00	89	7.35	98	1.58	36	61.47	III
November	40.76	93	12.53	53	66.00	34	13.00	90	6.68	98	2.37	22	65.45	III
January/13	66.45	47	8.95	65	15.00	79	168.33	52	6.45	96	1.20	43	61.68	III

APPENDIX I II

DISTRIBUTION OF DOE-WQI AND CLASSIFICATION OF SURFACE WATER AT STATION 3-4 (SB2-IZ1)

Month	DO		BOD		COD		SS		pH		NH_3-N		WQI	Water Class
	(%)	SIDO	(mg/L)	SIBOD	(mg/L)	SICOD	(mg/L)	SISS	Value	SIPH	(mg/L)	SIAN		
Station 3 (SB2)														
February/12	20.05	85	29.22	19	36.67	56	11.00	91	7.90	92	3.27	8	58.06	III
March	24.32	18	8.65	66	17.33	76	17.33	88	7.48	97	3.83	1	54.45	III
May	84.93	45	36.40	11	66.00	34	5.33	94	7.48	97	1.24	42	50.37	IV
July	57.93	100	23.32	28	60.33	38	8.00	93	7.60	96	2.80	15	61.83	III
August	27.13	82	25.52	24	47.33	47	9.33	92	7.18	99	1.97	30	61.33	III
September	84.08	72	7.67	70	6.33	91	20.33	86	7.42	97	1.47	38	74.84	III
November	48.17	86	10.45	60	43.67	50	14.33	89	6.69	98	1.43	39	70.26	III
January/13	75.48	51	8.62	66	10.67	85	135.67	55	6.67	98	0.94	50	65.48	III
Station 4 (IZ1)														
February/12	27.04	18	28.07	20	46.67	48	16.67	88	8.21	88	1.22	43	46.37	IV
March	46.65	45	9.30	64	24.00	70	12.33	90	7.68	18	3.15	10	51.16	IV
May	94.45	100	37.42	10	66.67	33	4.67	95	7.71	95	1.12	45	62.56	III
July	73.61	82	20.63	33	50.33	45	6.67	94	7.63	95	2.29	24	61.49	III
August	65.61	72	27.50	21	48.33	46	10.00	92	7.99	91	1.81	32	57.76	III
September	77.21	86	7.37	71	8.67	88	9.00	92	7.02	99	1.19	43	79.74	II
November	51.00	51	11.98	55	46.00	48	12.00	91	6.41	96	1.38	40	61.29	III
January/13	76.31	85	8.78	66	12.00	83	69.33	64	6.75	99	0.76	55	74.93	III

APPENDIX I III

DISTRIBUTION OF DOE-WQI AND CLASSIFICATION OF SURFACE WATER AT STATION 5-6 (IZ2-IZ3)

Month	DO		BOD		COD		SS		pH		NH_3-N		WQI	Water Class
	(%)	SIDO	(mg/L)	SIBOD	(mg/L)	SICOD	(mg/L)	SISS	Value	SIPH	(mg/L)	SIAN		
Station 5 (IZ2)														
February/12	33.12	25	28.05	20	53.67	42	17.67	87	8.86	71	1.29	41	44.80	IV
March	52.22	53	10.22	61	23.33	70	19.67	86	7.06	99	3.05	11	61.81	III
May	54.70	57	36.67	11	66.67	33	19.00	87	7.50	97	0.87	52	53.06	III
July	39.63	34	25.98	23	73.00	30	65.67	66	7.37	98	2.10	28	43.14	IV
August	16.54	7	36.97	10	103.67	16	11.33	91	8.11	89	1.37	40	37.29	IV
September	82.06	91	7.30	72	16.33	77	18.67	87	5.95	90	1.06	47	77.72	II
November	47.55	46	16.10	43	41.33	52	12.33	90	7.04	99	1.28	41	59.20	III
January/13	72.63	81	11.17	57	22.00	72	40.00	76	6.50	97	0.52	62	73.49	III
Station 6 (IZ3)														
February/12	22.87	13	27.47	21	54.67	41	16.33	88	8.67	79	0.88	51	44.67	IV
March	41.27	37	9.05	65	34.00	59	16.67	88	7.36	19	3.33	7	47.25	IV
May	32.19	24	35.27	12	47.67	47	5.33	94	7.82	93	0.32	70	51.83	III
July	25.53	16	34.25	13	87.00	23	18.33	87	7.38	98	1.82	32	40.07	IV
August	10.31	3	37.22	10	137.00	7	14.67	89	8.04	90	1.51	37	34.23	IV
September	64.51	71	8.80	66	12.00	83	20.33	86	6.66	98	0.86	52	74.65	III
November	32.42	24	10.08	61	49.67	45	17.00	88	7.34	98	1.15	44	56.64	III
January/13	72.82	81	9.12	65	13.33	81	479.33	26	6.52	97	2.50	20	61.96	III

APPENDIX I IV

DISTRIBUTION OF DOE-WQI AND CLASSIFICATION OF SURFACE WATER AT STATION 7-8 (IZ4-US1)

Month	DO		BOD		COD		SS		pH		NH_3-N		WQI	Water Class
	(%)	SIDO	(mg/L)	SIBOD	(mg/L)	SICOD	(mg/L)	SISS	Value	SIPH	(mg/L)	SIAN		
Station 7 (IZ4)														
February/12	39.75	34	32.53	15	69.67	32	15.67	88	7.95	92	1.75	33	45.62	IV
March	52.94	54	33.22	14	103.00	16	13.67	90	7.36	98	0.94	50	50.67	IV
May	81.84	91	37.88	10	103.33	16	10.00	92	7.04	99	1.70	34	56.09	III
July	69.47	77	38.30	9	106.00	15	9.67	92	7.15	99	1.60	36	53.11	III
August	71.34	80	37.90	10	38.00	55	9.33	92	6.08	92	0.97	49	61.28	III
September	80.83	90	7.62	70	4.00	94	5.33	94	6.84	99	0.81	53	83.13	II
November	79.49	89	21.50	31	26.00	67	2123.67	0	7.15	99	1.08	46	54.94	III
January/13	52.16	53	7.82	69	26.67	67	10.00	92	6.10	92	0.58	60	70.31	III
Station 8 (US1)														
February/12	53.99	56	11.58	56	28.67	65	10.00	92	5.18	63	1.71	34	60.45	III
March	40.57	36	1.60	94	24.33	69	13.67	90	4.73	20	1.32	41	59.57	III
May	34.85	28	15.95	43	24.67	69	12.00	91	4.70	47	1.44	38	51.26	IV
July	28.71	20	20.47	33	63.33	36	10.00	92	5.26	66	2.15	27	42.80	IV
August	57.68	61	13.75	49	34.00	59	18.33	87	4.45	40	1.73	34	56.02	III
September	55.77	58	5.23	80	8.00	88	5.67	94	4.67	46	0.65	58	71.56	III
November	17.78	8	8.00	69	65.67	34	26.33	83	4.85	52	1.87	31	44.50	IV
January/13	42.40	38	6.17	76	31.33	62	3.00	96	5.04	58	0.65	58	63.78	III

APPENDIX I V

DISTRIBUTION OF DOE-WQI AND CLASSIFICATION OF SURFACE WATER AT STATION 9-10 (SA1-SA2)

Month	DO		BOD		COD		SS		pH		NH_3-N		WQI	Water Class
	(%)	SIDO	(mg/L)	SIBOD	(mg/L)	SICOD	(mg/L)	SISS	Value	SIPH	(mg/L)	SIAN		
Station 9 (SA1)														
February/12	27.43	18	7.38	71	2.67	96	2.33	96	6.02	91	0.16	83	71.60	III
March	30.92	22	0.88	97	15.33	79	17.00	88	4.25	35	0.33	69	64.50	III
May	18.65	9	10.38	60	13.33	81	9.00	92	5.65	85	0.05	95	65.49	III
July	19.19	9	4.87	80	57.00	40	9.33	92	4.28	36	0.45	65	52.28	III
August	10.49	3	10.80	59	38.00	55	19.67	86	4.49	41	0.60	60	48.28	IV
September	19.39	9	5.90	77	13.67	81	6.33	94	7.72	95	0.42	66	66.00	III
November	22.22	12	8.32	68	36.67	56	11.67	91	4.44	40	0.18	82	56.14	III
January/13	33.93	26	6.37	75	21.67	72	12.67	90	4.62	45	0.35	69	61.82	III
Station 10 (SA2)														
February/12	38.42	33	16.02	43	10.67	85	13.67	90	6.18	93	2.37	22	57.85	III
March	30.92	22	2.45	90	8.33	88	7.00	93	5.54	21	2.06	29	57.85	III
May	34.54	27	18.13	38	20.00	73	6.00	94	5.18	63	1.91	31	52.02	III
July	22.39	12	6.08	77	17.33	76	8.67	92	5.40	71	3.27	8	53.96	III
August	31.19	23	10.23	60	14.33	80	3.33	95	5.13	61	2.06	29	56.20	III
September	64.74	71	6.63	74	10.33	85	13.00	90	6.19	94	1.00	48	76.22	II
November	35.44	28	7.50	71	24.33	69	6.33	94	5.20	63	2.33	23	56.83	III
January/13	58.97	63	6.48	75	7.00	90	18.33	87	5.04	58	0.71	56	71.75	III

APPENDIX J

LIST AND TYPES OF MAJOR INDUSTRIES IN GEBENG INDUSTRIAL ESTATE ADJACENT TO THE MONITORING STATIONS

SL No.	Name of Industries	Type of Industries	Adjacent station
1.	Mieco Manufacturing Sdn. Bhd	Wooden industry	IZ1 & IZ2
2.	LKH Lamps Sdn. Bhd.	Electric bulb manufacturer	IZ1
3.	Asturi Metal builders (M) Sdn. Bhd.	Metal industry	IZ2
4.	Vibrant wave Sdn. Bhd.	Metal industry	IZ2
5.	SHEMICAL Sdn. Bhd.	Metal industry	IZ2
6.	Cargil Palm Product Sdn Bhd	Palm oil industry	IZ2
7.	PTS Gold Kist	Food industry	IZ2
8.	Gas Malaysia Berhad	Power & Gas industry	IZ2
9.	KNM Process System Sdn Bhd	Metal industry	IZ2
10.	Hope Mining	Coal mine industry	IZ2
11.	Southern Steel Mesh Sdn Bhd	Metal industry	IZ2
12.	AMS Engineering Sdn Bhd	Metal industry	IZ2
13.	Malaysian Oxygen	Gas industry	IZ2
14.	Amalgamated Metal Corporation (M) Sdn Bhd	Metal industry	IZ2
15.	Polypropylene Malaysia	Chemical and polymer	IZ2
16.	MTBE	Chemical/petrochemical industry	IZ2
17.	British Petroleum (BP)	Chemical industry	IZ3
18.	Flexsys Chemical Sdn Bhd	Chemical industry	IZ3
19.	W. R. Grace Specialty Chemicals (Malaysia) Sdn. Bhd	Chemical industry	IZ3
20.	Eastman Chemical Sdn. Bhd	Chemical industry	IZ3 & IZ4
21.	Polyplastic	Plastic industry	IZ4
22.	Eco Tower	Metal Industry	IZ4
23.	Grandee Biotechnology Sdn Bhd	Detergent; chemical	IZ4
24.	Siong Heng Engineering Sdn Bhd	Metal industry	IZ4
25.	Vega Precision Technology	Metal, mechanical, electronic, and Gun manufacturer	IZ4

APPENDIX K

GEO-ACCUMULATION INDEX FOR ALL SOIL SAMPLES IN ALL ZONES OF THE STUDY AREA

Samples		Geo-accumulation index (*Igeo*)									
		Cr	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Ba**	**Pb**	**Hg**
Res.-cum-semi-ind. Zone	1.1	-2.02	-4.04	-3.46	-3.95	-2.68	0.25	-8.15	-3.09	-1.61	0.69
	1.2	-1.97	-4.04	-3.38	-4.05	-2.43	0.52	-8.51	-3.10	-1.49	0.20
	1.3	-1.92	-4.04	-3.51	-3.77	-2.51	0.39	-8.33	-3.07	-1.70	0.88
	2.1	-1.73	-4.04	-3.63	-3.45	-1.96	0.86	-8.59	-3.55	-1.54	0.11
	2.2	-1.81	-4.04	-3.75	-4.33	-2.48	0.76	-9.23	-3.48	-1.53	-0.61
	2.3	-1.88	-4.04	-3.74	-3.86	-5.99	0.49	-9.30	-2.94	-1.18	-0.06
	3.1	-1.63	-4.04	-3.50	-2.53	-3.14	0.71	-7.53	-3.42	-1.07	2.46
	3.2	-1.86	-4.04	-2.96	-2.93	-3.13	0.73	-7.96	-3.24	-1.20	0.45
	3.3	-1.49	-4.04	-3.15	-2.58	-3.21	0.78	-6.07	-3.47	-1.03	0.24
Industrial Zone	4.1	-1.73	-4.04	-2.18	-0.54	-0.96	2.92	-5.95	-2.89	0.50	3.94
	4.2	-1.60	-4.04	-1.89	0.01	-0.64	3.36	-5.93	-2.87	0.72	3.53
	4.3	-1.73	-4.04	-1.93	-0.26	-0.65	3.17	-5.94	-2.61	0.83	0.92
	5.1	-1.64	3.06	-2.20	-0.14	-0.92	3.30	-5.84	-3.04	-1.73	3.97
	5.2	-1.55	3.13	-2.02	-1.88	-1.56	3.48	-6.75	-3.74	-1.55	2.67
	5.3	-1.42	3.12	-1.46	0.10	-0.42	2.88	-5.31	-3.23	-1.79	5.72
	6.1	-1.58	4.21	-2.34	-1.71	-0.77	1.24	-6.35	-2.82	-1.53	2.07
	6.2	-1.64	3.70	-2.42	-1.28	-0.98	2.13	-6.26	-3.14	0.48	1.78
	6.3	-1.57	3.98	-2.30	-0.43	-0.86	3.11	-5.89	-3.23	0.47	1.77
	7.1	-1.29	-2.83	-2.66	-0.07	-0.98	2.70	-6.59	-2.72	-0.69	3.04
	7.2	-1.96	-3.08	-3.14	0.04	-0.98	3.63	-5.20	-3.60	0.26	2.39
	7.3	-1.51	-3.29	-2.89	-0.74	-1.09	2.67	-6.26	-3.55	0.28	2.74
Swampy Area	8.1	-1.47	-5.91	-3.26	-3.20	-3.08	0.20	-8.07	-3.52	-1.53	1.68
	8.2	-1.30	-4.04	-2.78	-2.96	-2.66	0.34	-8.02	-3.93	-1.82	0.80
	8.3	-1.44	-3.00	-3.27	-3.27	-2.82	0.37	-8.27	-3.71	-1.64	1.67
	9.1	-1.12	-4.04	-4.07	-4.10	-3.05	0.69	-8.77	-4.91	-2.06	1.74
	9.2	-1.24	-4.04	-4.00	-4.00	-3.22	0.64	-8.62	-4.90	-1.87	1.20
	9.3	-1.48	-4.04	-3.53	-3.13	-2.93	0.42	-8.00	-4.08	-1.99	1.34
	10.1	-1.31	-4.04	-3.84	-3.77	-3.16	0.50	-8.86	-3.99	-2.00	-0.06
	10.2	-1.59	-2.92	-3.06	-3.68	-3.98	1.30	-6.60	-2.53	-0.91	0.86
	10.3	-1.49	-3.72	-3.56	-2.89	-2.66	0.67	-7.80	-2.85	-1.56	0.61

APPENDIX L

LIST OF PUBLICATIONS

A. Journal Publications

1. **Assessment of Spatial Variation of Surface Water Quality at Gebeng Industrial Estate, Pahang, Malaysia**
International Journal of Civil Engineering and Geo-Environment 3(1): 51-56, 2012 ISSN: 2180-2742, Universiti Malaysia Pahang, Malaysia

2. **Effect of industrial pollution on the spatial variation of surface water quality**
American Journal of Environmental Science, 9 (2): 120-129, 2013
ISSN: 1553-345X, Science Publications, USA

3. **Water Quality Index: an Indicator of Surface Water Pollution in Eastern part of Peninsular Malaysia**
Research Journal of Recent Sciences, 2(10): 10-17, 2013
ISSN 2277-2502, International Science Congress Association, India.

4. **Multivariate Statistical Techniques to Identify the Source of Pollution and Assessment of Surface Water Quality**
International Journal of Ecology and Environmental Sciences, 39(3): 187-193, 2013
ISSN 0377-015X, National Institute of Ecology, New Delhi.

5. **Source apportionment and quality assessment of surface water using principal component analysis and multiple linear regression statistics**
Environment Conservation Journal, 14(3): 9-16, 2013
ISSN: 0972- 3099 (Print) 2278-5 124 (Online), Action for Sustainable Efficacious Development and Awareness (ASEA), India

6. **Application of QUAL2Kw for water quality modeling in the Tunggak River, Kuantan, Pahang, Malaysia (accepted for publication)**
Research Journal of Recent Sciences, 3(6), 2014
ISSN 2277-2502, International Science Congress Association, India

7. **Spatial distribution and source apportionment of heavy metals in soils of Gebeng industrial city, Malaysia**
Environmental Earth Sciences, DOI: 10.1007/s12665-014-3398-z © Springer-Verlag Berlin Heidelberg, 2014; ISSN: 1866-6280 (print), 1866-6299 (electronic)

LIST OF PUBLICATIONS

B. Conference Proceedings

1. **Spatial variation of surface water quality at Gebeng industrial estate Pahang, Malaysia**
   National Conference on Postgraduate Research (NCONPGR, 2012), Universiti Malaysia Pahang (UMP), 7th – 9th September 2012

2. **Assessment of Spatial Variation of Water Quality of Tunggak River Adjacent to Gebeng Industrial Estate, Malaysia**
   The 3rd International Conference on Environmental Aspects of Bangladesh [ICEAB 2012], University of Kitakyushu, Fukuoka, Japan; October 13~14, 2012

3. **Water Quality Index of Sungai Tunggak: An Analytical Study**
   The 3rd International Conference on Chemical, Biological and Environment Sciences (ICCEBS'2013), Kuala Lumpur, Malaysia, January 8-9, 2013.

4. **Surface water quality assessment of Tunggak River Gebeng, Pahang, Malaysia**
   The 4th International Conference on Water & Flood Management (ICWFM-2013), Dhaka, Bangladesh; March 9-11, 2013

5. **Automated QUAL2Kw for water quality modeling in the Tunggak River, Gebeng, Kuantan, Malaysia**
   Malaysian Technical Universities Conference on Engineering & Technology (MUCET), Kuantan, Pahang; December 3-4, 2013