GEOSPATIAL MAPPING OF SELECTED HEAVY METALS BASED ON LAND USE WITHIN KINTA RIVER CATCHMENT

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By

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ABSTRAK

Tadahan Sungai Kinta merupakan rangkaian sungai terpenting yang mengalir melalui bandar Ipoh dan berfungsi membekalkan air kepada penduduk untuk tujuan penggunaan. Kajian penyelidikan ini telah dijalankan untuk menilai status kualiti air berdasarkan parameter yang dipilih serta kepekatan logam berat bagi memahami senario kualiti air di hilir Sungai Kinta. Dalam kajian ini, lima parameter in-situ telah dianalisis termasuk jumlah pepejal dan oksigen terlarut, pH, kemasinan, dan suhu diikuti oleh dua parameter makmal yang melibatkan jumlah pepejal terampai dan kekeruhan. Sebanyak 21 jenis logam berat telah dianalisis dengan menggunakan ICP-OES. Walau bagaimanapun, hanya 9 logam berat terpenting telah dibincangkan dalam kajian ini seperti arsenik (As), kadmium (Cd), kromium (Cr), kuprum (Cu), magnesium (Mg), mangan (Mn), plumbum (Pb). dan zink (Zn). TMDL dan ArcGIS telah digunakan untuk menunjukkan taburan logam berat di seluruh tadahan Sungai Kinta dan untuk mengira jumlah logam berat yang dilepaskan ke dalam sungai. Berdasarkan kajian ini untuk parameter in-situ, suhu, pH, oksigen terlarut, kemasinan, dan jumlah pepejal terlarut adalah antara 24.4 hingga 30.4 ℃, 5.88 hingga 6.37, 4.39 hingga 8.98 mg/L, 0.01 hingga 0.09 ppt dan 17.5 ppt. 126.1 mg/L masing-masing. Bagi analisis makmal, jumlah pepejal terampai dan kekeruhan mencatatkan nilai antara 11.7 hingga 63.7 mg/L dan 14.43 hingga 97.67 NTU bagi setiap parameter. Seterusnya, bagi logam berat, tiada kehadiran kuprum (Cu), plumbum (Pb) dan zink (Zn) yang dikesan di 22 titik persampelan ini di seluruh tadahan Sungai Kinta. Kromium dan kadmium hanya dikesan di hulu Sungai Kinta. Nilai arsenik, besi, magnesium dan mangan adalah antara 0.01972 hingga 0.136286 mg/L, 0.143418 hingga 1.13776 mg/L, 1.29807 hingga 4.58733 mg/L dan 0.01452 hingga 0.16468 mg/L masing-masing. Seterusnya, ArcGIS digunakan untuk menunjukkan serakan parameter ini dalam peta di seluruh tadahan Sungai Kinta bersama-sama dengan pengiraan TMDL.

ABSTRACT

The Kinta River catchment is a significant river network that flows through the city of Ipoh and functions to supply water to the residents for consumption purposes. This research study has been conducted to assess the status of the water quality based on the selected parameters as well as the concentration of heavy metals in order to understand the present scenario of water quality of the downstream of Kinta River. In this study, five in-situ parameters had been analyzed including total dissolved solids, dissolved oxygen, pH, salinity, and temperature followed by two laboratory parameters involving total suspended solids and turbidity. A total of 21 types of heavy metals are being analyzed by using ICP-OES. However, only 9 significant heavy metals that are being discussed in this study such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), magnesium (Mg), manganese (Mn), lead (Pb) and zinc (Zn). TMDL and ArcGIS are being used to show the distribution of heavy metals throughout Kinta River catchment and to calculate the amount of heavy metals released into the river. Based on this study for in-situ parameters, the temperature, pH, dissolved oxygen, salinity, and total dissolved solids are ranging from 24.4 to 30.4℃, 5.88 to 6.37, 4.39 to 8.98 mg/L, 0.01 to 0.09 ppt and 17.55 to 126.1 mg/L respectively. As for laboratory analysis, total suspended solids and turbidity recorded a value ranging from 11.7 to 63.7 mg/L and 14.43 to 97.67 NTU for each parameter. Next, for heavy metals, there are no presence of copper (Cu), lead (Pb) and zinc (Zn) detected at these 22 sampling points throughout Kinta River catchment. Chromium and cadmium had only been detected at the upstream of Kinta River. Arsenic, iron, magnesium, and manganese values are ranging from 0.01972 to 0.136286 mg/L, 0.143418 to 1.13776 mg/L, 1.29807 to 4.58733 mg/L and 0.01452 to 0.164668 mg/L respectively. Next, ArcGIS is used to show the dispersion of these parameters in a map throughout Kinta River catchment along with TMDL calculations.

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LIST OF ABBREVIATIONS AND SYMBOLS

°C	: Degree Celsius
As	: Arsenic
AN	: Ammoniacal Nitrogen
Be	: Beryllium
BOD	: Biological Oxygen Demand
Ca	: Calcium
Cd	: Cadmium
Co	: Cobalt
COD	: Chemical Oxygen Demand
Cr	: Chromium
Cu	: Copper
DO	: Dissolved Oxygen
DOE	: Department of Environment
DOE-WQI	: Department of Environment Water Quality Index
EPA	: Environmental Protection Agency
Fe	: Iron
GIS	: Geographic Information System
GPS	: Global Positioning System
ICP-OES	: Inductively Coupled Plasma Optical Emission Spectroscopy
IDW	: Inverse Distance Weighted
INWQS	: Interim National Water Quality Standard
LA	: Load Allocation
Li	: Lithium

Mg : Magnesium

Mn : Manganese

Mo : Molybdenum

MOS : Margin of Safety

Ni : Nickel

NPS : Non-Point Source

NTU : Nephelometric Turbidity Unit

Pb : Lead

PS : Point Source

RS : Remote Sensing

Sb : Antinomy

Se : Selenium

Sr : Strontium

TDS : Total Dissolved Solids

Ti : Titanium

Tl : Thallium

TMDL : Total Maximum Load Capacity

TSS : Total Suspended Solids

USEPA : United States Environmental Protection Agency

V : Vanadium

WLA : Waste Load Allocation

WQI : Water Quality Index

WQS : Water Quality Standards

Zn : Zinc

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The primary supply of fresh water for all human activities are rivers (Hema & Subramani, 2013). A river is a massive natural stream of water that discharges into a lake, ocean, or other water bodies and is generally distributed by uniting tributaries along its path. River water that falls in hilltop areas is drained by rivers and streams. Although running water dilutes and decomposes contaminants more quickly than stagnant water, however many rivers and streams across the world are severely polluted nowadays. Water is an essential commodity for both human survival and the global economy. However, the quality of worldwide water has been progressively declining for decades owing to both natural and manmade reasons (Vadde et al., 2018).

Water quality comprises of three main categories that describe its state of condition based on chemical, physical, and biological properties in relation to its intended usage. Rivers are generally pristine and uncontaminated at its source. However, as the water flows further downstream, it receives point sources (PS) and non-point pollution sources (NPS), resulting in poor quality of river water. Due to the water quality deterioration of many water resources on a global scale, it has become impertinent to constantly monitor anthropogenic activities in order to determine the current state of water quality (Chowdhury, 2017). Monitoring a wide variety of physical, chemical, and biological characteristics is required to determine water quality pollution. Because of the enormous amount of data available, water quality analysis is difficult and complicated. As a result, using a certain statistical procedure is critical for producing relevant data (Baharuddin et al., 2014). Some of the procedures that can be used in determining and monitoring water quality are by using Geographic Information System (GIS).

However, the access of clean water is prevented from being supplied because of water pollution that had been in big scale in our world. Environmental pollution is the contamination of physical and biological components of the earth and affect the normal environmental process. This pollution is a global problem to both developed and developing countries. It affects biodiversity, ecosystems, and human health by contaminating the water and soil. This pollution also will affect the growth of prokaryotic and eukaryotic organisms for marine ecosystems. To be specific, water pollution is one of the most common in our society since it occurs in large scale in our world and has become a growing threat to human society and natural ecosystem (Baharuddin et. al., 2014). It includes the contamination of water sources such as lakes, rivers, and seawater. The source of water pollution might be from point sources and non-point sources. This type of pollution can actually deplete the water quality and increase the toxicity of the water. As a result, the water is not suitable to be consumed by humans and environment.

1.2 Problem Statement

The Kinta River catchment is a significant river network that flows through the city of Ipoh and functions to supply water to the residents for consumption purposes. It also has become a receiving end for many human activities discharging their waste. Therefore, the urgency to monitor the Kinta River’s water quality is highly necessary. However, the Kinta River’s water quality is now rated as average Class III, with a water quality score of 51.9 – 76.5 (Mustafa et al., 2020). This indicates that the water is contaminated and will require substantial treatment before it can be consumed.

Hence, there are several studies conducted regarding the water quality assessment in Kinta River. Though, the water quality data is still not systematically presented and insufficient throughout Kinta River catchment. Plus, pollutants can be discharged from several sources in water body. However, the ending of where the pollutants finishes and how far it will affect the human is still being questioned throughout Kinta River catchment. Without analyzing the movement of pollutants, the distribution of pollutants cannot be examined and the extent to which the heavy metals had impacted the human cannot be identified. Thus, the use of Geographic Information System (GIS) Mapping and TMDL are necessary in order to produce a more systematic water quality data where it can show the differences in concentration and mobility of the selected pollutants and shows the presence of heavy metals in a day throughout Kinta River catchment.

1.3 Objectives of the Study

This study aims to achieve the main goal through the following objectives:

1. To determine the water quality base line based on selected in-situ and heavy metal parameters within Kinta River catchment.
2. To calculate and analyses the river condition based on selected heavy metals to see the maximum released of pollutants into Kinta River catchment by using Total Maximum Daily Load (TMDL).
3. To develop a water quality map to represent the degree of pollution by using Geographic Information System (GIS).

1.4 Scope of the Study

The scope of the study mainly focusing on the water quality base line of the Kinta River basin which located in Ipoh, Perak. This river is known to be one of the important rivers in Perak state in supplying water for the consumption of Ipoh City. The analysis scope includes the analysis of basic water quality parameters such as in-situ analysis and laboratory analysis. In-situ analysis that had been conducted involves pH, dissolved oxygen (DO), temperature, total dissolved solids (TDS), and salinity. As for laboratory analysis, three analyses had been done which are on turbidity, total suspended solids (TSS) and heavy metal analysis using ICP-OES. A total of 21 types of heavy metals are being analyzed. However, there are only 9 types of heavy metals that will be discussed which includes As, Cd, Cr, Cu, Fe, Mg, Mn, Pb, and Zn. Then, TMDL had been established for these heavy metals followed by the GIS Mapping using ArcGIS to model the distribution of pollutants throughout Kinta River catchment.

1.5 Significance of the Study

There are some studies conducted locally in a small scale regarding the water quality and pollution distribution in Kinta River catchment. However, none of the data are presented systematically. Therefore, the use of GIS will help to systematically present the distribution of selected pollutants and the mobility of the pollutants can be clearly seen in Kinta River. Plus, TMDL can also show the released of pollutants inside Kinta River.

The use of GIS in monitoring the water quality will be effective as GIS has the ability to help managers analyze water quality more effectively, anticipate pollution loadings, and execute preventative and remedial water quality actions more efficiently (Locher, 2004). GIS provides a platform on which the analysis and communication regarding data is presented in a clear and concise manner. The water quality data can be expressed in a more palatable format, and it will ease the people to understand and absorb all these data. Plus, the coordinates of the field sites where water quality samples are obtained can be recorded using hand-held global positioning system (GPS) devices, and subsequently put into the GIS database. Therefore, the locations will be much more precise and accurate when presented through GIS Mapping. Therefore, the extent to which the heavy metals had impacted the human can also be identified.

CHAPTER 2

LITERATURE REVIEW

2.1 River Network System

2.1.1 Introduction to River Network System

A river is a significant natural stream network. A river network is a dynamic component that conveys material and drains a watershed. It may also be described as a sizable natural torrent of water moving across wide bodies of water or canals. A series of rivers that drain their water into the sea is known as the river network system. As an alternative, it may also be described as a watershed where a number of rivers combine to drain into a larger body of water (Chowdhury, 2017). Different river systems make up a river network. Every river system has a unique origin and range of operation which is called as basin. Rivers also may grow into a variety of minor network topologies while having a single source owing to various geological and geomorphological factors (Jiang et al., 2014).

A river is divided into two sections which are called upstream and downstream. An upstream river or upriver is a water that flows near to the source while a downstream river is a water that runs near to the mouth of a stream. A river system is made up of a main river (head water), tributaries, a confluence, a river mouth, and a sub-basin and the main river is source of the river. A freshwater stream that flows into a bigger stream or river is called a tributary. The mainstem of a river refers to its parent, or bigger river. The confluence is the location where a tributary joins the main stem and affluents, often known as tributaries which do not enter the ocean immediately. A river's mouth is where it empties into a lake, a bigger river, or the ocean. River mouths are incredibly active locations. A river's flow gathers up silt from the riverbed, eroded bank material, and floating debris. Figure 2.1 below illustrated a common river system where it begins at a hilly area and continues to flow into an ocean or lake.

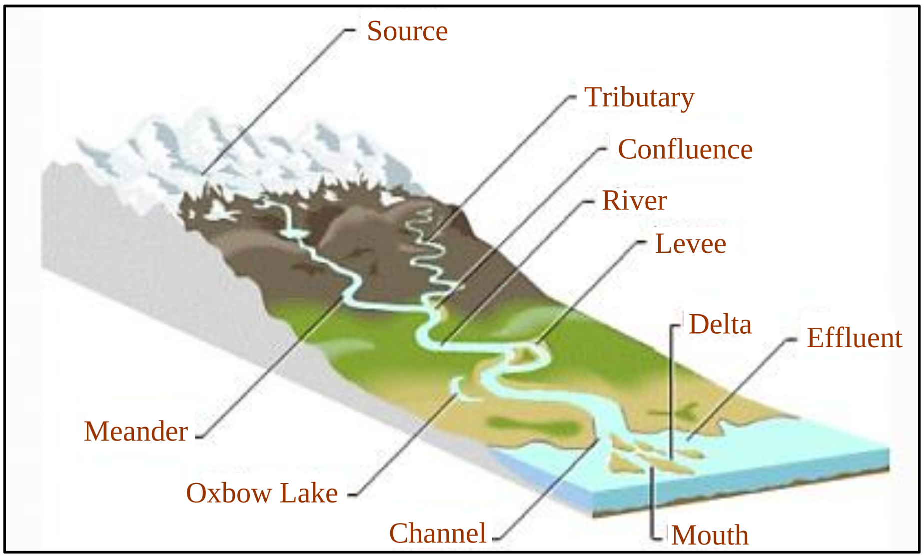

Figure 2.1: A Common River System.

Rivers are used by people for a variety of purposes, including irrigation of agricultural land, drinking water supply, transportation, the generation of energy by hydroelectric dams, and recreation activities like boating and swimming. The ecosystems around a river and its surroundings may suffer as a result of any of these uses. In addition to offering a variety of other ecological services, rivers have intrinsic and biological benefits too.

2.2 Water Quality Monitoring

2.2.1 Introduction to Water Quality Monitoring

Globally, water quality is a concern to our world. The term water quality monitoring refers to the process of collecting samples of water and analyzing them. Due to human activity, urbanization, industrialization, and waste disposal, water quality metrics significantly deteriorate in highly populated places (Fikadu, 2022). Therefore, water quality monitoring is important for observing water contamination and may assist direct water resource management for a supply of clean water (Karomah, 2022).

2.2.2 Water Quality Parameters

One of the key concerns in managing water resources is water quality. Physical, chemical, and biological are the three primary categories that may be used to categorize water quality, and each category contains a number of characteristics. By field monitoring rivers, these three categories are evaluated. This information is used to identify patterns, notify water authorities about the quality of the water, and suggest future courses of action. The normal method of doing this evaluation is to consider the planned applications, human health, and natural water quality (Sutadian et al., 2016).

Depending on the intended water parameters of concern, tests or monitoring can be done for the chemical, physical, and biological characteristics that make up water quality parameters. As for the physical parameters, it includes color, taste, odor, temperature, turbidity, solids, and electrical conductivity. Instead, chemical parameters can involve pH, acidity, alkalinity, chlorine, hardness, dissolved oxygen, and biological oxygen demand. Last but not least, bacteria, algae, and viruses are some of the biological parameters that are been analyzed for river water quality.

2.2.3 Importance of Water Quality Monitoring

There are several reasons to monitor the quality of the water. It can identify specific concerns with the current or projected quality of the water and gather information to create plans for the treatment or prevention of pollution. It might determine whether programme goals like abiding by pollution laws and carrying out efficient pollution prevention are being met. The monitoring of water enables the early discovery of events like spills and floods (Karomah, 2022).

Besides, monitoring offers the accurate information required to make wise decisions about the management of water quality now and in the future. In order to safeguard other beneficial uses of water as well as to identify and address current, continuing, and new issues, water quality monitoring is utilized. Monitoring data assessments assist legislators and water managers in evaluating the efficacy of water regulations, determining if water quality is improving or declining, and developing new policies to better safeguard public health and the environment (Myers, 2016).

2.3 Malaysian Water Quality Standards and Regulations

Water quality standards (WQS) are clauses in state, territory, authorized tribal, or federal legislation that have been recognized by EPA. They specify the ideal state of a water body and the steps that must be taken to safeguard or attain that state (USEPA, 2013).

The Department of Environment (DOE) is in charge of keeping an eye on the state of Malaysia's rivers, developing guidelines for water quality, and identifying the causes of pollution. Based on the Malaysian Department of Environment Water Quality Index (DOE-WQI) and the Malaysia Interim National Water Quality Standard (INWQS), the level of water quality in Malaysian rivers was determined. While INWQS offers the classification based on beneficial uses, the DOE-WQI serves as the foundation for river water assessment linked to the pollutant load categorization (Zaideen et al., 2017).

2.3.1 Water Quality Index (WQI)

Based on a variety of water quality factors, the water quality index (WQI) delivers a single value that indicates the total water quality at a certain place and time. WQI's goal is to translate complicated water quality data into information that the general public can use and comprehend. A variety of indicators have been devised to present data on water quality in a straightforward and understandable manner. The WQI simply uses arithmetic to create a single number from a collection of test data (Adelagun et al., 2021). Total suspended solids (TSS), dissolved oxygen (DO), pH, chemical oxygen demand (COD), biological oxygen demand (BOD5), and ammoniacal nitrogen (AN) are the six metrics that DOE-WQI established to determine the condition of surface water quality (Zaideen et al., 2017). The six mean values for the water quality metrics are entered into the computation using the following formula to determine the WQI:

$$WQI = (0.22\ x\ SIDO) + (0.19\ x\ SIBOD) + (0.16\ x\ SICOD) + (0.15\ x\ SIAN) + (0.16\ x\ SISS) + (0.12\ x\ SIpH) \quad (2.1)$$

Table 2.1: Best Fit Equations for the Estimation of Various Subindex Values (DOE, 2014).

Subindex for DO (in % saturation)	
SIDO = 0	for $x \leq 8$
SIDO = 100	for $x \geq 92$
SIDO = $-0.395 + 0.030x^2 - 0.00020x^3$	for $8 < x < 92$
Subindex for BOD	
SIBOD = 100.4 - 4.23x	for $x \leq 5$
SIBOD = 108 * exp(-0.055x) - 0.1x	for $x > 5$
Subindex for COD	
SICOD = -1.33x + 99.1	for $x \leq 20$
SICOD = 103 * exp(-0.0157x) - 0.04x	for $x > 20$
Subindex for NH3-N	
SIAN = 100.5 - 105x	for $x \leq 0.3$
SIAN = 94 * exp(-0.573x) - 5 * |x – 2|	for $0.3 < x < 4$
SIAN = 0	for $x \geq 4$
Subindex for SS	
SISS = 97.5 * exp(-0.00676x) + 0.05x	for $x \leq 100$
SISS = 71 * exp(-0.0061x) - 0.015x	for $100 < x < 1000$
SISS = 0	for $x \geq 1000$
Subindex for pH	
SIpH = $17.2 - 17.2x + 5.02x^2$	for $x < 5.5$
SIpH = $-242 + 95.5x - 6.67x^2$	for $5.5 \leq x < 7$
SIpH = $-181 + 82.4x - 6.05x^2$	for $7 \leq x < 8.75$
SIpH = $536 - 77.0x + 2.76x^2$	for $x \geq 8.75$

2.3.2 Interim National Water Quality Standard (INWQS)

Malaysia's INWQS is a standard that focuses on the quality of water in relation to its beneficial applications. Water is deemed appropriate for a usage as long as it falls within the range set out for the designated classes. It emphasized on the utilization of water for agriculture, fishery, aquatic life, cattle drinking, and recreation. The criteria also assist in determining the root causes of water quality issues, such as improperly treated wastewater discharges, fertilizer runoff, and pollutants from agricultural regions. Based on the beneficial use of the water, INWQS are categorized into five classes which are shown in Table 2.2 until 2.5 below.

Table 2.2: Definition of Classes for INWQS (DOE, 2014).

Class	Uses
Class I	Conservation of natural environment. Water Supply 1 - practically no treatment necessary (except by disinfection or boiling only) Fishery 1 - very sensitive aquatic species
Class IIA	Water Supply II - conventional treatment required Fishery II - sensitive aquatic species
Class IIB	Recreational use with 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

Table 2.3: Interim National Water Quality Standard (INWQS) for physicochemical parameter (DOE, 2014)

Parameter	Unit	Class				
		I	II	III	IV	V
NH_3-N	mg/L	< 0.1	0.1 – 0.3	0.3 – 0.9	0.9 – 2.7	> 2.7
BOD	mg/L	< 1	1 – 3	3 – 6	6 – 12	> 12
COD	mg/L	< 10	10 – 25	25 – 50	50 – 100	> 100
DO	mg/L	> 7	5 – 7	3 – 5	1 – 3	< 1
pH	-	> 7	6 – 7	5 – 6	< 5	> 5
TSS	mg/L	< 25	25 – 50	50 – 150	150 – 300	> 300
WQI	-	< 92.7	76.5 –92.7	51.9 – 76.5	31.0 – 51.9	> 31.0

Table 2.4: Water Quality Standards for Heavy Metals (DOE, 2014).

Parameter	Unit	Class				
		I	IIA / IIB	III	IV	V
Al	mg/L	NATURAL LEVELS OR ABSENT	-	(0.06)	0.5	LEVELS ABOVE IV
As	mg/L		0.05	0.4 (0.05)	0.1	
Ba	mg/L		1	-	-	
Cd	mg/L		0.01	0.01* (0.001)	0.01	
Cr (IV)	mg/L		0.05	1.4 (0.05)	0.1	
Cr (III)	mg/L			2.5		
Cu	mg/L		0.02	-	0.2	
Hardness	mg/L		250	-	-	
Ca	mg/L		-	-	-	
Mg	mg/L		-	-	-	
Na	mg/L		-	-	3 SAR	
K	mg/L		-	-		
Fe	mg/L		1	1	1 (Leaf) 5 (Others)	
Pb	mg/L		0.05	0.02* (0.01)	5	
Mn	mg/L		0.1	0.1	0.2	
Hg	mg/L		0.001	0.004 (0.0001)	0.002	
Ni	mg/L		0.05	0.9*	0.2	
Se	mg/L		0.01	0.25 (0.04)	0.02	
Ag	mg/L		0.05	0.0002	-	
Sn	mg/L		-	0.004	-	
U	mg/L		-	-	-	
Zn	mg/L		5	0.4*	2	
B	mg/L		1	(3.4)	0.8	
Cl	mg/L		200	-	80	
Cl_2	mg/L		-	(0.02)	-	
CN	mg/L		0.02	0.06 (0.02)	-	
F	mg/L		1.5	10	1	
NO_2	mg/L		0.4	0.4 (0.03)	-	
NO_3	mg/L		7	-	5	
P	mg/L		0.2	0.1	-	
Silica	mg/L		50	-	-	
SO4	mg/L		250	-	-	
S	mg/L		0.05	(0.001)	-	
CO_2	mg/L		-	-	-	
Gross-α	Bq/L		0.1	-	-	
Gross-ß	Bq/L		1	-	-	
Ra-226	Bq/L		< 0.1	-	-	
Sr-90	Bq/L		< 1	-	-	
CCE	µg/L		500	-	-	
MBAS / BAS	µg/L		500	5000 (200)	-	
O&G (Mineral)	µg/L		40;N	N	-	
O&G (Emulsified Edible)	µg/L		7000;N	N	-	
PCB	µg/L		0.1	6 (0.05)	-	

Phenol	µg/L		10	-	-	
Aldrin/Dieldrin	µg/L		0.02	0.2 (0.01)	-	
BHC	µg/L		2	9 (0.1)	-	
Chlordane	µg/L		0.08	2 (0.02)	-	
t-DDT	µg/L		0.1	(1)	-	
Endosulfan	µg/L		10	-	-	
Heptachlor/Epoxide	µg/L		0.05	0.9 (0.06)	-	
Lindane	µg/L		2	3 (0.4)	-	
2, 4-D	µg/L		70	450	-	
2, 4, 5-T	µg/L		10	160	-	
2, 4, 5-TP	µg/L		4	850	-	
Paraquat	µg/L		10	1800	-	

Table 2.5: Water Quality Standard for physicochemical parameter (DOE, 2014).

Parameter	Unit	Class					
		I	IIA	IIB	III	IV	V
NH_3-N	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	µS/cm	1000	1000	-	-	6000	-
Floatable	-	N	N	N	-	-	-
Odour	-	N	N	N	-	-	-
Salinity	%	0.5	1	-	-	2	-
Taste	-	N	N	N	-	-	-
TDS	mg/L	500	1000	-	-	4000	-
TSS	mg/L	25	50	50	150	300	300
Temperature	ºC	-	Normal + 2 ºC	-	Normal + 2 ºC	-	-
Turbidity	NTU	5	50	50	-	-	-
Faecal Coliform	count/ 100 mL	10	100	400	5000 (20000)[a]	5000 (20000)[a]	-
Total Coliform	count/ 100 mL	100	5000	5000	50000	50000	> 50000

2.4 River Water Pollution

2.4.1 Introduction to River Pollution

The degradation of river water bodies, generally as a result of human activities is known as river pollution. Contaminants are introduced into the natural ecosystem which results in river pollution (Mauludi, 2020). With the fast growth of the economy and the increase in urbanization, river water pollution is a serious global problem, and it is especially acute in many developing countries (Wang et al., 2012). Many regions of globe are lacking in legislation to preserve river water quality and environmental reliability, and even when restrictions do exist, they are commonly not applied effectively or regularly. As a result, many rivers are heavily contaminated, posing threats and harms to human health, plant and animal life, and environment. Therefore, proper water quality monitoring is essential to determine compatibility for usage as well as assist in water quality management or improvement.

Based on a study conducted in Malaysia, it is known that a total of 42 tributaries were recognized as extremely contaminated in the 1980s (Kozaki et al., 2020). As of now, Department of Environment (2020) had reported that out of the 672 rivers analyzed in Malaysia, 443 (66%) had excellent water quality, 195 (29%) were moderately contaminated, and 34 (5%) were severely polluted as illustrated in Figure 2.2 (DOE, 2020). According to the United Nations Environment Programme, significant pollution has damaged up to one-third of all rivers in developing nations (Loi et al., 2022). However, continuous changes in river water quality can be detected by using the monitoring data. Thus, politicians and the government should pay attention to the deterioration of water quality and enforce stricter environmental rules to protect and rehabilitate the rivers (Loi et al., 2022).

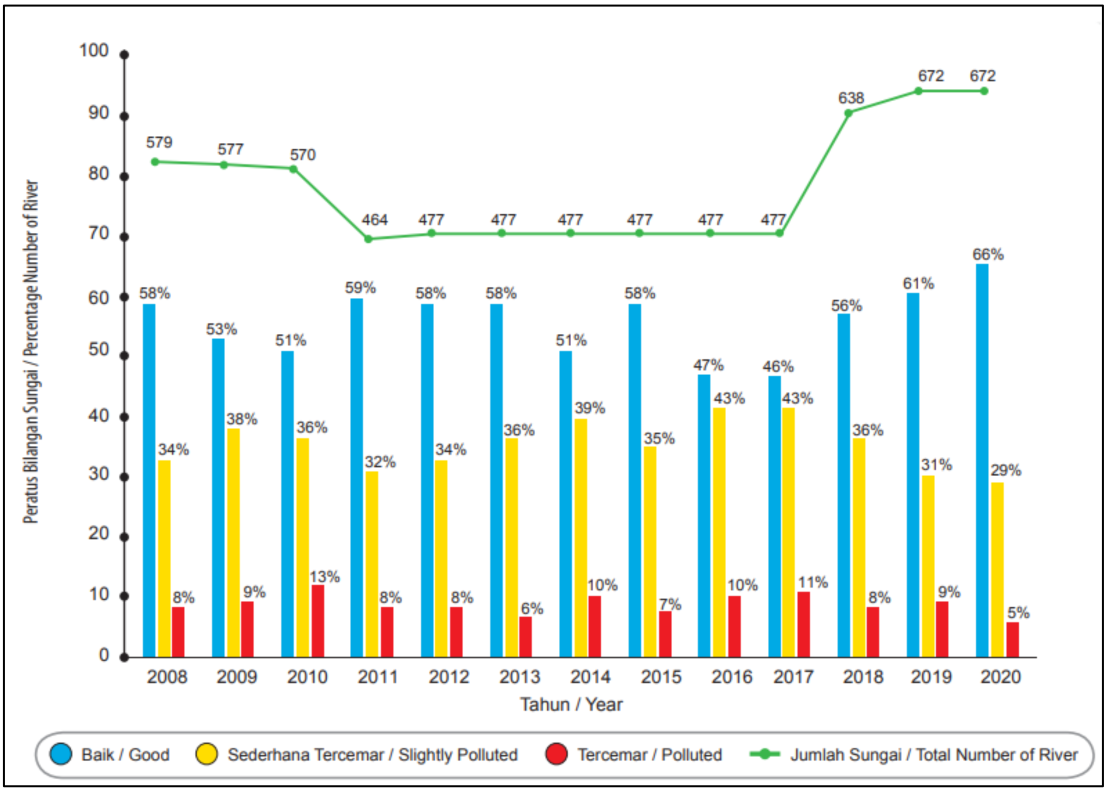

Figure 2.2: River Water Quality Trend from 2008-2020 (DOE, 2020).

2.4.2 Types of Water Pollution

According to Hydro International, there are several categories of contamination of water focusing on river pollution. It includes the trash and gross solids, sediment, and fine solids, as well as the entering of chemicals into the river (Hydro International, 2016).

Trash and gross solids are perhaps the most visible types of river pollution. Styrofoam, metal containers, and plastic packaging are unpleasant and persist in the environment. They can block streams and pose a threat to birds and fish as they consume them or become entangled in them (Hydro International, 2016).

As for sediment and fine solids, they are also considered as a major concern because storm water carries sand, grit, and other fine materials into the river, where they pile up. Thus, the total suspended solids (TSS) siltation can obstruct rivers, and this accumulation can harm invertebrate life and fish egg viability (Hydro International, 2016).

Besides, chemical contaminants also can go into the rivers from a range of resources, ranging from the most noticeable, such as waste from industrial to the less evident, such as runoff of agricultural. These mixtures can cause rapid and disastrous environmental harm, and they can develop up over time, storing in plant and animal life to the point where human health and environmental consequences are not spotted for several years. There are several typical chemical pollutants that are normally found in river or stream such as ammonia, surfactants and detergents, fertilizers, organic solvents, heavy metals, hydrocarbons, and oils. Plus, nutrient contamination may cause environments to become unstable, resulting in algal blooms that generate toxins that harm other aquatic varieties (Hydro International, 2016).

2.4.3 Sources of River Water Pollution

Pollution from both point source and non-point sources can cause danger to our streams. The primary point sources of pollution are sewage treatment plants, agro-industry, manufacturing, sulfur or grey water from business and residential properties, and pig farms (Daud, 2010). A great number of prior studies have mostly focused on the influence of point source pollution emissions on river basin water pollution, such as industrial pollution and urban domestic pollution (Luo et al., 2015). Due to water depletion from housing, industrial, and business or servicing sectors, about 60% of the main rivers were regulated for domestic, agricultural, and industrial uses in the 1990s and 2000s (Kozaki et al., 2020).

Water pollution that impacts a water body through numerous secondary sources, such as land use, land-use changes, and dirty runoff from agricultural regions that drain into a river, is known as non-point source pollution. At the same time, as the urban population grows and water consumption rises, therefore the contaminants started to accumulate. It is also regarded as one of the most important elements influencing river water quality. Plus, the increased input of wastewater induced by fast economic, industrial, and agricultural expansion without the installation of appropriate water infrastructure and treatment facilities has resulted in water pollution and eutrophication of lakes, rivers, and seas (Kozaki et al., 2020).

Besides, Bashir et al. (2020) claimed that suspended solids, organic wastes, and nutrients are all major contaminants that are needed to be worried about. High-level of suspended solids are caused by eroded sediments caused by sand mining, land clearance, and rainwater runoff. Plus, high organic and nutrient pollution loads are produced by wastewater discharge from household sewage and intensive animal farms (Malaj et al., 2014).

2.4.4 Effects of River Water Pollution

Rivers are vital to both human society and the wider environment, and their pollution may have a wide range of negative consequences for plant, animal, and human life. Pollution is accumulated and transported through the riverine environment, which concentrates organic and inorganic pollutants in ways that harm flora, animals, and human health, as well as transferring them to the sea (Hydro International, 2016). Severe pollution of the aquatic environment not only increases the incidence of harmful infections in the community and affects social welfare, but it also has a long-term negative impact on long-term economic growth (Hasan et al., 2019). Water contamination is caused by a variety of chemicals and microorganisms, as well as physical factors (Mauludi, 2020).

Organic and inorganic substances can be contaminants. Concentrated and extremely hazardous industrial pollutants can surpass the rivers' self-purification potential, thus contribute to the increasing of water quality degradation (Xu et al., 2022). Besides, polluted river water can also be a result of high temperatures. The use of water as a coolant by power plants and industrial enterprises is a frequent source of thermal pollution. Increased water temperatures will limit the oxygen levels, which can kill the fishes and change the nature of food chains, thus diminish the species biodiversity, and encourage the invasion of new thermophilic species (Mauludi, 2020).

2.4.5 Effects of Land Use towards Water Quality

Land use is defined as the anthropogenic usage of lands and their supplies, and the basic qualities of these lands are the product of a long-term interaction between humans and the natural environment. It is well acknowledged that the type of land use and water quality are inextricably linked with each other. The water quality of river is significantly influenced by land use within the watershed. As human activities grow, the water quality of rivers may deteriorate owing to changes in land cover patterns within the watershed.

Changes in land use as a result of urbanization, industrialization, and agriculture can alter the surface features of watersheds, affecting runoff quality and quantity (Tu, 2011). In common, undeveloped regions such as natural forest areas, are correlated to good water quality whereas larger percentages of land use connected with human activities and economic development in watersheds are linked to high levels of water pollutants (Rodrigues et al., 2018). Therefore, good river water quality will have better care towards the people surrounding in terms of health and aquatic animals whereas poor river quality will cause a massive negative impact towards the ecosystems and human health.

2.4.6 Water Pollution Preventive Measures

Every citizen has a responsibility to keep rivers and lakes clean since they are the source of our drinking water and food production. Once these waterways have been poisoned, there is not much that can be done to restore it. Mirror Now Digital (2020) stated some of the steps that can be taken to help in controlling river pollution.

First, rivers can be saved by avoiding the dumping of untreated sewage into lakes and rivers, as it pollutes the water when it mixes with it. Next, solid waste should not be thrown into waterways because it will restrict the flow of water and causes pollution. Plus, construction garbage should not be dumped in the river and the use of pesticides and other herbicides must be avoided by employing organic farming practices. Lastly, keeping hazardous chemicals and oils out of storm drains and streams will also help in controlling the river pollution (Mirror Now Digital, 2020).

2.5 Heavy Metals in River

2.5.1 Introduction to Heavy Metals

Surface water heavy metal contamination is a global environmental issue (Tiwari et al., 2015). Heavy metals are naturally occurring elements with a high atomic weight and at minimum 5 times the density of water. Heavy metals are very persistent and non-degradable pollutants that penetrate the environment and contaminating both surface and groundwater resources (Mokarram et al., 2020). Because of their production in numerous activities such as industrial, household, agricultural, medicinal, and technical applications, they have been extensively distributed in the environment, raising worries about their possible consequences on human health and the environment (Tchounwou et al., 2012).

Some heavy metals have significant physiological and biochemical functions in biological systems, and their absence or excess can affect metabolic disturbances and, as a result, a variety of disorders. Metals and metalloids are required for biological life to exist. They may be found in biomolecules like as enzymes, which catalyze biochemical processes in the body, and so play crucial physiological and biochemical roles in the body (Ali et al., 2019).

2.5.2 Sources of Heavy Metals Pollution in River

Heavy metals can be found in both natural and man-made environments (Muhammad et al., 2011). Bedrock weathering is recognized to be the most frequent natural source of heavy metals while Krishna et al. (2009) stated that industrial production, fertilizer usage, and sewage outflow are all examples of anthropogenic sources. On top of that, heavy metal concentrations in biogeochemical cycles have increased as a result of mining and industrial processing for the extraction of mineral resources and their subsequent usage in industry and agriculture (Ali et al., 2019). Besides, a study had also been conducted in China's Yunnan Province which indicated that metal mining and smelting were the key cause of the increase of heavy metals in surface water of that studied area (Zhou et al., 2020). Furthermore, metal corrosion, air deposition, soil erosion of metal ions and leaching of heavy metals, sediment re-suspension, and metal evaporation from water supplies to soil and ground water can all cause environmental pollution (Nriagu, 1989). Also, metal processing in refineries, coal combustion in power plants, petroleum combustion, nuclear power plants and high-tension lines, plastics, textiles, microelectronics, wood maintenance and paper processing factories are all examples of industrial sources that can contribute to heavy metal pollution (Arruti et al., 2010).

2.5.3 Effects of Heavy Metals Contamination in River

Toxic heavy metal pollution of terrestrial environments and aquatic is an issue that is a public health threat. Heavy metals accumulate in the environment as persistent contaminants and harm food systems as a result (Ali et al., 2019). Metal poisoning can create physiological problems and contribute to an increase in oxidative stress (Hossain et al., 2021). Heavy metal bioaccumulation which is toxic in riverine environment biota may have adverse outcomes for humans and animals. Higher levels of heavy metals in biota can have negative effects on the ecological health of aquatic animal species and may contribute to declines in their populations (Luo et al., 2015). Thus, fish communication with their surroundings may be disrupted by heavy metals interacting with chemical cues and this action will affect their growth rates, survival, welfare, and external image.

Consumption of heavy metals also had a serious impact on the human health. For example, acute intoxication can arise as an effect of intentional intake of arsenic in the issue of suicide attempts or unintentional consumption by youngsters (Mazumder, 2008). As a whole, the effects of heavy metal poisoning on the human body are numerous. It can cause mental disorders, harm blood components, and cause damage to the lungs, liver, kidneys, and other essential organs, leading to a variety of medical problems. In addition, long-term heavy metal deposition in the body may also impede the advancement of physical, muscular, and neurological degenerative processes that cause disorders like Parkinson's disease and Alzheimer's disease (Jaishankar et al., 2014).

2.6 Total Maximum Daily Load (TMDL)

2.6.1 General Description of TMDL

The maximum quantity of a pollutant that can enter a water body while still allowing it to maintain the water body's ability to fulfil water quality criteria is calculated as a TMDL. A TMDL selects a pollutant reduction target and assigns the required load reductions to the polluting sources (USEPA, 2015).

The goal of a TMDL is to identify the waterbody's loading capacity and distribute that load among various polluting sources so that the proper management measures may be implemented, and water quality criteria can be met. The TMDL process is crucial for enhancing water quality because it acts as a link between the deployment of control measures to achieve water quality standards and the establishment of water quality standards. The TMDL is expressed as:

$$TMDL = \Sigma WLA + \Sigma LA + MOS \quad (2.1)$$

Where: WLA = The sum of waste load allocations from point sources (kg/day)

LA = The sum of load allocations non-point sources (kg/day)

MOS = Margin of safety (%)

2.6.2 TMDL Allocations

2.6.2.1 Waste Load Allocation (WLA)

A waste load allocation (WLA) is the fraction of the TMDL that is attributable to watershed-based point sources (Kurth & Buyck, 2010). There are several point sources (WLA) that commonly contribute to the river such as from the industries, sewage treatment plant, wet market, restaurants, food courts, fishponds, livestock farms, car wash, landfill, laundromats and so on. These point sources normally have a direct outlet to the stream and are classified first to set the limits of effluent for point source emission to attain the targeted water quality.

2.6.2.2 Load Allocation (LA)

The load allocation (LA) is the component of the TMDL that the watershed's nonpoint sources are responsible for (Kurth & Buyck, 2010). In LA, the common contributors are industrialization, land clearing and development, clearance of oil palms and rubber trees, encroachment of oil palms into river reserve, overgrazing near riverbank and so on.

These non-point sources normally produced from several sources with no particular point of basis.

2.6.2.3 Margin of Safety (MOS)

The margin of safety (MOS) provides a comprehensive description of the level of protection for a waterbody by accounting for uncertainties in the total maximum daily load (TMDL) planning process and the variabilities involved in modelling systems. A margin of safety (MOS) determination is necessary as part of the TMDL formulation process. Any ambiguity regarding the link between pollution loads and the quality of the receiving waterbody is taken into consideration by the MOS component of a TMDL (Dors & Tsatsaros, 2012).

2.7 Geospatial Mapping using ArcGIS

2.7.1 Introduction to GIS

A Geographic Information System (GIS) is a software program that aids in the digitization of our surroundings. Government organizations, corporations, and even individuals use digital maps and location-based information to keep up with the changing speed of the world (Wanamaker, 2021). GIS is also known as a system that combines computer hardware, software, geographic data, processes, and people to manage all aspects of geographic data collection, storage, analysis, query, display, and output. GIS mainly concentrating on the procedures and strategies for sampling, representing, manipulating, and presenting data about the world (Estoque, 2010). Plus, when dealing with map and non-graphic attribute data, GIS gives tools to increase efficiency and effectiveness (Tsihrintzis et al., 1996). It is employed as computer cartography, or computerized mapping, at its most basic level. The actual strength of GIS comes from its ability to examine characteristics and geographic data using spatial and statistical methodologies. The analysis can provide derived information, interpolated information, or prioritized information as a consequence (Gopi et al., 2022).

2.7.2 Mapping in GIS

One of the most efficient methods to communicate data is by using GIS maps. Gigante (2019) stated that GIS mapping is the technique of constructing a map by entering data layers into GIS software. Maps provide consumers with easily readable information that raw data cannot. Because people absorb information more effectively when looking at a visual depiction of data rather than a numerical dataset, GIS mapping, which converts data into maps, is the most effective approach to show geographical data. Mainly, GIS software includes a place where users may enter all of the statistical data that will be shown on a map. To reflect said data, the related map is updated in actual time.

Geographers and other professionals also can make use of GIS mapping to assess the distance and relationship between geographical places using spatial analysis. This allows us to better comprehend the globe, geography, and climate by allowing us to pull out fresh facts and data on precise locations for geographers to geocode (Gigante, 2019).

There are several types of GIS maps that are commonly used which includes category maps, heat maps and cluster maps. The most popular and basic sort of GIS map is the category map. Using the IGIS Map Converter Tool, a GIS category map may be readily constructed. The GIS Category map aids us in visualizing and identifying the location's category. Categorization is a prerequisite for map users to readily evaluate and comprehend the data (Upadhyay, 2018). In terms of GIS, heat mapping is a means of displaying the spatial clustering of a phenomena. Heat maps, often known as hot spot mapping, depict areas with higher concentrations of geographic entities. Heat mapping is a method of spatially displaying areas in order to identify patterns of higher-than-average occurrences of things like crime, traffic accidents, and retail locations (Dempsey, 2012). Lastly, cluster maps are yet another approach to show the density of a specific category in a given region. When a layer has hundreds or thousands of points that overlap and cover each other, clustering helps you to detect patterns in the data that are difficult to perceive (Gigante, 2019).

2.7.3 GIS Applications in River Quality Management

Geographic Information System (GIS) has been adopted and applied by many researchers in their studies when involving river quality management. GIS has a variety of applications and is hence of significant interest in a variety of disciplines of study due to its tremendous capacity to analyses spatial data (Khatami & Khazaei, 2014).

For example, GIS has been used in simulating the flood in the Baitarani river Basin, India. The major goal of this work is to create a flood danger map using a geographic information system (GIS) that considers six flood causative characteristics and investigates its impact on flood magnitude prediction. It is confirmed that the findings of the study may be used to assist national and local governments in planning future growth and building new infrastructure that is acceptable for the local environmental conditions for safeguarding the lives and property of residents in the studied region (Samantaray et al., 2022). GIS has been effectively used as a geographical analysis tool in practically every area where spatial data has been gathered (Alssgeer et al., 2018).

Besides, nowadays the recent advancements in remote sensing (RS) techniques have enabled the acquisition of water quality data at geographical and temporal resolutions that are beyond the capability of rare and point scale in-situ measurements. Remote sensing is often related to GIS as an approach in studying water quality issues. The goal of this study is to propose an integrated strategy to addressing water quality