ASSESSMENT OF RIVER WATER QUALITY USING WATER QUALITY INDEX (WQI) IN URBAN, SUBURBAN AND RESIDENTIAL AREAS IN KELANTAN RIVER

by

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A report submitted in fulfillment of the requirements for the degree of Bachelor of Applied Science (Sustainable Science) with Honours

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THESIS DECLARATION

I hereby declare that the work embodied in this Report is the result of my own original research and has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

…………………………………………..

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Date : 24th January 2021

I certify that the Report of this final year project entitled Assessment of River Water Quality Using Water Quality Index (WQI) in Urban, Suburban and Residential Areas in Kelantan River by Fatin Syamimi Binti Radin Nizar, matric number E17A0010 has been examined and all correction recommended by examiners have been done for the degree of Bachelor of Applied Science (Sustainable Science) with Honors, Faculty of Earth Science, University Malaysia of Kelantan.

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Assessment of River Water Quality using Water Quality Index (WQI) in Urban, Suburban and Residential Areas in Kelantan River

ABSTRACT

Kelantan River is the main river in Kelantan, and it is been relied for water sources for irrigation, small-scale fishing industries and receive wastewater effluent. This research study is aims to identify the significant difference in water quality index (WQI) and its parameters and the correlation between WQI and its parameters in urban, suburban and residential area along Kelantan River. Water quality stations in urban, suburban and residential areas had been selected with facilitation of ArcMap 10.0 software. International Business Machines Corporation Statistical Package for the Social Sciences (IBM SPSS Statistics) software is utilized to analyzed WQI and its parameters using analysis of variance (ANOVA) and Pearson correlation to correlate between WQI and its parameters. From this research, there is no significant difference in water quality between urban, suburban and residential areas along Kelantan River. The correlation of water quality parameters vary between locations which indicates different water pollution contributors except correlation between BOD and COD, pH and AN, and TSS and WQI. WQI in urban, suburban and residential areas were classified in Class II from 2015 until 2019 except WQI in residential area in 2019 which was classified in Class III. This study will provide scientific reference for future use to protect local aquatic environment in Kelantan River and also can be used to manage the river basin development in future.

Penilaian Kualiti Air Sungai Menggunakan Indeks Kualiti Air (WQI) di Kawasan Bandar, Pinggir Bandar dan Kediaman di Sungai Kelantan

ABSTRAK

Sungai Kelantan adalah sungai utama di Kelantan dan merupakan sumber air untuk pengairan, industri perikanan berskala kecil dan menerima air sisa. Kajian ini bertujuan untuk mengenal pasti perbezaan yang signifikan dalam indeks kualiti air (IKA) dan parameternya serta hubungan antara IKA dan parameternya di kawasan bandar, pinggir bandar dan kediaman di sepanjang Sungai Kelantan. Stesen kualiti air Jabatan Alam Sekitar (JAS) di bandar, pinggir bandar dan kawasan kediaman masing-masing telah dipilih dengan bantuan perisian ArcMap 10.0. Perisian *International Business Machines Corporation Statistical Package for the Social Sciences* (Statistik IBM SPSS) telah digunakan untuk menganalisis data IKA dan parameternya menggunakan analisis varians (ANOVA) dan korelasi Pearson untuk mendapatkan korelasi antara IKA dan parameternya. Dari kajian ini, tiada perbezaan yang signifikan antara kualiti air di kawasan bandar, pinggir bandar dan kawasan perumahan di sepanjang Sungai Kelantan. Korelasi parameter kualiti air berbeza antara lokasi yang menunjukkan penyumbang pencemaran air yang berbeza kecuali korelasi antara BOD dan COD, pH dan AN, dan TSS dan WQI. WQI di kawasan bandar, pinggir bandar dan kediaman diklasifikasikan dalam Kelas II dari tahun 2015 hingga 2019 kecuali WQI di kawasan perumahan pada tahun 2019 yang diklasifikasikan dalam Kelas III. Kajian ini akan memberikan rujukan ilmiah untuk digunakan pada masa hadapan untuk melindungi persekitaran akuatik tempatan di Sungai Kelantan dan juga dapat digunakan untuk mengurus pengembangan lembangan sungai di masa hadapan.

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LIST OF ABBREVIATIONS

AN	Ammoniacal Nitrogen
ANOVA	Analysis of Variance
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DOE	Department of Environment
DOSM	Department of Statistics Malaysia
IBM SPSS	International Business Machines Corporation Statistical Package for the Social Sciences
KB	Kota Bharu
KK	Kuala Krai
pH	Potential of Hydrogen (pH)
SIAN	Subindex Ammoniacal Nitrogen
SIBOD	Subindex Biochemical Oxygen Demand
SICOD	Subindex Chemical Oxygen Demand
SIDO	Subindex Dissolved Oxygen
SIpH	Subindex Potential of Hydrogen (pH)
SISS	Subindex Total Suspended Solids
TM	Tanah Merah
TSS	Total Suspended Solids
UNICEF	United Nations Children's Fund
USGS	United States Geological Survey
WQI	Water Quality Index
WWF	World Wide Fund

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Water covered 71% of the Earth's surface with 96.5% of it is salt water in ocean while 3.5% of water is exists as water vapour, lakes and rivers, icecaps and glaciers, in the ground as groundwater and aquifers (USGS, 2020). The accessible surface water such as rivers and streams are relied for human use and are very important for human survivability. Rivers play vital role in sustaining the economy and quality of life. River makes the surrounding soil fertile for agricultural activities. Generally, it is an important source of water for drinking, sanitation and hygienic usage for human and water is also important for livestock farming and agricultural activities. River also can generate power through hydrological power stations in dams.

In ancient time, every development of civilization begins at river area before developing into a big civilization in the world. As example, a historical region of Mesopotamia in Western Asia is located within the Tigris-Euphrates River and Indus Valley Civilization, a historical region in north western of South Asia is located within Indus River. These historical activities prove that river is a vital element in civilization development in entire earth. Today, Malaysia residents depends on river as main water resources. In developing area, the water from the river will be treated in water treatment plants before been utilize by residents while in inland area which is not equipped with water treatment plants often use raw water from river. The quality of raw water from river is depends on the activities along the river.

In Kelantan, the main river basin which is Kelantan River has the most tributaries among other river basins. As the longest river in Kelantan, Kelantan River is flowing from Mountain Ulu Sepat which is in Perak state of Malaysia to South China Sea (Ibbit et al., 2002). It flows through seven main towns named Kuala Krai, Tanah Merah, Machang, Pasir Mas, Tumpat, capital of Kelantan; Kota Bharu and Pengkalan Chepa. The river also has pass through many urban, suburban and residential areas for daily source of water. The activities near river influence the water quality directly and indirectly according to the sources of pollution.

Pollution and contamination have very close definition. Pollution is a presence of harmful or hazardous substance into the environment while contamination is a presence of unwanted, impurity and constituent elements. Water pollution is one of the main environmental concern because surface water will be scarce and limited in future if not well-managed. Water pollution contributors can be categorized as organic and chemical pollutants and contaminants. Organic pollutants and contaminants exist as oil spills, hormones, dyes, pesticides, herbicides and fungicide. Organic pollutants also can be found as suspended solids in sediments. Chemical pollutants and contaminants are existing as chemical fertilizers which increase the amount of nitrogen (N), phosphorus (P) and potassium (K). In addition, there are two types of water pollution sources which are point source and non-point source pollution.

Recently in 2019, water pollution has affected the health of Orang Asli residents at Kuala Koh located in Gua Musang in Kelantan. Their water resources from nearer river and hill have been polluted by manganese and steel mining activities. Other than pollution in Gua Musang, Kim Kim River also has been polluted by harmful and toxic chemicals which has been dumped into the river by irresponsible party which resulted in health interference among residents along the river. This environmental disaster has proven that river is not a suitable dumping site for various wastes from industries.

Water quality is important as it ensures the quality of environment, life and human well-being. Water resources can be used directly for drinking purpose, sanitation, hygiene purpose for human, agriculture activities and livestock farming. However, these activities need a good water quality. Good water quality also important for water ecosystem as sensitive aquatic animals and plants can be found in good water quality area. Superior management of water quality is compulsory and important for human well-being and avoid endangering aquatic living things. Nevertheless, egocentricity among people can contribute to poor water management thus deteriorating water quality which brings bad implications to environment and human health such as dying ecosystem, depletion of fish stocks in the river and water-borne diseases.

To achieve good water quality, a standard of Water Quality Index (WQI) is published for water quality assessment relation to pollution (Hee et al., 2019). There are six parameters in calculating WQI which are Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH

(Potential of Hydrogen), Total Suspended Solids (TSS) and Ammoniacal Nitrogen (AN). Department of Environment (DOE) has been monitoring water quality to determine the status of river and to detect changes in river water quality annually. Then, the results of WQI of rivers are reported in Environmental Quality Report (EQR) in River Water Quality Section.

WQI of water is strongly depends on the abundance of pollutants and contaminants. By reasons of that, WQI values vary in different areas because of different activities. Thus, three different locations could obtain three different results at locations either WQI value or parameters used in WQI calculations. Urban, suburban and residential areas are three different areas with different environment.

Urban area is region surrounds by city and is very developed. Urban area has a density of human population building structures such as houses, commercial buildings, roads, and railways (National Geographic, 2020). Urban city citizens have non-agricultural jobs as the jobs in urban areas have more tendencies to administration and office jobs. Commercial areas in urban may contribute to pollution because of mismanagement of solid waste or direct wastewater discharge. Direct wastewater discharge is often related to small industry that have not enough equipment for treating waste. In the end, river always be a final destination of many types of solid and liquid matters.

Suburban area is defined as small urban area at the outside of city area. This region has less density of population than urban area. The suburbs often have single-family house, stores and services (National Geographic, 2020). The human structures in suburban area are not dense as structures in urban area. Suburban offers residential place for those who work near town.

Residential area is an area with high density of houses and likely to be permanent residence area with no industries or commercial areas. The residential area can be one of polluted area especially in village area not equipped or not enough equipped large waste disposal which prepared by local authority. The villagers who unaware of environmental awareness and water pollution would dump the waste into the river.

1.2 Problem Statement

Parameters for Water Quality Index (WQI) values are differ based on different areas. Urban, suburban and residential areas are three different areas probably contribute to different values of WQI parameters which are Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammoniacal Nitrogen (AN), Total Suspended Solids (TSS) and pH (Potential of Hydrogen). WQI can predict changes and trends in river water quality status (Juahir, 2011).

Kelantan River is the main river in Kelantan and it is been relied for water sources for irrigation, small-scale fishing industries and receive wastewater effluent. As stated in Environmental Quality Report, the most significant parameters in WQI are BOD, AN and TSS (DOE, 2017). Generally, these parameters are significant in Malaysia rivers. There was limited study conducted on the correlation of WQI in urban, suburban and residential areas in Kelantan. The information about the comparison on WQI in selected areas were also limited. Therefore, this research study aims to identify the significant parameters in WQI and to correlate the WQI values in urban, suburban and residential area along Kelantan River.

1.3 Objectives

Objectives of this study are as follows:

i. To compare Water Quality Index (WQI) and its parameter in urban, suburban and residential area in Kelantan River using statistical analysis.

ii. To correlate Water Quality Index (WQI) parameters of river in Kelantan River using Pearson correlation.

1.4 Scope of Study

River water quality data which are Water Quality Index (WQI) and its parameters of urban, suburban and residential areas in Kelantan River had been analyzed. The parameters in WQI are included Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammoniacal Nitrogen (AN), Total Suspended Solids (TSS) and pH (Potential of Hydrogen). The river water quality datas were obtained from Department of Environment (DOE) Malaysia. Therefore, Kota Bharu represented urban area, Kuala Krai represented suburban area and Tanah Merah represented residential area. Data analysis were executed using International Business Machines Corporation Statistical Package for the Social Sciences (IBM SPSS Statistics) and Microsoft Excel softwares. WQI and its parameters data were analyzed using analysis of variance (ANOVA). Pearson correlation was utilized to correlate between WQI and its parameters.

1.5 Significance of Study

The yearly mean Water Quality Index (WQI) and its parameters of three different stations in urban, suburban and residential areas were shown. The correlations between water quality parameters were analyzed. Moreover, WQI correlations between locations were analyzed. The outcomes from this research are primarily to provide awareness to the communities about the importance of taking care the river thus reducing water pollution. Results of WQI and its parameters showed the significant parameters influencing the values of WQI in the different areas. In short, the communities resided nearby Kelantan River would know the main factors of pollution in the mentioned areas. Besides, this research would provide scientific reference for future use to protect local aquatic environment and could be used to manage the river basin development in future in Kelantan River.

CHAPTER 2

LITERATURE REVIEW

2.1 Roles of Rivers

River provides critical goods and services to human and environment in many different ways including drinking purpose, recreational area, agricultural activities and hydrological power generation and habitats of many organisms (Khooroshi et al., 2016). River is an important element in hydrological process. However, these good and services may have been disturbed by human.

Freshwater ecosystem plays vital roles in the lives of human, providing critical services, acting as basis for economic activities including agriculture and also a wide range of regulating and cultural services (Meng et al, 2011). Development and human population growth can cause water stress. Because of that, a superior plan of development is needed to maintain the irreplaceable freshwater ecosystems. Natural flow of river maintain and support ecological processes thus man-made alteration to water environment can significantly change the environment, ecosystem and organisms species in water. For hydrological power generation, storage dams, water diversions and run-of-the-river dams are built in river basin and bring huge impact to river ecosystem as it stops flowing (WWF, 2006).

2.2 Rivers in Malaysia

In Malaysia, 60% of major rivers are used for domestic usage, agricultural activities, and industrial manufactures. These water usages have led to major pollution in Malaysia (Juahir et al., 2011). According to Huang et al. (2015), the most significant water quality parameters in Malaysia rivers are biochemical oxygen demand (BOD), Ammoniacal Nitrogen (AN) and Total Suspended Solids (TSS) due to livestock farming, untreated or partially treated sewage from manufactures and agro-based industries.

In Kelantan, which is a Malaysia state located at the east coast of Peninsular Malaysia, main river basin is Kelantan River which is facing the South China Sea in Kelantan. Kelantan River is flowing through the capital city of Kota Bharu and it provides various benefits for irrigation for plantation, agricultural, sand mining activities, small scale fishing industries and also receive wastewater treatment effluent (Hee et al, 2019). Increasing population growth in the area has resulted water stress and water pollution as the usage of water increase. Usually, in developing country includes Malaysia, the wastewater from industries and domestic has been discharged into the surface water because lack of improper wastewater treatment facilities (Joshua et al., 2017).

2.3 The Sources of Pollution

Pollution can exist everywhere, anywhere and nowhere without any realization. Water pollution is generally induced by humans (Owa, 2014). The growth of human population, agricultural activities and industrial has been a great water stress contributor.

Over exploitation of water resources, lack of awareness and knowledge of people cause water quality degradation. Water pollution can be contributed by organic and inorganic pollutants in solid and liquid form depends on the activities along the water resources. Therefore, there are two types of sources that contribute to water pollution known as point source pollution and non-point source pollution.

Point source of pollution is a direct and identifiable source of pollution. As example, the wastewater effluent discharged from pipes attached to a manufacture factory and industries which affects most near area. Point sources pollution is easy to managed as it can easily been identified. The wastewater from industries has lots of contaminants and pollutants consist of biological and unbiological contaminants that can affect the natural water resource especially surface water such as rivers and lakes (Ijaz et al., 2016).

The second type of source of water pollution is non-point source of pollution. This type of pollution source is unidentifiable specific polluters and pollution arrived in water from nowhere. Agricultural run-off and contaminants seeping through the ground into groundwater are the example of non-point pollution source (Singh & Gupta, 2016). Unlike point sources pollutions, non-point sources pollutions are more difficult to monitor and control.

Owa (2014) stated sewage is the biggest pollutant of fresh water when directly discharge into the water. Discharging untreated sewerage affects unhealthy consequences to human and aquatic organisms. Dissolved oxygen will be used up by decomposers to break down sewage pollutants. Other than that, fertilizers from agricultural areas would cumulate amount of nutrients such a potassium (K), phosphorus (P) and nitrogen (N). Excess amount of phosphorus and nitrogen in water cause eutrophication. Eutrophication is the process which water body is enriched by nutrients though algae and other aquatic plants will grow surface of water which leads to restricted amount of sunlight to be penetrate into water. This situation will cause the aquatic plants in the water cannot undergo photosynthesis process and cause depletion of dissolved oxygen in water.

The pollutants and contaminants influence the water quality status directly. Each water quality parameters can indicate water quality status. Specific pollutant such as sewerage affects specific water quality parameter which is Ammoniacal Nitrogen (AN).

2.4 Water Quality

Water quality need to be monitored for every water resource before been utilize in daily life. Water scarcity gives a lot of bad impacts towards environment and human well-being especially children. United Nation Children's Fund (UNICEF) reported 85,700 children under-15 die from diarrhoeal disease every year due to lack access to safe water sources, sanitation and hygiene facilities. Annually, 72,000 under-fives children died because of similar illness (UNICEF, 2019). There are many standards for water quality that have been published. Every water quality standard are unique according to regions. In Malaysia, National Water Quality Standard (NWQS) has been published by Department of Environment (DOE).

2.4.1 Water Quality Index (WQI)

Department of Environment (DOE) of Ministry of Environment and Water which is responsible to prevent, eliminate, control pollution and improve environment has published National Water Quality Standards for Malaysia (NWQS). Thus, Water Quality Index (WQI) in NWQS is being used for determining water quality status of river in Malaysia. WQI is designated to show and to achieve good water quality surface water (Hee et al., 2019). WQI is a comprehensive way to show water quality status (Baghapour & Shooshtarian, 2017). As shown is Table 2.1 (DOE, 2006), DOE Water Quality Index Classification has six parameters to be counts in which are Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH (Potential of Hydrogen), Total Suspended Solids (TSS) and Ammoniacal Nitrogen (AN).

Table 2.1 DOE water quality index classification

Parameter	Unit	Class				
		I	II	III	IV	V
Ammoniacal Nitrogen	mg/L	< 0.1	0.1 - 0.3	0.3 - 0.9	0.9 - 2.7	> 2.7
Biochemical Oxygen Demand	mg/L	< 1	1 - 3	3 - 6	6 - 12	> 12
Chemical Oxygen Demand	mg/L	< 10	10 - 25	25 - 50	50 - 100	> 100
Dissolved Oxygen	mg/L	> 7	5 - 7	3 - 5	1 - 3	< 1
pH	-	6.5-8.5	6 - 9	5 - 9	5 - 9	-
Total Suspended Solids	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

(Source: DOE, 2006)

Water Quality Index (WQI) is calculated based on the Eq (2.1):

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

Where, SIDO = Subindex Dissolved Oxygen, SIBOD = Subindex Biochemical Oxygen Demand, SICOD = Subindex Chemical Oxygen Demand, SIAN = Subindex Ammoniacal Nitrogen, SISS = Subindex Total Suspended Solids and SIpH =

Subindex pH. Based on Eq (2.1), every subindex parameters represents an amount of percentage to WQI. SIDO, SIBOD, SICOD, SIAN, SISS and SIpH represents 22%, 19%, 16%, 15%, 16% and 12% respectively.

Water quality classes have been divided to five major classes with Class II is divided into two categories as listed in Table 2.2 (DOE, 2006).

Table 2.2 Water classes and uses

Class	Uses
Class I	Conservation of natural environment. Water supply I - Practically no treatment necessary. Fishery I - Very sensitive aquatic species.
Class IIA	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, 2006)

2.4.2 Water Quality Index (WQI) Parameters

There are six important parameters contribute in Water Quality Index namely Dissolved Oxygen(DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH (Potential of Hydrogen), Total Suspended Solids (TSS) and Ammoniacal Nitrogen (AN).

Dissolved Oxygen (DO) is considered to be one of the most important water qualities in streams, rivers and lakes. Aquatic organisms need DO to live in the water. DO is a measurement of dissolved oxygen in the water. It indicates how much oxygen presents in the water for aquatic organisms. The higher value of DO concentration shows the better the water quality. DO is slightly soluble in water and is produces by aquatic plants that undergo photosynthesis in water and mixing of air and water. The amount of DO is depends on pressure, temperature and salinity of the water (Omer, 2019). DO depletion can cause water ecosystem died. Besides, DO has strong relationship with Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD).

Biochemical Oxygen Demand (BOD) is the amount of dissolved oxygen used by bacteria and other microorganisms to break down unnecessary organic matters in water into simpler compounds such as carbon dioxide and water. Therefore, DO concentration values will be reduced as it is used up in this process. BOD is used as parameter based of organic pollution in water. BOD is a function of time. At initial time, the BOD is equal to zero. As the days pass by, the dissolved oxygen will be consumed and resulted reading of BOD increases (Omer, 2019).

Chemical Oxygen Demand (COD) is a measure of amount of oxygen consumed by chemical reactions to decompose organic matter and oxidize inorganic and particulate matter in water. COD is a widely used parameter in determining the water quality. COD measurement is likely to be higher in area which contaminated by chemical contaminants which resulted in depletion of DO in water thus reducing the survivability of aquatic organisms. The measurement of COD can be gained through chemical test using strong oxidizing agents, strong acids and heat (Omer, 2019).

Next, pH (Potential of Hydrogen) indicates the measurement of relative amount of free hydrogen and hydroxyl ions in water. pH is defined as the negative logarithm of the hydrogen ion concentration which indicates the strength of acidic or basic solution. The common rain is slightly acidic due to carbon dioxide in atmosphere. Most aquatic animals and plants have adapted with the normal pH in the environment, thus a small change of pH would be a suffer condition for them. Change in pH can dissolve chemicals into the water which affect the aquatic ecosystems (Omer, 2019). pH affects the toxicity of water directly as acidic water can solute harmful substances in water such as heavy metals.

Total Suspended Solids (TSS) is small particles that are not dissolved in water and become sediments in sedimentation process. TSS is often linked to run-off which is draining water from higher area to lower area. Deforestation near to river area and heavy rain will cause heavy run-off and bring soil into the streams as the impact of rain splash erosion. It is important to cover 50% of soils to avoid soil loss on the embankments and to mitigate the concentration of TSS in water ways (Shah et al. 2014).

Lastly, Ammoniacal Nitrogen (AN) is an indicator of pollution from sewerage and it is toxic to its surrounding. AN is a natural product of decaying organic pollutants in water and very soluble in water. The pollutants that influence AN can be brought from fertilizers, manures, leachate and wastewater discharge. AN which its formula written as NH_3-N can be oxidized using oxygen and converted into nitrate nitrogen (NO_3-N). Aerobic bacteria are responsible to for the decay process of ammonia. The ammonia nitrogen decay rate of river water under tropical environment of Malaysia is range between 0.194 and 0.554 per day (Nuruzzaman et al. 2016).

2.5 Water Quality Index (WQI) in Kelantan River

In EQR 2017, 219 (46%) out of 477 rivers monitored were found to be clean, 207 (43%) rivers were found to be slightly polluted and 51 (11%) rivers are polluted (DOE, 2017). In Kelantan, there are three main river basin which are Golok River basin, Kelantan River basin and Kemasin River basin. Kelantan River of river basin has at most tributaries among the other river basins in Kelantan. The tributaries are named Ber River, Pergau River, Belatop River, Tuang River, Lebir River, Nenggiri River, Berok River, Galas River, Betis River, Kerilla River, Nal River, Relai River Sokor River and Kelantan River. According to DOE (2017), in 2017, all tributaries except Kelantan River were classified as Class II with WQI values were above 82 and categorized as clean river. Kelantan River had been classified in Class II with WQI value of 79 and was categorized as slightly polluted river. The classification of river water quality based on WQI is shown in the Table 2.3 (DOE, 2006).

Table 2.3 DOE water quality classification based on water quality index

SUBINDEX & WATER QUALITY INDEX	INDEX RANGE		
	CLEAN	SLIGHTLY POLLUTED	POLLUTED
Biochemical Oxygen Demand	91 - 100	80 - 90	0 - 79
Ammoniacal Nitrogen	92 - 100	71 - 91	0 - 70
Total Suspended Solids	76 - 100	70 -75	0 - 69
Water Quality Index	81 - 100	60 - 80	0 - 59

(source: DOE, 2006)

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Area

The study area encompasses along Kelantan River basin in Kelantan. Kelantan River flows from the north-east Malaysia through capital city of Kota Bharu, Kelantan to South China Sea (longitude 101˚ 20’ to 102˚ 20’ N and latitude 4˚ 40’ to 6˚ 12’ E). Water Quality Index data of water stations along River Kelantan which is in urban, suburban and residential areas were obtained.

Kelantan River flows from South to North Kelantan facing Southeast China Sea. It flows through important cities in Kelantan including Kota Bharu, Tanah Merah and Kuala Krai. Based on the land use and population of the locations, Kota Bharu represents urban area, Kuala Krai represents suburban area and Tanah Merah represents residential areas.

The locations were selected based on suitability of locations meeting the criteria of urban, suburban and residential areas. In 2018, population in Kota Bharu is 596,900 approximately while population in Kuala Krai is about 135,200 and population in Tanah Merah is approximately at 149,200 (DOSM, 2018). DOE water quality stations are located at Sultan Yahya Petra Bridge in Kota Bharu, Guillemard Bridge in Tanah Merah and Tangga Krai in Kuala Krai.

The surrounding area at Sultan Yahya Petra Bridge, Kota Bharu is dense with buildings and infrastructures along Kelantan River. Thus, Kota Bharu is densely populated and is known as urban area in Kelantan. The surrounding area at Tangga Krai, Kuala Krai is less dense with buildings and infrastructures than Kota Bharu, qualifying to represent suburban area. Lastly, the surrounding area at Guillemard Bridge, Tanah Merah is the least dense with buildings and infrastructures. However, Tanah Merah has housing area nearby Kelantan River, thus, Tanah Merah is suitable to represent residential area in this study. Figure 3.1, Figure 3.2 and Figure 3.3 show the surrounding areas at Sultan Yahya Petra Bridge, Kota Bharu; Tangga Krai, Kuala Krai and Guillemard Bridge, Tanah Merah.

Figure 3.1 Surrounding area at Sultan Yahya Petra Bridge, Kota Bharu. (Source: Google)

Figure 3.2 Surrounding area at Tangga Krai, Kuala Krai. (Source: Google)

Figure 3.3 Surrounding area at Guillemard Bridge, Tanah Merah. (Source: Google)

Moreover, the selection of DOE water quality stations also based on the sufficiency of water quality data for five years from 2015 to 2019. DOE water quality stations namely 4KE01,4KE06, 4KE19 were selected representing river water quality in urban, suburban and residential areas in Kelantan River as shown in Table 3.1.

Table 3.1 Selected water quality stations characteristics

Station No.	Area	Location	Latitude	Longitude
4KE01	Residential	Tanah Merah	102.151374	5.775413
4KE06	Urban	Kota Bharu	102.227101	6.116425
4KE19	Suburban	Kuala Krai	102.195505	5.534445

Using ArcMap 10.0 software, urban, suburban and residential areas along with DOE water quality stations were selected. Figure 3.4 shows the map of study area in Kelantan River. Kota Bharu, Kuala Krai and Tanah Merah and DOE water quality stations were marked in Figure 3.4.

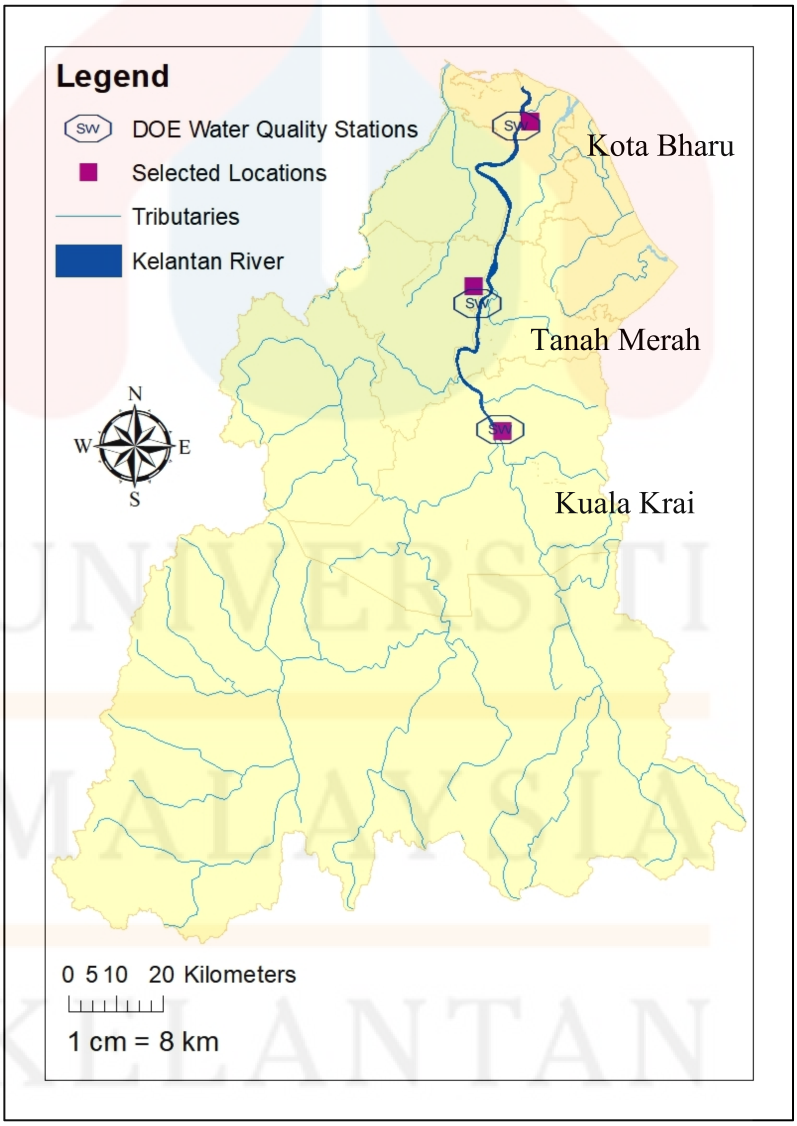

Figure 3.4 Map of study area in Kelantan River basin and locations of DOE water quality stations

3.2 Data Collection

Water Quality Index (WQI) and its parameters data from 2015 until 2019 were obtained from Department of Environment (DOE). The data acquisition was applied using data application form on Official Portal of Department of Environment. The required data are Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH, Total Suspended Solids (TSS) and Ammoniacal Nitrogen (AN). Three DOE water quality stations located along Kelantan River has been selected to fulfil the characteristics of urban, suburban and residential areas which are Kota Bharu, Kuala Krai and Tanah Merah respectively.

3.3 Statistical Analysis

International Business Machines Corporation Statistical Package for the Social Sciences (IBM SPSS Statistics) software was utilized to run Analysis of Variance (ANOVA) and Pearson correlation. ANOVA was utilized for determining significant value to compare parameters in Water Quality Index (WQI) and determined the effect size values of every parameter in Kota Bharu, Kuala Krai and Tanah Merah.

The correlation analysis was analysed using Pearson correlation. The correlation analysis was able to identify the association of WQI parameters. Direct correlation in Pearson correlation is exists when increase or decrease in the value of parameter is associated with a corresponding increase or decrease value of another parameter.

Pearson's correlation has two types of correlation which are positive correlation and negative correlation. The Pearson coefficient is denoted as r. The Eq (3.1) shows range of r is from -1 to +1 with 0 means no correlation between variables.

Positive correlation is when *r*-value is positive, *r*-value more than zero and negative correlation is when *r*-value is negative, value less than zero.

$$-1 < r < +1 \tag{3.1}$$

The strength of Pearson's correlation in this study is classed into Table 3.2 below (Evan, 1996):

Table 3.2 *r*-value and strength of correlation

r-value	Strength of correlation
0.00-0.19	Very weak
0.20-0.39	Weak
0.40-0.59	Moderate
0.60-0.79	Strong
0.80-1.0	Very strong

3.3.1 Descriptive Analysis

The mean of WQI, its parameters and subindex parameters were obtained from descriptive analysis using IBM SPSS Statistics software. The trend analysis of WQI and its parameters was shown in Figure 4.1.

3.3.2 Comparisons of Water Quality Index (WQI) and Its Parameters Between Urban, Suburban and Residential Areas

WQI and its parameters in urban, suburban and residential areas were compared using Analysis of Variance (ANOVA). The significant difference, sum of squares, mean of squares and effect size in selected areas were shown in Table 4.5. The effect size values were determined from sum of squares of every parameter.

3.3.3 The Correlation Between Parameters In Water Quality Index (WQI)

Correlation between water parameters in WQI were analyzed to indicate the association between two parameters (variables) of six parameters in WQI. Besides, the most influence parameter in WQI calculation will be identify in correlation analysis between six parameters and WQI value in the area either in urban, suburban and residential areas.

3.4 Research Flowchart

Figure 3.5 below shows the research flowchart from data collection to results acquisition.

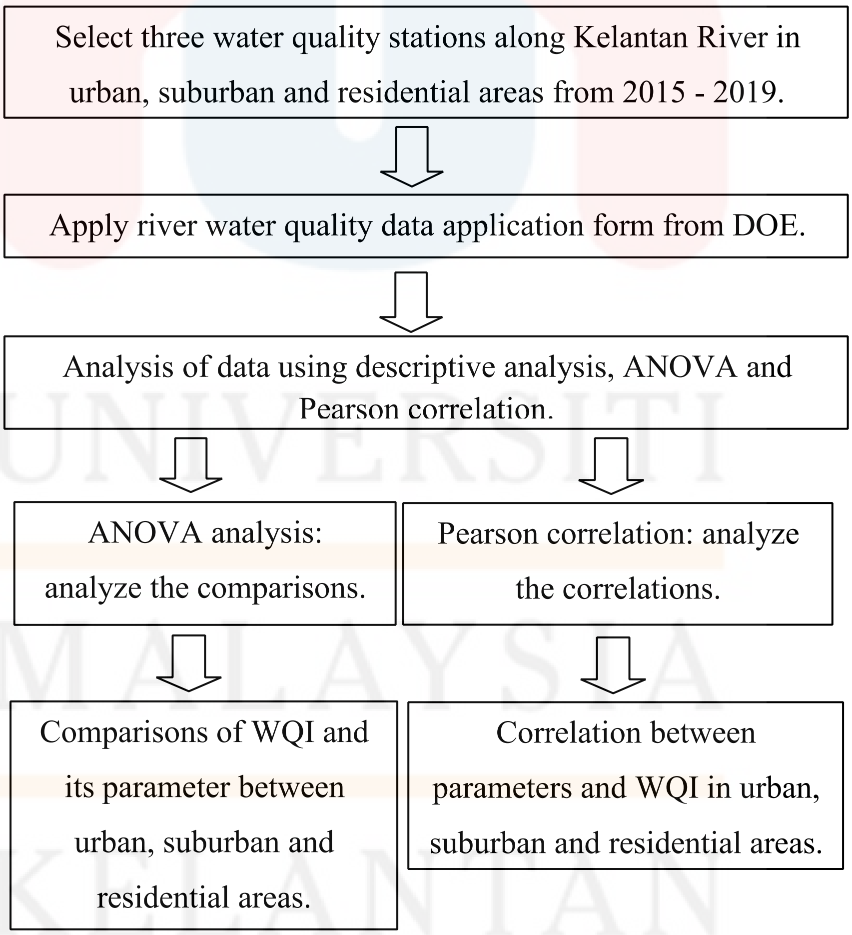

Figure 3.5 Research Flowchart

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Descriptive Analysis

Kota Bharu, Kuala Krai and Tanah Merah were selected to represent urban, suburban and residential areas in Kelantan River. Therefore, descriptive analysis of Water Quality Index (WQI) and its parameters in three selected locations were analyzed using International Business Machines Corporation Statistical Package for the Social Sciences (IBM SPSS Statistics) software to attain the yearly mean of every parameter from 2015 to 2019. The yearly mean of parameters which are Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), pH and Ammoniacal Nitrogen (AN), and WQI are shown in Table 4.1.

Table 4.1 Yearly mean of WQI and its parameters

Area	Location	Year	Parameters						
			DO	BOD	COD	TSS	pH	AN	WQI
Urban	Kota Bharu	2015	6.19	5.40	17.20	45.40	7.07	0.07	84.66
		2016	5.93	5.60	16.02	244.80	6.50	0.65	76.23

Table 4.1 (continued)

		2017	6.73	4.40	15.20	452.20	6.85	0.14	79.83
		2018	7.53	5.50	20.17	286.83	7.29	0.12	80.76
		2019	7.32	6.33	21.67	309.33	7.68	0.12	78.81
Suburban	Kuala Krai	2015	5.59	7.00	24.30	27.60	7.20	0.06	82.57
		2016	6.26	6.40	22.20	52.20	6.59	0.53	82.37
		2017	6.91	4.40	15.20	370.60	6.88	0.07	80.19
		2018	7.44	6.17	19.67	641.67	7.41	0.11	78.24
		2019	7.34	3.83	13.33	1036.67	7.60	0.06	80.46
Residential	Tanah Merah	2015	5.79	4.00	13.30	71.00	7.24	0.05	84.85
		2016	6.52	5.20	16.76	158.60	6.70	1.31	77.06
		2017	6.98	5.40	18.60	557.40	6.83	0.09	77.29
		2018	7.28	6.50	23.67	431.00	6.94	0.26	76.88
		2019	7.31	5.67	20.67	403.33	7.46	0.11	70.39

The range of mean DO (mg/L) from 2015 to 2019 in Kota Bharu was between 5.93 and 7.53, while in Kuala Krai was between 5.59 and 7.44. Besides, the range of mean DO in Tanah Merah was between 5.79 and 7.30. Thus, DO in different locations was distributed approximately equal. Numerous scientific studies suggest that DO range within 4 and 5 mg/L is the least amount that will support a diverse fish population (Ching et al, 2015). According to Ongley (2009), the proposed limit for aquatic life of DO value is 5.0 mg/L in Mekong and DO value in Malaysia is 5.0 to 7.0 mg/L. Overall, DO in Kelantan River could support aquatic life within range from 2015 to 2017.

The range of mean BOD (mg/L) from 2015 to 2019 in Kota Bharu was between 4.40 and 6.33. In Kuala Krai, range of mean BOD was between 3.83 and 7.00, and the range of mean BOD in Tanah Merah was between 4.00 and 6.50. Slightly polluted rivers would have BOD of 2.0 to 8.0 mg/L, while rivers could be known to be seriously contaminated if the BOD value reaches 8.0 mg/L (Verma & Singh, 2013). Generally, BOD in Kota Bharu, Kuala Krai and Tanah Merah were not considered as severely polluted as the values did not exceed 8.0 mg/L.

The range of mean COD (mg/L) from 2015 to 2019 in Kota Bharu was between 15.20 and 21.67, while in Kuala Krai was between 24.30 and 13.33. Besides, the range of mean COD in Tanah Merah was between 13.30 and 23.67. Suggested potassium permanganate index (COD_{MN}) based on Mekong River is less than 4.0 mg/L. Acceptable value of COD based on DOE WQI Classification is less than 25.0 mg/L which the values would be classed in Class II and below (DOE 2006). The COD in Kelantan River had not exceeded the suggested value and is considered as not severely polluted.

The range of mean TSS (mg/L) from 2015 to 2019 in Kota Bharu, Kuala Krai and Tanah Merah were 45.40 to 452.20, 27.60 to 1036.67 and 71.00 to 557.40 respectively. Kuala Krai had the highest amount of TSS among the selected locations. The maximum limit of TSS that can support aquatic life is 150.0 mg/L (DOE, 2006; Rosli, 2010). All three locations had exceeded the limit value of aquatic life threshold. Based on TSS, Kelantan River had been polluted with suspended solids severely.

The typical range of pH in natural water falls between 6.0 to 8.0 (Thakre et al., 2010). Ranges of mean pH in Kota Bharu, Kuala Krai and Tanah Merah from 2015 to 2019 were 6.50 to 7.68, 6.59 to 7.60 and 6.70 to 7.46 respectively. Overall, pH value in Kota Bharu, Kuala Krai and Tanah Merah ranged within 6.5 to 7.7. Therefore, pH range in Kelantan River at Kota Bharu, Tanah Merah and Kuala Krai fell into appropriate pH range for aquatic life which are pH 6.5 to 9.0 (Al-Badaii et al., 2013). pH is under the range of values that are appropriate for local use between 6.5 and 8.5 (Akibinle et al., 2013). pH value below than this level, the water may be considered acidic and would not be suitable for domestic use, and above this range, it could be considered alkaline, containing some pollutants (Akibinle et al., 2013).

AN (mg/L) in Kota Bharu, Kuala Krai and Tanah Merah from 2015 to 2019 ranged between 0.07 - 0.65, 0.06 - 0.11 and 0.05 - 1.31 respectively. The highest AN was recorded in Kuala Krai and had exceeded the limit AN value. According to the DOE WQI classification, the maximum level of AN for Malaysian rivers that support aquatic organisms is 0.9 mg/L (DOE, 2006). Overall, AN in Kota Bharu was below than the maximum level of AN, AN in Tanah Merah was 0.2 mg/L more than the maximum level of AN and AN in Kuala Krai has exceed 0.41 mg/L from maximum level of AN. High AN is harmful for aquatic life but a small amount of AN can be a source of nutrient for excessive growth of algae (Al-Badaii et al., 2013).

Hence, range of WQI from 2015 to 2019 in Kota Bharu, Kuala Krai and Tanah Merah were 76.23 to 84.66, 78.24 to 82.57 and 70.39 to 84.85 respectively. Mean WQI in three selected locations from 2015 to 2019 were calculated using Eq (2.1) from mean subindex of WQI.

Subindex of WQI parameters are subindex DO (SIDO), subindex BOD (SIBOD), subindex COD (SICOD), subindex TSS (SISS), subindex pH (SIpH) and subindex AN (SIAN). Each subindex parameter weighs different contributions to WQI calculation as shown in Eq (2.1). Each subindex were calculated using formula from National Water Quality Standard (NWQS) For Malaysia shown in Table A.1. Descriptive analysis using IBM SPSS Statistics has calculated the yearly mean of subindex WQI parameters from 2015 to 2019 and is shown in Table 4.2.

Table 4.2 Yearly mean of subindex WQI parameters

Area	Location	Year	Parameters					
			SIDO	SIBOD	SICOD	SISS	SIpH	SIAN
Urban	Kota Bharu	2015	89.84	78.77	76.90	75.26	97.18	92.84
		2016	86.12	77.67	78.81	50.38	94.53	70.09
		2017	92.40	81.79	78.88	42.76	96.88	85.80

Table 4.2 (continued)

		2018	99.50	78.50	74.00	45.17	97.83	87.67
		2019	100.00	75.33	71.67	40.33	95.00	87.83
Suburban	Kuala Krai	2015	81.89	74.40	70.96	82.67	97.31	94.42
		2016	88.55	74.53	71.40	71.92	96.55	94.71
		2017	92.54	82.20	78.88	39.98	94.06	92.73
		2018	98.83	77.33	75.67	30.17	96.00	89.00
		2019	98.67	84.00	81.33	26.33	95.33	94.17
Residential	Tanah Merah	2015	82.22	84.28	82.14	72.89	96.98	95.36
		2016	91.42	79.33	77.89	57.46	96.65	57.51
		2017	93.38	78.81	75.39	29.34	94.91	90.84
		2018	97.33	74.33	70.00	39.33	97.50	81.00
		2019	97.83	77.33	73.00	57.00	95.67	89.67

Subindex of parameters in Kota Bharu, Kuala Krai and Tanah Merah were shown in Table 4.2. SIDO in Kuala Krai, 2015 was the lowest which was 81.89 and SIDO in Kota Bharu, 2019 was the highest which was 100.00. Tanah Merah had the highest SIBOD in 2015 and lowest SIBOD among three locations which were 84.28 and 74.33 respectively. Moreover, the lowest SICOD and the highest SICOD were recorded in Tanah Merah which were 70.00 in 2018 and 82.14 in 2015 respectively. Besides, Kuala Krai had the lowest SISS at 26.33 in 2019 and the highest SISS at 82.67 in 2015. Furthermore, SIpH was the lowest in Kuala Krai at 94.06 in 2017 and SIpH in Kota Bharu was the highest at 97.83 in 2016. Lastly, Tanah Merah had the highest SIAN which was 95.35 in 2015 and the lowest SIAN in 2016 which was 57.51.

Classification of river water quality based on Department of Environment (DOE) water quality index use SIBOD, SIAN, SISS and WQI to classify the water quality. Table 4.3 shows the classifications of river water quality in Kota Bharu, Kuala Krai and Tanah Merah from 2015 to 2019 on based on calculated SIBOD, SIAN, SISS in Table 4.2 and WQI in Table 4.1.

Table 4.3 Classification of river water quality based on DOE water quality index

Area	Location	Year	SUBINDEX AND WQI			
			SIBOD	SIAN	SISS	WQI
Urban	Kota Bharu	2015	P	C	SP	C
		2016	P	SP	P	SP
		2017	SP	SP	P	SP
		2018	P	SP	P	SP
		2019	P	SP	P	SP
Suburban	Kuala Krai	2015	P	C	C	C
		2016	P	C	SP	C
		2017	SP	C	P	SP
		2018	P	SP	P	SP
		2019	SP	C	P	SP
Residential	Tanah Merah	2015	SP	C	SP	C
		2016	P	P	P	SP
		2017	P	SP	P	SP
		2018	P	SP	P	SP
		2019	P	SP	P	SP

Where, C = Clean, SP = Slightly Polluted, P = Polluted.

Classification of water quality based on SIBOD and SISS using classification of water quality using DOE water quality index showed the river in Kota Bharu, Kuala Krai and Tanah Merah were polluted through 2015 to 2019 excluded Kota Bharu in 2017, Kuala Krai in 2017 and 2019, and Tanah Merah in 2015. However, based on SIAN and WQI, the river was clean and slightly polluted except SIAN in Tanah Merah in 2016.

Other than the classification of water quality based on DOE water quality index, the classification of river water quality using DOE WQI classification is commonly used in Malaysian rivers. Table 4.4 shows the classification of river water quality in Kota Bharu, Kuala Krai and Tanah Merah from 2015 to 2019 using DOE WQI classification. The classification is classified based on the calculated mean WQI and its parameters in Table 4.1.

Table 4.4 Classification of river water quality using DOE WQI classification

Area	Location	Year	Parameters						
			DO	BOD	COD	SS	pH	AN	WQI
Urban	Kota Bharu	2015	II	III	II	II	I	I	II
		2016	II	III	II	IV	II	II	III
		2017	II	III	II	V	II	II	II
		2018	I	III	II	IV	I	II	II
		2019	I	IV	II	V	I	II	II
Suburban	Kuala Krai	2015	II	IV	II	II	I	I	II
		2016	II	IV	II	III	II	III	II
		2017	II	III	II	V	II	I	II
		2018	I	IV	II	V	I	II	II
		2019	I	III	II	V	I	I	II
Residential	Tanah Merah	2015	II	III	II	III	I	I	II
		2016	II	III	II	IV	II	IV	II
		2017	II	III	II	V	II	I	II
		2018	I	IV	II	V	II	II	II
		2019	I	III	II	V	I	II	III

According to DOE water classes and uses (DOE, 2006) which is shown in Table 2.2, Class I and Class II are considered acceptable while Class III, Class IV and Class IV are not acceptable. Water quality classed in Class III and above required extensive water treatment before being distributed to consumers. It also can be used for livestock drinking and is only suitable for tolerant species to live in Class III condition while Class IV is only suitable for irrigation use.

Based on Table 4.4, DO, COD and pH in Kota Bharu (urban), Kuala Krai (suburban) and Tanah Merah (residential) were in acceptable water class which were classed in Class I and Class II. Thus, DO, COD and pH were acceptable in Kelantan River. Furthermore, recorded AN in Kota Bharu, Kuala Krai and Tanah Merah from 2015 to 2019 were in Class I and II which were acceptable except AN in Kuala Krai and Tanah Merah in 2016 were classed in Class III and Class IV respectively. Moreover, BOD in Kelantan River was classed in Class III and Class IV in all three locations from 2015 to 2019. Starting from 2016, TSS in Kelantan River had classed in Class III, Class IV and Class V. In 2015, TSS in Kota Bharu and Kuala Krai were in Class II which were slightly polluted (DOE, 2006).

Overall, WQI in three selected locations from 2015 to 2019 were classed in Class II except Kota Bharu in 2016 and Tanah Merah in 2019 which were classed in Class III. Based on class of WQI, Kelantan River was suitable for recreational activities except Kota Bharu in 2016 and Tanah Merah in 2019. However, conventional water treatment was needed before utilizing water from Kelantan River.

The yearly WQI and its parameters differ between urban, suburban and residential areas. The trends of WQI and its parameters in Kota Bharu, Kuala Krai and Tanah Merah from 2015 to 2019 were shown in Figure 4.1.

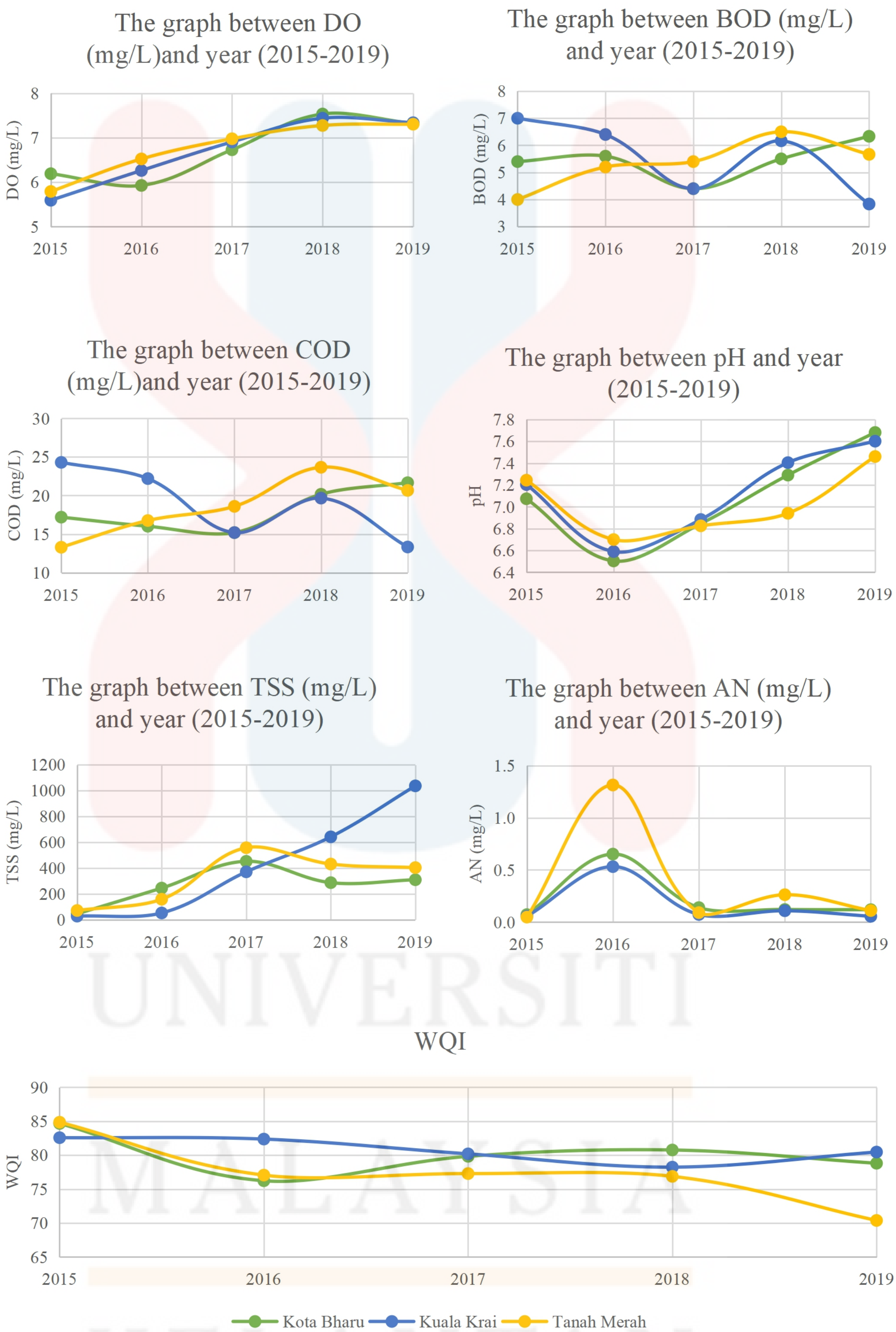

Figure 4.1 Trends of DO, BOD, COD, pH, TSS, AN and WQI in Kota Bharu, Kuala Krai and Tanah Merah (2015-2019)

The range of DO concentration in Kelantan River was from 5.5 mg/L to 7.5 mg/L. The DO in Kuala Krai and Tanah Merah rose gradually by years but DO in Kota Bharu decreased in 2016 and then continued to increase steeply until 2018. The degradation of the DO was might be due to a rise in the growth rate of the microorganisms that utilize the organic matter found in the improper disposal that was drained into the river (Zaideen et al., 2017). According to DOE WQI Classification, DO had improved in all three locations. From 2015 to 2017, DO was classed in Class II, but in 2018 to 2019, DO has improved to Class I.

The BOD in Kota Bharu and Kuala Krai fluctuated from 2015 to 2019 between 3.8 mg/L - 7 mg/L. However, in 2019, the BOD in Kota Bharu went up. BOD in Kuala Krai and Tanah Merah dropped. BOD in Kota Bharu had worsened in 2019 and dropped from Class III to Class IV. BOD in Kuala Krai had classed in Class IV in 2015, 2016 and 2018 while in 2017 and 2019, BOD in Kuala Krai were classed in Class III. Lastly, BOD in Tanah Merah was classed in Class III throughout years except year 2018. The low value of BOD suggests that there is less organic matter in the water sample to be metabolised by bacteria (Singh et al. 2016).

COD in Kuala Krai was the highest in 2015 while COD in Tanah Merah increased gradually from 2015 to 2018. Therefore, it indicated more oxygen was required to chemically oxidize organic matters in water. The trend of COD and BOD plots was quite similar which is fluctuated because COD and BOD has a strong relationship. COD and BOD are linearly correlated in most studies (Abdalla & Hammam, 2014). High COD value would specify that there were many organic contaminants such as leachate in sample (Samudro & Mangkoedihardjo, 2010). However, COD in all three locations were classed in Class II throughout years.

TSS in Kota Bharu, Kuala Krai and Tanah Merah ranged from 71 mg/L - 1036 mg/L. TSS in Kota Bharu and Tanah Merah increased from 2015 to 2017 and slightly decreased from 2018 to 2019. However, TSS in Kuala Krai increased steadily from 2016 to 2019. The increased of SS in Kuala Krai may come from nearby soil erosion caused by human activities (Al-Badaii et al., 2013). TSS has worsened from 2015 to 2019. TSS of Kota Bharu, Kuala Krai and Tanah Merah had reached Class V in 2019. The deterioration of TSS in all three locations might cause from the development nearby river and sand mining activities cause excessive particles polluted Kelantan River (Rahim et al., 2019).

All three locations recorded lowest pH in 2016. pH in Kota Bharu, Kuala Krai and Tanah Merah dropped in 2016 and then increased steadily until 2019. pH in Tanah Merah increased lower than pH in Kota Bharu and Kuala Krai. It might be due to amount of organic matter that had been decomposed in Tanah Merah was higher than other locations. The composition of organic matter in water increases carbon dioxide which is acidic in river which could lower pH (Zaideen et al., 2017). pH has improved in all locations from 2016 and classed in Class I in 2019.

AN in all three locations ranged from 0.049 mg/L - 1.314 mg/L. AN had steep increased in 2016 in Kota Bharu, Kuala Krai and Tanah Merah and then continued to fluctuate within 0.09 mg/L - 0.27 mg/L from 2017 to 2019. The highest AN recorded was in 2016 with the highest AN location is Tanah Merah, based on DOE WQI Classification, it was classed in Class IV. Thus, Tanah Merah has exceeded the maximum level of proposed AN which can support aquatic environment in 2016. Untreated sewage might have contributed into the increase of AN (Huang et al., 2015). But, in 2019, AN has improved and was classed in Class I for Kuala Krai, and Class II for Kota Bharu and Kuala Krai.

WQI in Kota Bharu, Kuala Krai and Tanah Merah steadily ranged between 84.8 and 77 from 2015 to 2019 except for Tanah Merah in 2019. WQI in Tanah Merah was deteriorating from 2015 to 2016 and from 2018 to 2019, however WQI was slightly levelled from 2016 to 2018. According to DOE WQI classification (DOE, 2006), the WQI of three locations were in Class II throughout years except Kota Bharu; 2016 and Tanah Merah; 2019 were in Class III. According to Classification Based on classification of river water quality using DOE water quality index, all of WQI in the locations were slightly polluted except Kota Bharu in 2015, Kuala Krai in 2015 and 2016, and Tanah Merah in 2015 were classified as clean. Thus, the water quality in Kelantan River recorded by three DOE water quality stations in different locations stated that the water quality has deteriorated from 2015 to 2019.

4.2 Comparisons of Water Quality Index (WQI) and Its Parameters Between Urban, Suburban and Residential Areas

The contributions of urban (Kota Bharu), suburban (Kuala Krai) and residential (Tanah Merah) area to the values of WQI and its parameters were evaluated using one-way between groups analysis of variance (ANOVA) was ran. The results are shown in Table 4.5.

Table 4.5 Table of ANOVA of WQI and its parameters

ANOVA							
Parameter	Analysis	Sum of Squares	df	Mean Square	F	Sig.	Effect Size (Ƞ2)
DO	Between Groups	3.359	2	1.680	0.025	0.976	0.004
	Within Groups	811.328	12	67.611	-	-	
	Total	814.688	14	-	-	-	

Table 4.5 (continued)

BOD	Between Groups	0.107	2	0.054	0.051	0.951	0.008
	Within Groups	12.655	12	1.055	-	-	
	Total	12.762	14	-	-	-	
COD	Between Groups	2.013	2	1.006	0.068	0.934	0.012
	Within Groups	177.253	12	14.771	-	-	
	Total	179.266	14	-	-	-	
TSS	Between Groups	64118.363	2	32059.181	0.396	0.681	0.062
	Within Groups	970609.284	12	80884.107	-	-	
	Total	1034727.647	14	-	-	-	
pH	Between Groups	0.026	2	0.013	0.086	0.918	0.139
	Within Groups	1.838	12	0.153	-	-	
	Total	1.865	14	-	-	-	
AN	Between Groups	0.107	2	0.053	0.412	0.671	0.065
	Within Groups	1.553	12	0.129	-	-	
	Total	1.660	14	-	-	-	
SIDO	Between Groups	6.001	2	3.000	0.070	0.933	0.012
	Within Groups	512.217	12	42.685	-	-	
	Total	518.218	14	-	-	-	
SIBOD	Between Groups	0.462	2	0.231	0.018	0.982	0.003
	Within Groups	151.843	12	12.654	-	-	
	Total	152.305	14	-	-	-	
SICOD	Between Groups	0.499	2	0.250	0.014	0.986	0.002
	Within Groups	208.728	12	17.394	-	-	
	Total	209.227	14	-	-	-	
SIAN	Between Groups	292.602	2	146.301	1.430	0.277	0.193
	Within Groups	1227.530	12	102.294	-	-	
	Total	1520.133	14	-	-	-	
SISS	Between Groups	2.457	2	1.228	0.003	0.997	0.00
	Within Groups	4567.654	12	380.638	-	-	
	Total	4570.111	14	-	-	-	
SIpH	Between Groups	0.725	2	0.362	0.232	0.796	0.037
	Within Groups	18.725	12	1.560	-	-	
	Total	19.450	14	-	-	-	

Table 4.5 (continued)

WQI	Between Groups	33.648	2	16.824	1.298	0.309	0.178
	Within Groups	155.489	12	12.957	-	-	
	Total	189.137	14	-	-	-	

The ANOVA assumptions of normality and homogeneity of variance were not violated, and F-test were not significant, $F(2,12)$ = 0.025, 0.051, 0.068, 0.396, 0.086, 0.412, 0.070, 0.018, 0.014, 1.430, 0.003, 0.232 and 1.298 for parameters DO, BOD, COD, TSS, pH, AN, SIDO, SIBOD, SICOD, SIAN, SISS, SIpH and WQI respectively as the values did not exceed from F-statistic = 3.89.

Based on the ANOVA table in Table 4.5, mean of each parameter and WQI has been analyzed. The significance values (p-values) of ANOVA were 0.976, 0.951, 0.934, 0.681, 0.918, 0.671, 0.933, 0.982, 0.986, 0.277, 0.997, 0.796 and 0.309 for parameters DO, BOD, COD, TSS, pH, AN, SIDO, SIBOD, SICOD, SIAN, SISS, SIpH and WQI respectively. The p-values of the parameters were higher than p-value = 0.05, thus there was no significant differences between the groups. Therefore, the null hypothesis (H_0) is accepted. There were no significant contributions of different locations to the value of parameters and WQI thus these parameters and WQI values distributed equally between locations.

Furthermore, the values of effect size indicate the percentage of variability in dependent variables (parameters) can be attributed to the independent variables (locations). All effect size values (η^2) of parameters were below than 0.2 and Cohen suggested that η^2 less than 0.2 is weak (McLeod, 2019).

4.3 The Correlation Between Parameters in Water Quality Index (WQI)

To analyze the relationship between every water quality parameter namely Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), pH (Potential of Hydrogen) and Ammoniacal Nitrogen (AN), and Water Quality Index (WQI), Pearson correlation had been conducted. The correlation classified into three groups location, Kota Bharu (KB), Kuala Krai (KK) and Tanah Merah (TM).

Table 4.6 Strength of Pearson correlation of WQI and its parameters

Parameters			DO	BOD	COD	SS	pH	AN	WQI
DO	Strength of Pearson's Correlation	KB	-	W	VS	W	VS	-M	VW
		KK	-	-S	-S	VS	M	-W	-VS
		TM	-	VS	VS	S	W	-VW	-VS
BOD		KB	W	-	S	-W	M	VW	-VW
		KK	-S	-	VS	-S	-W	W	W
		TM	VS	-	VS	S	-VW	VW	-S
COD		KB	VS	S	-	-VW	VS	-M	VW
		KK	-S	VS	-	-VS	W	M	M
		TM	VS	VS	-	S	-VW	-VW	-S
TSS		KB	W	-W	-VW	-	VW	VW	-M
		KK	VS	-S	-VS	-	S	-M	-S
		TM	S	S	S	-	-VW	-W	-M
pH		KB	VS	M	VS	VW	-	-S	W
		KK	M	-W	W	S	-	-S	-M
		TM	W	-VW	-VW	-VW	-	-S	-VW
AN		KB	-M	VW	-M	VW	-S	-	-S
		KK	-W	W	M	-M	-S	-	M
		TM	-VW	VW	-VW	-W	-S	-	-VW
WQI		KB	VW	-VW	VW	-M	W	-S	-
		KK	-VS	W	M	-S	-M	M	-
		TM	-VS	-S	-S	-M	-VW	-VW	-

Where, positive correlation: VW = very weak, W = weak, M = moderate, S = strong, VS = very strong; negative correlation: -VW = very weak, -W = weak, -M = moderate, -S = strong, -VS = very strong; KB = Kota Bharu, KK = Kuala Krai, TM = Tanah Merah.

In Kota Bharu and Tanah Merah, DO had very strong positive correlation with COD, *r*-value=0.848 and *r*-value=0.931 respectively. In Kota Bharu, DO and pH has very strong positive correlation (*r*-value=0.847). Very strong correlation between DO and pH can be explained by photosynthesis reaction in water. The rapid consumption of carbon dioxide during photosynthesis resulted in an increase of the pH value (Zang et al., 2011). pH of carbon dioxide ranges between 5.2 and 5.8 which is acidic (Boyd, 2000). Photosynthesis has resulted in an increase of oxygen in water, thus, DO increase. However, the correlation between DO and pH in Kuala Krai is moderate and in Tanah Merah is weak.

Based on Table 4.6, the correlations between WQI parameters varied in locations. However, BOD and COD had strong positive correlation in all three locations which were Kota Bharu; *r*-value = 0.79, Kuala Krai; *r*-value = 0.987, significant at $p < 0.01$, and Tanah Merah; *r*-value = 0.982, significant at $p < 0.01$. In natural wastewater, BOD and COD are significantly correlated, and the correlation is a linear positive (Abdallaa & Hammam, 2014). Correlation of BOD and COD indicated biodegradability in water. Therefore, *r*-value of correlation between BOD and COD more than 0.6 indicates the waste in water can be treated effectively using biological treatment (Abdalla & Hammam, 2014). Generally, most of pollutants in Kelantan River can be treated biologically.

Furthermore, pH and AN had negative strong correlation in all three locations due to chemical reaction between hydrogen ion (H^+) and AN. pH in Kelantan River was ranged between 6.5 to 7.7. When the pH of the solution is less than 9.3, H^+ reacts with AN to produce ammonium ions (NH_4^+) (Gupta et al., 2015). AN has a more toxic form at high pH which is NH_3, and a less toxic form at low pH which is NH_4^+ (Wurts, 2003). In addition, correlation between TSS and WQI had found to be negative in all three locations which are -0.563, -0.669, -0.595. It indicated that increase of TSS resulted in decrease of WQI. Thus, the most influential WQI parameter to WQI values is TSS.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, there is no significant difference between Water Quality Index (WQI) and its parameters in Kota Bharu (urban), Kuala Krai (suburban) and Tanah Merah (residential) in Kelantan River. WQI in urban, suburban and residential areas were classified in Class II throughout 2015 until 2019 except WQI in residential area in 2019 is classed in Class III. Most contributor of pollution in Kelantan River is TSS in all three locations. TSS of three locations mostly classified in Class IV and Class V throughout 2015 to 2019. Furthermore, TSS increases year by year which might come from sand mining activities along the riverbank. Besides, BOD was classified Class III and IV from 2015 to 2019. High BOD indicates high amount of organic matter present in Kelantan River. Organic matter presents in water may come from sewage wastewater from domestic usage or decaying matters in river. However, non-point source contamination is the biggest concern due to its nuanced origin (Giri & Qiu, 2016). Agricultural and/or urban land were the most significant predictor of water quality complexity (Johnson et al., 1997; Jones et al., 2001; Osborne & Wiley

1988; Sliva & Williams 2001; Dodds & Oakes, 2008). The correlation of water quality parameters varies between selected locations which indicate different water pollution contributors except correlation between Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), pH and Ammoniacal Nitrogen (AN), and Total Suspended Solids (TSS) and WQI. The strong correlations between parameters are resulted from strong relationships between the parameters chemically or physically. In this study, the most influential WQI parameter to WQI values is TSS in Kelantan River.

5.2 Recommendation

There are some limitations in this study that need further research in the future. Source of pollution that contributes into urban, suburban and residential area along Kelantan River need to be identify in order to understand how Water Quality Index (WQI) and its parameters differ from each other. Therefore, another study using model research is recommended to find the relationship between different locations, to observe the magnitude of source pollution.

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APPENDIX A

Table A.1 Best fit equations for the estimation of various subindex values

Subindex	Formula	Range of x values
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 AN	SIAN = 100.5 - 105x	for $x \leq 0.3$
	$SIAN = 94 * \exp(-0.573x) - 5 * \lvert x - 2 \rvert$	for $0.3 < x < 4$
	SIAN = 0	for $x \geq 4$
Subindex for TSS	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	$SIpH = 17.02 - 17.2x + 5.02x^2$	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 $x \geq 8.75$

(Source: DOE, 2006)

APPENDIX B

Table B.1 Pearson correlation coefficients between WQI and its parameters

LOCATION			DO	BOD	COD	SS	pH	AN	WQI
KB	DO	Pearson Correlation	1.000	0.362	0.848	0.334	0.847	-0.588	0.065
	BOD	Pearson Correlation	0.362	1.000	0.790	-0.366	0.570	0.094	-0.191
	COD	Pearson Correlation	0.848	0.790	1.000	-0.061	0.907*	-0.409	0.044
	TSS	Pearson Correlation	0.334	-0.366	-0.061	1.000	0.002	0.014	-0.563
	pH	Pearson Correlation	0.847	0.570	0.907*	0.002	1.000	-0.720	0.297
	AN	Pearson Correlation	-0.588	0.094	-0.409	0.014	-0.720	1.000	-0.756
	WQI	Pearson Correlation	0.065	-0.191	0.044	-0.563	0.297	-0.756	1.000
KK	DO	Pearson Correlation	1.000	-0.619	-0.731	0.897*	0.570	-0.281	-0.880*
	BOD	Pearson Correlation	-0.619	1.000	0.987**	-0.753	-0.320	0.366	0.372
	COD	Pearson Correlation	-0.731	0.987**	1.000	-0.818	-0.386	0.401	0.516
	TSS	Pearson Correlation	.0897*	-0.753	-0.818	1.000	0.776	-0.478	-0.669
	pH	Pearson Correlation	0.570	-0.320	-0.386	0.776	1.000	-0.750	-0.497
	AN	Pearson Correlation	-0.281	0.366	0.401	-0.478	-0.750	1.000	0.422
	WQI	Pearson Correlation	-0.880*	0.372	0.516	-0.669	-0.497	0.422	1.000
TM	DO	Pearson Correlation	1.000	0.892*	0.931*	0.733	0.209	-0.163	-.0891*
	BOD	Pearson Correlation	0.892*	1.000	0.982**	0.719	-0.191	0.038	-0.692
	COD	Pearson Correlation	0.931*	0.982**	1.000	0.742	-0.018	-0.132	-0.697
	TSS	Pearson Correlation	0.733	0.719	0.742	1.000	-0.089	-0.396	-0.595
	pH	Pearson Correlation	0.209	-0.191	-0.018	-0.089	1.000	-0.635	-0.195
	AN	Pearson Correlation	-0.163	0.038	-0.132	-0.396	-0.635	1.000	-0.074
	WQI	Pearson Correlation	-0.891*	-0.692	-0.697	-0.595	-0.195	-0.074	1.000
*. Correlation is significant at the 0.05 level (2-tailed).									
**. Correlation is significant at the 0.01 level (2-tailed).									