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Generating Water Quality Maps of Klang River Based on Geographic Information System (GIS) and Water Quality Index (WQI)

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Abstract: Water quality index (WQI) and Geographic Information Systems (GIS) play a critical role in managing and modelling a variety of water resource issues, including urban drainage, point and non-point source pollution. Historically, the evaluation of water quality has been a domain reserved for experts, necessitating laborious and time-consuming in situ sampling and laboratory analysis. However, the integration of WQI and GIS has democratized this information, making it accessible to non-experts, thereby enhancing the comprehension of Klang River's water quality. The objective is to employ WQI and GIS to create comprehensive water quality maps. While WQI offers a straightforward numerical evaluation, the incorporation of graphical data provides a nuanced understanding of river pollution. Therefore, hourly WQI data observed at every week in 2 months from October to November 2021 over four stations (Kampung Medan, Kampung Lombong, Taman Pengkalan Batu and Jeti Sungai Udang) in Malaysia was acquired from the Selangor Maritime Gateway (SMG) website and the Malaysian National Water Quality Standard (NWQS). Adopting Inverse Distance Weighting (IDW) interpolation method, WQI parameters at unsampled locations were estimated based on values of nearby sampled points. Database was built to depict the water quality of the Klang River, particularly during the two-month monitoring. Mapping provides a clear indication of the river's water quality. The WQI mapping outcome fall between class II and class IV. The findings indicate varying water quality classes along the Klang River, revealing potential pollution sources in industrial and development areas. It was concluded from the study that the water pollution may be due to its proximity to industrial and development regions.

Keywords: Water quality, water quality index, GIS, IDW interpolation, Klang river

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1. Introduction

Water quality issues are among the most widely debated topics since they have a significant effect on water resources, biodiversity, and health impacts and well-being (Wan Mohtar et al., 2019). It has been one of the most valuable commodities in the developing world, a must for domestic use and an important element of many factories and services around the world (Pak et al., 2021). Water quality must be monitored continuously, on a regular basis, often over a long period of time. Nonetheless, most conventional monitoring techniques rely on laborious, costly, and time-consuming in situ sampling and laboratory analysis methods (Cao et al., 2018). For decades, water quality monitoring studies have relied on costly, time-consuming, and labor-intensive field sampling operations as well as real-time control (Niu et al., 2014).

Geographic information systems (GIS) play a critical role in managing and modelling a variety of water resource issues, including urban drainage, point and non-point source pollution. The use of GIS in the field of water management is on the rise (Babiker et al., 2007). Researchers have used GIS-based applications for a variety of purposes, including mapping diffuse stormwater pollutant hot spots (Mitchell, 2005), investigating space-time dynamics of coastal pollution (Roy et al., 2018), assessing health risks from stormwater pollution (Wijesiri et al., 2018), assessing chemical spill impacts in river basins (Jiang et al., 2012), and identifying risk sources for surface water pollution (Yao et al., 2015). Conventional method used to store water quality data is to use regular reports (Ahmed et al., 2020). This is less effective for monitoring water quality at each station because it requires effort to re-read the data.

The purpose of this study is to analyse and map the river by evaluating the WQI using GIS approach in four locations along the Klang River. Data on water quality was collected at Kampung Medan, Kampung Lombong, Taman Pengkalan Batu, and Jeti Sungai Udang. The WQI method is a useful tool for identifying water quality concerns by combining complicated data into a score that can be used to quickly summarise the current state of water quality (Sadat-Noori et al., 2014; Selvam et al., 2014). The combination of WQI and GIS offers decision makers timely, and accurate information to execute water pollution remedies and strategies. GIS can be applied using current technologies that will help store data and handle water quality data more effectively. Thus, water quality data in Klang River would be easier to store, manage and analyse by using GIS. To create a powerful analytical and spatially distributed modelling tool, current trends, and progress in river system management by GIS uses spatial databases that include various information like latitude and longitude, elevation, and various channel types to create a simple geographic query and visualization tool (Esri, 2021).

2. Literature Review

2.1 Water Quality Index (WQI)

The values of physical, chemical, and biological water quality indicators are often used to monitor water quality. The Water Quality Index (WQI) is used to analyse and report the water quality and health of water (Hameed et al., 2017). WQI is a useful tool because it is expressed as a single numerical value by incorporating six main water quality parameters, namely; Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Ammonia-Nitrogen (NH_3N), Suspended Solids (TSS), and pH to indicate a water's condition (Gazzaz et al., 2012). Table 1 shows the Department of Environment Water Quality Index (DOE-WQI) classification. Table 2 shows the National Water Quality Standard (NWQS) specified classes I–V, which related to water section classification based on highest to the lowest of water quality (DOE, 2021).

Table 1 - DOE-WQI classification (DOE, 2021)

Parameter	Unit	Class				
		I	II	III	IV	V
NH_3N	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 - National Water Quality Standard (NWQS) specified classes I–V (DOE, 2021)

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 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.

2.2 Geographical Information System (GIS)

GIS is an information gathering, managing, and analysis platform. GIS, which is based on geography, incorporates a wide range of results. It uses maps and 3D scenes to explore spatial position and arrange layers of information into visualizations. GIS' one-of-a-kind capability reveals greater insights into results, such situation, relationships, and patterns, allowing users to make better decisions. GIS allows to compare several different forms of details. Data regarding humans, such as population, wages, or education level, may be used in the system. It may provide details about the environment, such as the location of streams, various types of vegetation, and various types of soil. GIS technology combines geographic science with methods for interpretation and communication. It assists people in achieving a shared goal: gaining actionable information from all forms of data (Esri, 2021). In this research, the ArcGIS Pro are being used as the tool.

2.3 Benefit of Using GIS as Tool for Monitoring Environmental Issues

GIS can further efficiently and precisely prepare the data for analysis than is generally feasible by manual processes. For instance, it is easy to alter projection and scale, modify the weights of the various parameters or convert the map data into a grid form. GIS also offers greater technical skill and hence increases the precision of the data process (Bailey et al., 2020). GIS offers major uses in various areas, including the environment. Below are some of the environmental importance of GIS (GrindGIS, 2020).

3. Methodology

The commonly used method in GIS for water quality analysis is Inverse Distance Weighted (IDW) interpolation that can estimate values at unsampled locations based on values of nearby sampled points. This method involves several steps which is data collection, data preprocessing, GIS data preparation, interpolation process and visualization.

3.1 Data Collection

The typical structure of GIS mapping for water quality management is determined by the data collected and will generate in systematic way to the production of the information, analytical and graphic which interact between software and humans. The data was collected from the Continuous River Water Quality Monitoring System (CRWQMS) which is one of the smart elements of River Cleaning initiative of Selangor Maritime Gateway (SMG). Figure 1 shows the monitoring interface system that provides Real-Time data transmission. Table 3 shows the data collected and Table 4 shows the average WQI for one month. All data was sourced from the Selangor Maritime Gateway (SMG) website and as required, the Malaysian National Water Quality Standard (NWQS).

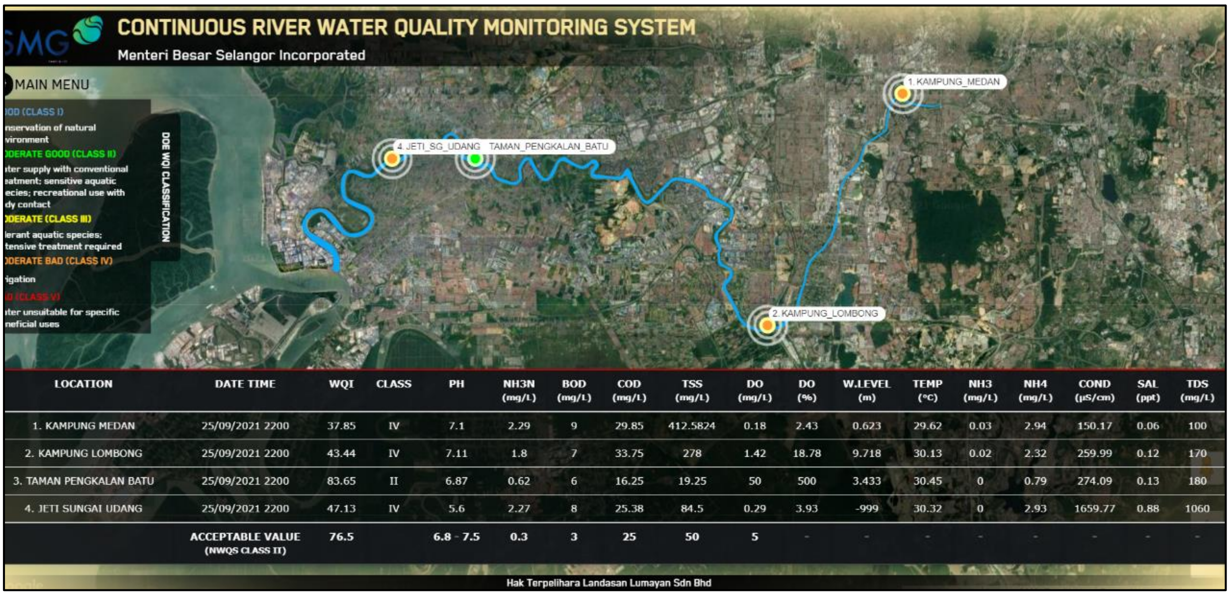

Fig. 1 - Water quality monitoring system in Klang River (SMG, 2023)

Table 3 - Parameter reading of WQI

Locations	Week	pH	NH3N	BOD	COD	TSS	DO	WQI	Average WQI
Jeti Sg. Udang	1	5.76	2.53	0	0	912	0.3	46.11	83.47
	2	5.6	2.85	10	31.62	117.5	0.34	38.9	
	3	5.7	2.62	9	30.12	484	0.3	34.8	
	4	5.6	2.27	8	25.38	84.5	0.29	47.13	
	5	5.75	2.06	8	27.25	255	0.31	40.1	38.61
	6	5.5	10.85	9	28.75	120	0.29	37.6	
	7	5.61	9.32	9	29.75	108.5	0.28	38.14	
	8	5.55	3.36	9	30	118	0.35	38.63	
Taman Pengkalan Batu	1	7.94	1.48	6	16.38	26.625	0	56.92	67.00
	2	8.13	1.17	8	21.5	124	50	68.99	
	3	8.06	0.64	7	19.25	26	0	58.45	
	4	6.87	0.62	6	16.25	19.25	50	83.65	
	5	6.96	0.43	7	18	41.25	0	59.78	65.83
	6	7.12	0.56	7	17.62	26.625	50	82.21	
	7	7.2	0.57	7	17.12	24.25	0	60.41	
	8	7.08	0.55	7	17	20	0	60.95	

Table 3 - Parameter reading of WQI (Continued)

Kampung Lombong	1	6.93	2.27	8	41.25	28.875	1.84	53.2	58.32
	2	7.16	2.77	10	49.75	24.875	1.62	48.96	
	3	7.02	0.3	3	15.31	15.43	7.69	87.71	
	4	7.11	1.8	7	33.75	278	1.42	43.44	
	5	7.08	1.44	7	35.75	22.12	1.84	57.35	37.97
	6	7.19	3.37	8	42	44.25	1.02	47.12	
	7	7.25	3.96	11	54.25	298	0.02	30.61	
	8	7.92	0.257	58	268	936	0.83	16.81	
Kampung Medan	1	7.06	1.58	10	30.74	130.016	1.15	44.95	44.66
	2	7.11	3.48	6	19.16	57.94	0.39	50.12	
	3	7	0.7	10	33.41	139.44	0.15	46.09	
	4	7.1	2.29	9	29.85	421.58	0.18	37.48	
	5	7.06	1.86	7	22.45	243.77	0.34	43.91	49.50
	6	7	1.73	8	25.58	96.23	2.36	54.62	
	7	7.19	50.28	42	126.85	23.5	0.18	28.02	
	8	7.62	0.63	7	22	10	4.04	71.47	

Table 4 - WQI and classes data of Klang River

Locations	October 2021		November 2021	
	WQI	Class	WQI	Class
Jeti Sg. Udang	83.47	II	38.61	IV
Taman Pengkalan Batu	67.00	III	65.83	III
Kampung Lombong	58.32	III	37.97	IV
Kampung Medan	44.66	IV	49.50	IV

3.2 Data Processing

i. Spatial Data

The data was processed using ArcGIS Pro software. There are four water monitoring stations along the Klang River: Kampung Medan, Kampung Lombong, Taman Pengkalan Batu, and Jeti Sg. Udang. the map of Klang River information was converted to a shapefile (.shp) using the ArcGIS Pro program. This is where georeferencing and digitization come into play to obtain a base map. Georeferencing is used to ensure that an image or hardcopy is positioned precisely on the earth's surface using a certain datum. On-screen digitization is manual digitization on a computer display with data sources as the background. It is an effective approach for changing and updating an existing layer, as well as adding a new layer. Location (latitude and longitude) water flow (upstream and downstream) and road are all included in the map's spatial data. There are four stations from upstream to downstream (Kampung Medan, Kampung Lombong, Taman Pengkalan Batu and Jeti Sungai Udang). The position of the station on the map were determined using their coordinates. Spatial features are characterised by their description and placement in relation to each other. Spatial data that is kept as raster type relates to the geometries of the spatial feature to provide visual representation of geographic space.

ii. Spatial Interpolation

To fulfil the research goal, data analysis was carried out on the collected information. It is the process of estimating unknown values based on the known values at nearby locations that is called interpolation. The precision, number, and distribution of the known points used in the calculation, as well as the level to which the mathematical function accurately predicts the event, all influence the quality of the interpolation results. For evaluating surface water quality, GIS-based IDW interpolation gives more comprehensive spatial information. Water quality was geographically analysed using GIS in locations where sampling was not possible (Aminu et al., 2015). This allows the estimation of the attribute at any location within the data boundary. Figure 2 illustrates the principle of IDW interpolation. Interpolation is referred to as a technique that uses values that are estimated instead of measured data. When attributes are continuous throughout space, then spatial interpolation is applied. Using control points with known values and mathematical equations, the calculation technique employs them to estimate values that are located between them (Chang, 2018).

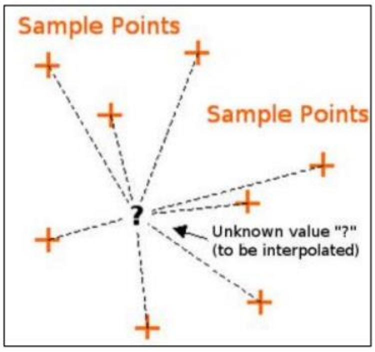

Fig. 2 - Inverse Distance Weighted (IDW) interpolation based on weighted sample point distance (Chang, 2018)

Thus, water quality index in areas where sampling is not available were estimated using the spatial IDW interpolation method in ArcGIS Pro environment.

iii. Attribute Data

Attribute data is qualitative information that may be measured and analysed. Attribute data is structured in a table by row and column, with each row representing spatial features and each column describing characteristics. The 'where' is represented by geographic data, and attribute data contains information about the 'what', 'where', and 'why'. Attribute data describes the features of spatial data. The data type that dictates how attributes are stored in GIS is the way of classifying attribute data. Water quality is the most important characteristic data used. All these data were obtained in softcopy form Selangor Maritime Gateway (SMG). WQI parameters such as type of parameter, parameter value (total hardness), and acceptability of parameter (normal or critical) are examples of attribute data utilized in the development of a database. Parameter of water quality consists of BOD, COD, NH_3N, pH, DO and TSS (DOE, 2021). The observation data contains WQI data taken hourly for every week in 2 months from October to November 2021.

3.3 Database Design Development

A digital database of non-graphical and graphical data is the main structure. This database is created when a single system combines spatial data and attribute data information. The database design and development divided into three part which are database concept design, logic design and physical design as show in Figure 3. While Figure 4 shows the entity-relationship model for water quality database.

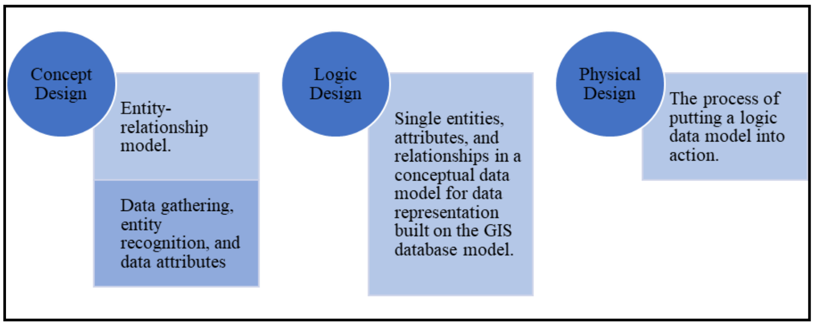

Fig. 3 - Database design and development divided into three part (AfterAcademy, 2019)

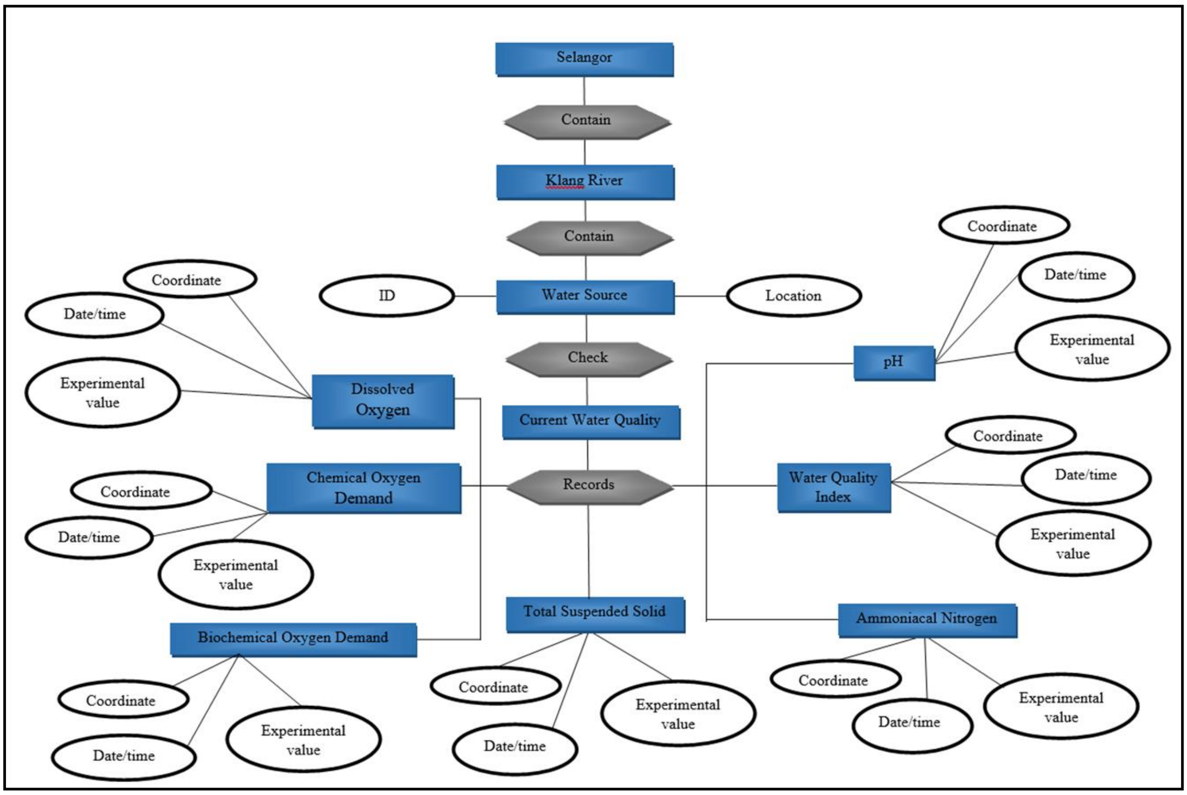

Fig. 4 - Entity-Relationship Model of Klang River

In this research, the Entity-Relationship Model is between a set of data attributes and entity sets. One-to-one, one-to-many, many-to-one, and many-to-many relationships are the four types of relationship databases (AfterAcademy, 2019).

i. One to one relationship
A one-to-one relationship occurs when a single instance of one entity is linked to a single instance of another entity.
ii. One to many relationship
A one-to-many relationship occurs when a single instance of one entity is linked to multiple instances of another entity.
iii. Many to one relationship
A many to one relationship occur when multiple instances of one entity are linked to a single instance of another entity.
iv. Many to many relationships
Many to many relationships are formed when several instances of one entity are linked to multiple instances of another entity.

The database contains all currently observed water quality parameters as WQI requirements. This was developed in ArcGIS Pro environment which allows maps depicting the river's water quality to be generated.

4. Result and Analysis

GIS was used in this study to create a database that combines all available information and data collected in the Klang River area. Map design, like graphic design, is a visual strategy to achieve an objective. The goal of map design is to make a map more understandable and capable of conveying the right message or information. The following results have been achieved, (1) database system of Klang River, (2) location of WQI stations and (3) spatial interpolation outcomes.

4.1 Database System of Klang River

The development of a WQI database system in Klang River is the outcome of this study. The goal of this system's development is to display all the information about the sample stations' locations as well as information about river water quality graphically. The map of Klang River as created with vector layer in ArcGIS Pro software is shown in figure 5.

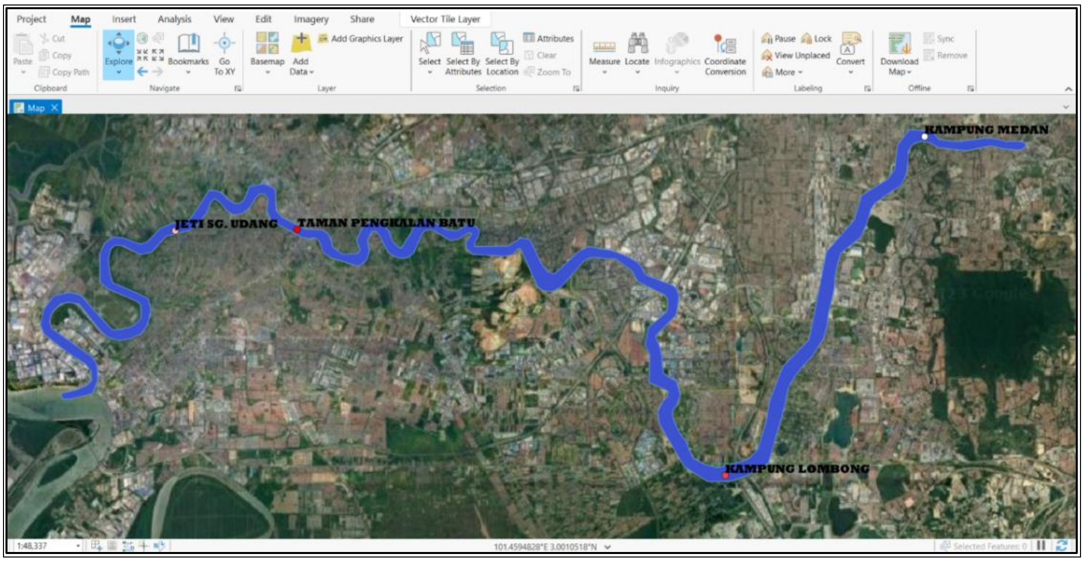

Fig. 5 - The map of Klang River

Using ArcGIS Pro software, all data relating to the WQI of the Klang River can be displayed in a more ordered table. Figure 6 shows the Klang River attribute data. The attribute data contains station's name, latitude, longitude, date, and time collected, class of WQI and WQI's parameter (ph, NH_3N, BOD, CO, TSS, DO).

	NAME	LATITUDE	LONGITUDE	DATE	TIME	WQI	CLASS	PH	NH3N (mg/L	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	DO (mg/L)
1	JETI SG. UDANG	3.0459250000...	101.41166200...	4/9/2021	10.00 PM	46.109...	IV	5.760...	2.53000000...	0	0	912.0000...	0.3
2	KAMPUNG LOMBONG	2.9763220000...	101.56877199...	4/9/2021	10.00 PM	53.200...	III	6.930...	2.27000000...	8	41.250000...	28.87500...	1.8400000...
3	KAMPUNG MEDAN	3.0726380000...	101.62565399...	4/9/2021	10.00 PM	44.950...	IV	7.060...	1.58000000...	10	30.739999...	130.0159...	1.1500000...
4	TAMAN PENGKALAN BATU	3.0462160000...	101.44659199...	4/9/2021	10.00 PM	56.920...	III	7.940...	1.48000000...	6	16.379999...	26.62500...	0

Fig. 6 - Klang River attribute data

4.2 Location of WQI Station

The locations of WQI stations were determined using the coordinates of the area, while the data collected by Microsoft Excel was converted to a shapefile (shp.) and the layer was added as a vector layer. Although the coordinates are not extremely precise, they are sufficient to show the location of the water quality area for the purposes of mapping in this research. Figure 7 shows the location of WQI stations.

Fig. 7 - Location of WQI stations

4.3 GIS Spatial Outcomes

The database contained several primary layers comprised of the Klang River line, the WQI stations, attribute data, and IDW interpolation. Figure 8 illustrates the interpolation values at every 3km from October to November 2021.

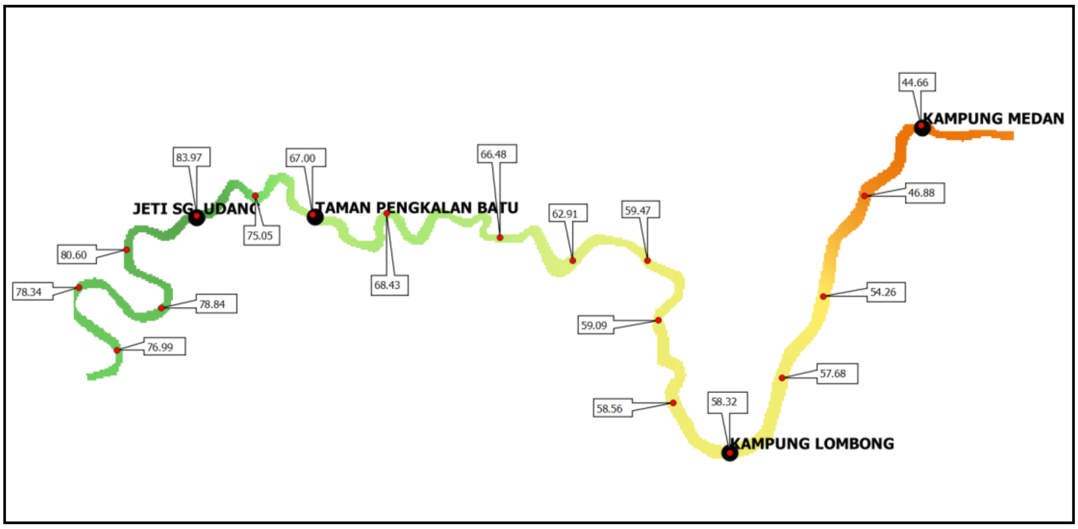

Fig. 1 - Interface of interpolation values of WQI at every 3km

The distance of every 3km was chosen because this is the best view to display in the ArcGIS Pro interface and the interpolation value can be seen more clearly. The visualization the WQI is illustrated in Figure 9.

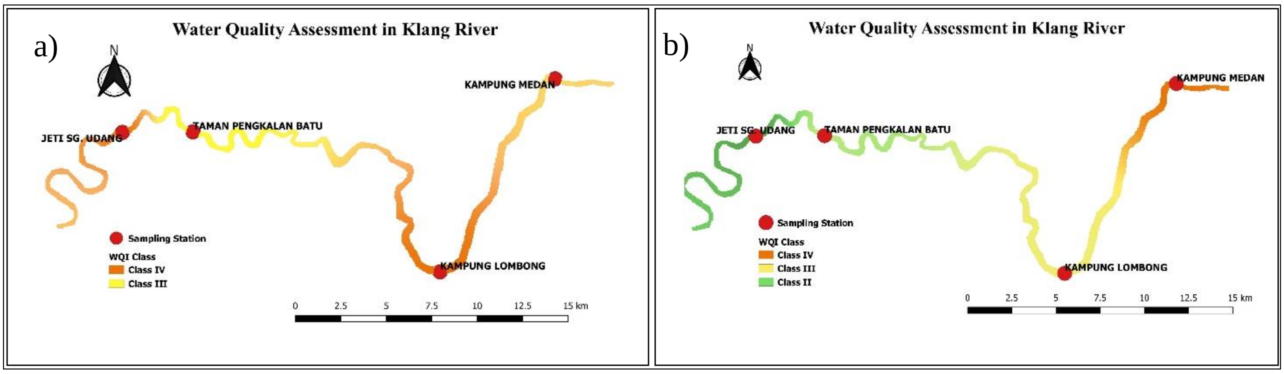

Fig. 2 - WQI Mapping a) Mapping outcome for October 2021; b) Mapping outcome for November 2021

4.4 Discussion

In figure 8, the closer the interpolation points to the station point, the closer the estimated value to the existing data value. The farther the distance of the interpolation point from the station point, the larger the difference from the value of the existing point. This could happen because of the stronger influence of the point, due to less distance and number of interpolation points that are involved in interpolation processing.

As seen in figure 9, the WQI mapping outcome were in between classes II and IV. Water quality in Jeti Sg. Udang detected as class II in November 2021 which indicated it requires conventional treatment for water supply and is a sensitive aquatic species for fishery. In addition, it can be used for recreational with body contact. The yellow is categorized as a class III contaminant that requires considerable treatment but is safe for livestock. Thus, an orange color of class IV indicates contaminated water that is suitable for irrigation purposes. The determination of water quality in unmonitored areas was accomplished with IDW interpolation, and the distance between each color could be estimated by calculating the longitude and latitude.

5. Conclusion

This study's primary aim is to employ WQI and GIS to map river water quality. WQI provides a straightforward numerical assessment of water quality, but the utilization of graphical data offers an alternative means to comprehend the diverse facets of river pollution. Consequently, the study successfully demonstrated the use of GIS for assessment of water quality in the Klang River. GIS emerges as an invaluable tool for conveying clear and informative representations of Klang River's water quality, transitioning from textual to graphical data. thus, water quality maps of Klang River were generated based on the water quality index (WQI). The use of GIS tools aided significantly in the collection, management and visualisation of data. The findings indicate varying water quality classes along the Klang River, revealing potential pollution sources in industrial and development areas. It could be concluded from the study that the water pollution may be due to its proximity to industrial and developed areas.

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