Spatial and temporal analysis of marine water pollution in Port Klang: Developing a GIS database for assessing patterns and trends.

I H K Supardi[1], N M Abdullah[1,2*], A Tugi[1], B H Ismail[3]

[1]Center of Applied Geomatics and Disaster Prevention (CAGeD), Faculty of Civil Engineering and Built Environment (FKAAB), Universiti Tun Hussein Onn, Batu Pahat, 86400, Parit Raja, Batu Pahat, Johor, Malaysia
[2]Faculty of Applied Sciences and Technology (FAST), Universiti Tun Hussein Onn, Pagoh Branch, KM1, Jalan Panchor, 84600, Muar, Johor, Malaysia
[3]Port Klang Authority, Jalan Pelabuhan Klang, Port Klang, 42005, Malaysia
[*]Corresponding author: nazirah@uthm.edu.my

Abstract. This study focuses on the assessment of marine water quality in Port Klang, with a particular emphasis on the spatial and temporal analysis of water quality parameters. The research investigates the sources of water pollution in the area, including industrial waste, non-point sources, heavy metals, and land use. The study utilizes geographic information systems (GIS) and the Inverse Distance Weighted (IDW) interpolation technique to map marine water quality parameters and analyze their spatial distribution. Additionally, a temporal analysis is conducted to identify trends, seasonal variations, and irregularities in water quality over an eight-month period. The study reveals TSS and O&G exceeding the allowable limits in certain locations. However, the analysis demonstrates a decreasing trend in TSS and O&G concentrations over time, indicating positive developments in water quality. The findings underscore the importance of continued monitoring and the implementation of pollution control measures to ensure sustainable and healthy marine water ecosystems in Port Klang.

1. Introduction

Water pollution can be caused by a variety of sources, including industrial waste, non-point sources, heavy metals, and land use. Many industries and commercial sectors situated in port areas discharge waste into nearby water bodies without proper treatment, leading to water pollution. Pollutants can also come from non-point sources such as agricultural or urban runoff, and commercial activity such as forestry and construction due to rainfall events [1], [2]. Sediment and water monitoring in the Klang Strait found significant variations in the distribution and concentrations of heavy metals which can come from various sources contributing to the contamination load in the Klang Strait [3]. The land use along various water bodies can have an impact on water quality depending on the uses. For example, commercial and industrial areas are found to have more effect on nearby surface water, leading to pollution [4].

Understanding the current state of coastal ecosystems and ensuring the long-term sustainability of marine water depend on the assessment of marine water quality. An excellent basis for integrating, analyzing, and visualizing geographical data relating to water quality parameters is provided by geographic information systems (GIS) [5]. The mapping of marine water quality parameters at Port Klang can be done using a GIS based on spatial analysis with Inverse Distance Weighted (IDW) interpolation. It has been monitored from April to September 2021, including both the rainy and dry seasons, using 14 samplings of locations. To see how trends in marine water quality evolve over time, temporal analysis is also taken into consideration.

2. Study area

2.1. Description of study area and sample location

The Port Klang region includes the port's infrastructure, surrounding bodies of water, and adjacent coastal regions, making up an important part of the coastline. The spatial scope of the analysis should include both the wider coastal zone where possible impacts may spread and the areas directly impacted by port activities, such as shipping lanes, berthing sites, and discharge points. Figure 1 shows the overall area of sampling location in marine water of Port Klang. The latitude and longitude coordinates of the monitoring sites are shown in Table 1.

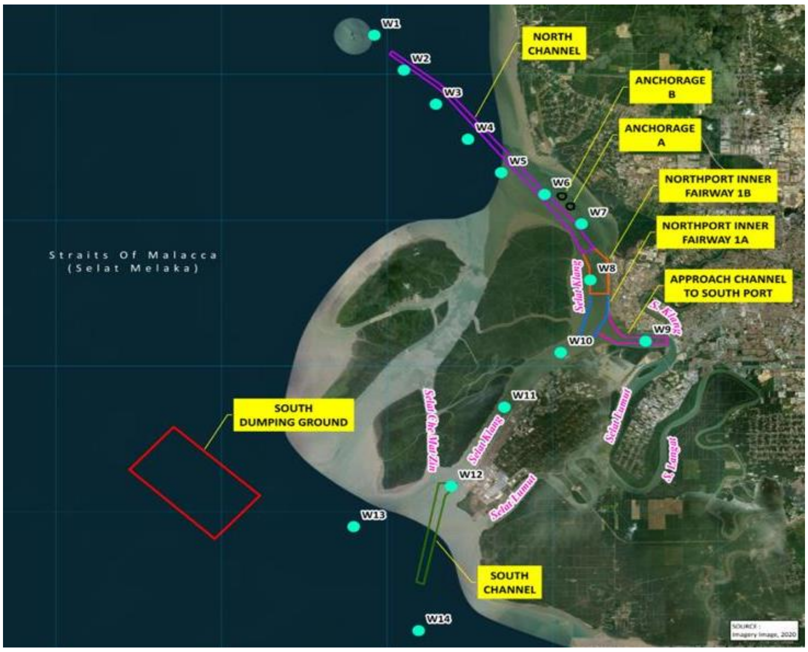

Figure 1. Port Klang

Table 1. Sample location

Sample Location	Latitude	Longitude	Sample Location	Latitude	Longitude
W1	3.18694444	101.2305556	**W8**	3.03361111	101.3472222
W2	3.16472222	101.2466667	**W9**	2.99583333	101.3772222
W3	3.14361111	101.2641667	**W10**	2.98888889	101.3311111
W4	3.12166667	101.2811111	**W11**	2.95555556	101.3005556
W5	3.10055556	101.2994444	**W12**	2.90527778	101.2713889
W6	3.08722222	101.3225000	**W13**	2.87972222	101.2186111
W7	3.06888889	101.3427778	**W14**	2.81500000	101.2536111

2.2. Marine water quality parameters

The goal is to sample and monitor 14 different locations of marine water. The Port Klang Authorities' consistent monitoring from April to September 2021 resulted in the selection of a water quality parameter. The variables include pH, total suspended solid (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen, and oil and grease (O&G). Samples were acquired using a clean water sampler and placed in assigned sample containers along with necessary preservatives. These samples are then chilled in a cooler box for temporary storage until transported to the laboratory within six hours of collection for analysis. The laboratory tests were conducted using the following techniques:

- Standard Methods for the Examination of Water and Wastewater (APHA)
- United States Environmental Protection Agency (USEPA) methods
- HACH methods

For the measurement of TSS, the sample is filtered using a glass fiber filter with a known weight. The solid residue remaining on the filter is dried until it reaches a consistent weight at a temperature of 103°C to 105°C over an hour. The concentration of TSS is calculated by dividing the mass of the dried residue by the volume of the original sample. The reports generated from these monitoring procedures adhere to the specifications mandated by the Department of Environment (DOE). The marine waters that are subject to direct discharge of effluent from anthropogenic activities is complied with the Class 3 in Malaysian Marine Water Quality Standards (MMWQS) [6].

Consequently, there has been some damage of the environment in this marine water [7]. The following are some examples of activities that might potentially influence the wellbeing of marine ecosystems:

i. Marinas, ports, jetties
ii. Coastal settlement
iii. Shipyards
iv. Oil and gas exploration and production activities
v. Land based aquaculture
vi. Land-reclamation activities

PARAMETER (µg/l) unless otherwise stated	CLASSIFICATION					
	CLASS 1	CLASS 2	CLASS 3	INTERIM CLASS E1	INTERIM CLASS E2	INTERIM CLASS E3
	Sensitive Marine Habitats	Fisheries (including Mariculture)	Industry, Commercial Activities & Coastal Settlements	Estuaries		
				Coastal Plain	Lagoon	Complex Distributary Network
Dissolved Oxygen (mg/l)	>6.0	>5.0	>3.0	>5.0	>5.0	>5.0
Total Suspended Solids (mg/l)	25.0	50.0	100.0	30.0	30.0	30.0
Phosphate	5.0	75.0	670.0	100.0	180.0	180.0
Nitrate	10.0	60.0	700.0	200.0	570.0	430.0
Ammonia	35.0	50.0	320.0	5.0	10.0	10.0
Mercury	0.04	0.04	0.04	0.04	0.04	0.04
Cadmium	0.50	2.00	3.00	1.00	1.00	1.00
Chromium (VI)	0.14	10.00	20.00	10.00	10.00	10.00
Copper	1.30	2.90	8.00	1.00	1.00	1.00
Cyanide	2.00	7.00	14.00	5.00	5.00	5.00
Lead	2.20	8.50	12.00	1.30	2.00	2.00
Zinc	7.00	50.00	100.00	16.00	5.00	5.00
Arsenic (III)	1.00	3.00	3.00	3.00	1.00	1.00
Aluminium	27.00	27.00	55.00	27.00	27.00	27.00
TBT	0.001	0.010	0.050	0.002	0.002	0.002
PAH	100.0	200.0	1000.0	5.0	5.0	5.0
Total Phenol	1.0	10.0	100.0	10.0	10.0	10.0
Oil & Grease mg/l	0.01	0.14	5.00	1.00	1.00	1.00
Faecal Coliform (Cfu/100ml)	70	70	70	70	70	70
Temperature (°C)	≤ 2°C increase over maximum ambient					
pH	6.5 - 9.0					
Marine litter	Free from marine litter					

Figure 2. Malaysian Marine water quality standard of year 2021

3. Methodology

3.1. Inverse distance weighted (IDW) interpolation
GIS can be utilized to identify areas of high pollution concentration in port regions. By analyzing the spatial distribution of pollution data, hotspot analysis techniques can locate regions with consistently high pollutant levels. This aids in pinpointing areas where pollution sources may be concentrated or where environmental impacts are most severe. According to [8], GIS employs two categories of spatial interpolation methods: geostatistical interpolation methods and deterministic interpolation methods. These methods enable the prediction of attribute values at unsampled locations, resulting in the generation of continuous spatial data [9]. Commonly used interpolation techniques include inverse distance weighted, Spline, kriging, Trend, and cokriging interpolations [10], [11]. Consequently, water assessment and pollution mapping extensively utilize interpolation techniques like IDW and kriging [12].

Additionally, [13] conducted a study demonstrating that the IDW method exhibited higher accuracy in forecasting pollutant levels in groundwater. The term "inverse" in IDW signifies that points in proximity carry more weight and have greater influence on the calculation of missing or unknown points, as compared to points farther away [14]. This methodology relies on a linear combination of data and is considered an exact method.

3.2. Temporal analysis
To comprehend the fluctuations that occur during different seasons, the long-term patterns, and the effects of port activities on marine water quality, it is essential to conduct a temporal analysis. This analysis involves studying water quality data over time to identify trends, seasonal variations, and irregularities.

By examining the trends and patterns in water quality parameters, researchers and decision-makers can gain valuable insights into the shifting conditions, identify potential causes and consequences, and implement effective management strategies [15]. This analysis enables the assessment of the effectiveness of pollution control measures, the potential impacts of maritime activities, and the long-term changes in water quality. The focus of this paper is to perform a temporal analysis specifically on the concentrations of TSS and O&G in marine water. The analysis will cover an eight-month period from April to September 2021, with an emphasis on observing the trends in these concentrations [16].

4. Result and discussion
The production and dispersal of sediment can lead to an increased level of Total Suspended Solids (TSS). This degradation of water quality may occur alongside other potential impacts, such as an oil spill in the event of an accident. Recent incidents have shown that large quantities of oil may be carried to the nearest shoreline, posing a threat to the coastal mangrove ecosystem. The oil slick can cause considerable harm to fishing equipment and rapidly devastate the marine ecosystem, particularly affecting plankton communities (zooplankton and phytoplankton), crustaceans, and fish. The presence of local fishermen and their fishing grounds in relation to the project area, sand source area, and spoil dumping area will also be affected, leading to reduced catches and fish landings [1].

Water quality standards consider six parameters: pH, COD, BOD, AN, TSS, and O&G. However, in marine water quality standards (as shown in Figure 2), only two parameters are considered: TSS and O&G, both of which meet the Class 3 requirements for MMWQS. By utilizing GIS and IDW interpolation, the analysis generated a map that highlighted, recognized, and assessed the fluctuations in pollutant levels across various points along the waters of Port Klang.

The application of colours in the interpolation technique depicted the spatial distribution of pollutants, with red and orange indicating areas of higher risk. However, it is worth noting that the orange areas remain below the standard value of MMWQS. On the other hand, yellow and green colours represent areas that are within acceptable limits and under control.

4.1. Data of marine water quality parameter

One of the most significant environmental issues related to port activities is the degradation of water quality as evaluated by pH, total suspended solid (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen, and oil and grease. The data for the six water quality parameters from April to September 2021 is shown in the figure 3 below.

Month	Sample Location	pH	Total Suspended Solid (mg/L)	BOD5 at 20 degree C (mg/L)	COD (mg/L)	Ammoniacal Nitrogen (mg/L)	Oil & Grease (mg/L)
April	W1	7.12	279	432	920	0.009	3.2
	W2	7.73	301	469	996	0.009	2.2
	W3	7.92	117	376	871	0.6	0.009
	W4	7.96	112	458	978	0.009	0.009
	W5	8	110	312	737	0.009	0.009
	W6	8.02	109	169	391	0.009	0.009
	W7	8.03	133	194	413	0.009	9.2
	W8	8	114	147	356	0.009	12.4
	W9	7.91	89	179	396	0.4	14.4
	W10	7.85	95	111	256	0.3	8
	W11	7.84	92	213	515	0.2	12.4
	W12	7.89	57	48	187	1	9.2
	W13	7.74	64	46	176	1.2	5.2
	W14	7.7	44	42	169	1.3	0.009
May	W1	7.86	122	163	414	0.009	8
	W2	7.97	289	177	508	0.009	2
	W3	8.02	182	170	360	0.009	0.009
	W4	8.08	126	169	400	0.009	0.009
	W5	8.11	105	196	472	0.009	9.6
	W6	8.12	109	166	384	0.009	6.4
	W7	8.1	124	141	325	0.009	0.009
	W8	8.03	103	196	473	0.1	0.009
	W9	7.97	83	142	321	0.5	0.009
	W10	7.89	85	243	562	0.4	0.009
	W11	7.96	97	159	404	0.2	0.009
	W12	7.82	57	122	237	1.1	0.009
	W13	7.7	45	39	144	1.2	0.009
	W14	7.57	47	35	108	1.3	0.009
June	W1	7.94	139	221	620	0.1	8.4
	W2	8.05	100	117	350	0.1	4.8
	W3	8.05	103	97	290	0.009	2.4
	W4	8.1	169	148	400	0.009	0.009
	W5	8.08	168	166	480	0.009	5.6
	W6	8.03	132	176	440	0.009	1.2
	W7	8.07	155	308	800	0.009	1.2
	W8	8.06	113	153	460	0.2	7.6
	W9	8.08	142	140	460	0.2	1.6
	W10	8.05	94	135	350	0.2	1.1
	W11	8.08	95	141	410	0.1	0.009
	W12	8.06	88	132	370	0.7	3.2
	W13	8.06	19	93	250	1.7	1.2
	W14	8.1	76	108	280	2.3	0.009
July	W1	8.08	128	207	560	0.009	1.6
	W2	8.09	96	188	490	0.009	5.2
	W3	8.1	8.8	216	540	0.1	3.6
	W4	8.1	134	252	630	0.009	0.009
	W5	8.08	126	171	480	0.009	1.2
	W6	8.1	122	152	440	0.009	4.4
	W7	8.1	101	150	420	0.009	6.4
	W8	8.1	99	151	530	0.2	7.4
	W9	8.1	86	165	560	0.2	4
	W10	8.1	97	152	470	0.1	0.009
	W11	8.07	86	189	530	0.2	0.009
	W12	8.13	76	172	500	0.5	5.2
	W13	8.05	56	157	440	1.8	2
	W14	8.07	0.009	156	470	2.1	9.2
Aug	W1	7.79	29	264	740	0.009	2.2
	W2	7.83	46	263	790	0.009	2.6
	W3	7.81	52	292	730	0.009	3.1
	W4	7.89	62	246	690	0.009	3.2
	W5	7.85	26	237	640	0.009	7.2
	W6	7.84	47	247	790	0.009	6.4
	W7	7.78	13	344	860	0.009	5.6
	W8	7.82	44	257	720	0.009	2.4
	W9	7.93	0.009	252	730	0.009	2.3
	W10	7.89	27	300	810	0.1	6
	W11	7.76	31	321	770	0.2	9.2
	W12	7.63	59	234	680	0.3	4.2
	W13	7.48	58	141	410	0.4	3.2
	W14	7.32	172	215	580	0.4	2.2
Sept	W1	7.81	27	271	741	0.009	2.1
	W2	7.81	45	261	792	0.009	2.5
	W3	7.83	54	294	733	0.009	3.2
	W4	7.81	64	247	693	0.009	3.3
	W5	7.88	24	235	642	0.009	7.3
	W6	7.87	45	246	791	0.009	6.3
	W7	7.79	12	342	862	0.009	5.5
	W8	7.81	42	255	722	0.009	2.5
	W9	7.91	0.009	251	732	0.009	2.4
	W10	7.86	25	303	812	0.2	6.1
	W11	7.75	30	320	720	0.1	9.1
	W12	7.61	58	232	682	0.2	4.1
	W13	7.46	59	143	412	0.3	3.3
	W14	7.3	170	212	582	0.3	2.3

Figure 3. Water quality data

4.2. Total suspended solid (TSS)

TSS pertain to the mass or concentration of fine inorganic and organic particles with a diameter smaller than 62 mm, present in water [17]. However, all water bodies naturally contain suspended matter, which can be exacerbated by human activities, leading to disturbances, and impacting the quality of marine water.

According to figure 4, areas colored red has exceeded the allowable TSS standard of 100 mg/L. The orange shading indicates TSS values ranging from 50 mg/L to 100 mg/L, while the yellow color represents TSS levels from 25 mg/L to 50 mg/L. Class 1 TSS concentrations, falling between 12 mg/L and 25 mg/L, were observed in June at location W13, in August at locations W7 and W9, and in September at locations W7, W9, and W10. Elevated suspended solids concentrations generally originate from human activities, urban areas, and industrial discharges in the vicinity. These high TSS concentrations can have detrimental effects on water quality, including increased turbidity, reduced light transparency, and interference with the photosynthesis process [17]. The spatial distribution of TSS from April to July clearly indicates elevated levels of suspended matter that surpass the allowable standard. The highest recorded value, reaching 301 mg/L, occurred at location W2 in April. TSS levels tend to be higher during the rainy season and lower during the dry season. According to [18], the wet season typically spans from October to May, which could explain the peak TSS value in April.

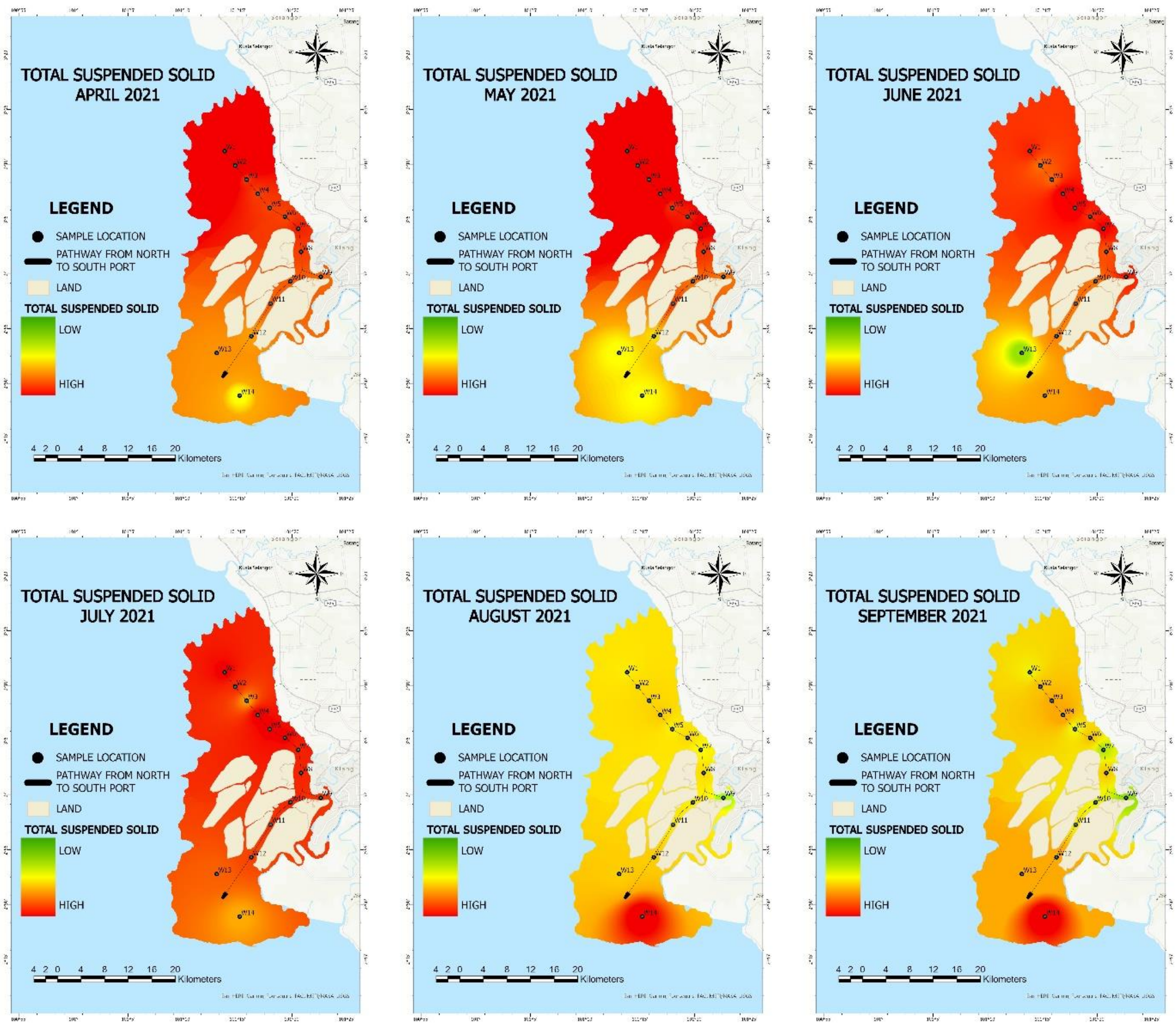

Figure 4. Spatial distribution of total suspended solid (TSS) from April to September 2021

To analyze the temporal variation of TSS in marine water, data was collected and plotted for an six-month period spanning from April to September 2021. This dataset consisted of regular TSS concentration measurements at specific locations. The resulting graph depicted the TSS concentration on the y-axis and the time (month or date) on the x-axis, enabling a visual assessment of the trend during the specified period.

As shown in figure 5, upon examination, it is apparent that TSS concentrations exhibited a decreasing trend from April to September 2021. The trendline, representing the overall direction of change, consistently displayed a downward slope. This observation provides valuable insights into the dynamics of water quality over the studied timeframe, potentially influenced by factors like local land use practices and human activities. Significant alterations in agricultural techniques, land development, or pollution control measures during this period might have impacted TSS concentrations.

Moreover, natural processes such as tidal currents and wave energy could have played a role in the dispersion and redistribution of suspended solids, influencing the observed trend. The declining trend in TSS concentrations from April to September 2021 is promising from a water quality standpoint. Lower TSS levels can benefit marine ecosystems by enhancing light penetration, improving habitat conditions, and reducing the risk of suffocating benthic organisms. These findings suggest that environmental management measures like erosion control, sediment retention basins, and wastewater treatment systems may effectively mitigate TSS inputs and uphold favorable water quality conditions.

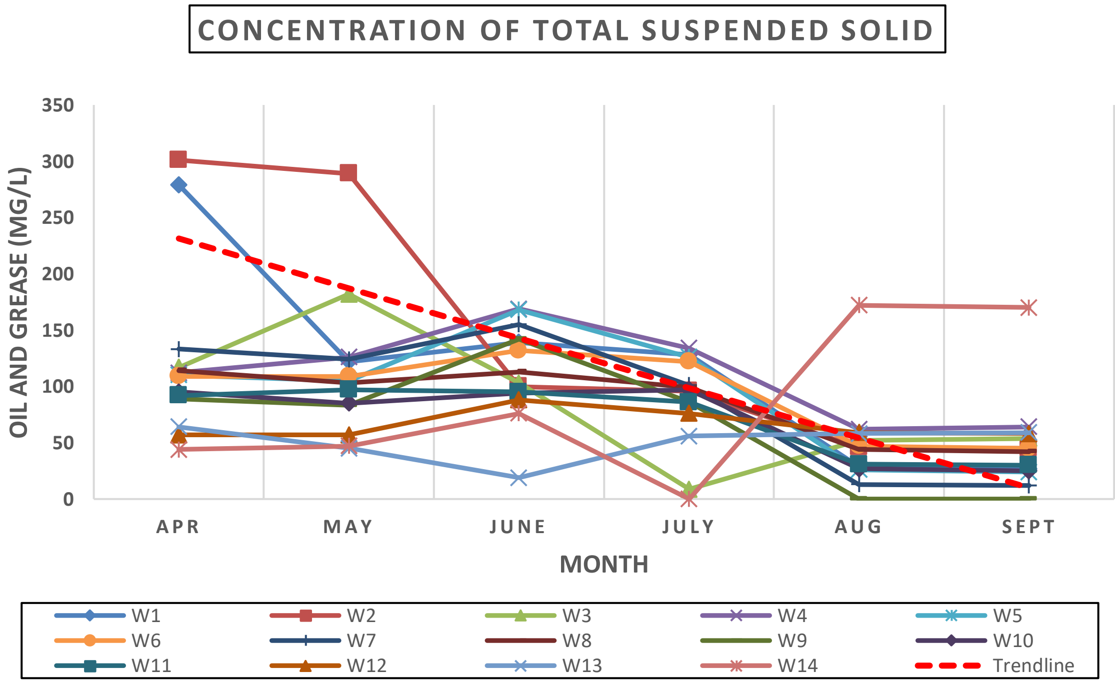

Figure 5. Temporal analysis of TSS

4.3. Oil and grease

According to map in figure 6, the concentration of oil and grease exhibits severity across all locations during the periods of April to September. From May to July, the impact of oil and grease is relatively less significant in most areas. The allowable limit set by MMWQS is below 5mg/L, and certain locations have exceeded this limit at different times. The color-coded representation in the figure indicates that red signifies O&G values surpassing 5mg/L, orange represents class 3 with values ranging from 0.14mg/L to 5mg/L, yellow represents class 2 with values between 0.01mg/L to 0.14mg/L, and values below 0.01mg/L fall under class 1, indicating very low O&G concentration and minimal presence of oil in the area. Analysis of oil and grease was conducted to assess the impact caused by indiscriminate waste oil disposal and inadequate oil management practices within the stations. The primary contributor to high O&G levels in Port Klang is the runoff water from the land into the marine environment. Daily washing activities in wharf driveway areas have led to the runoff of oily substances into the marine water. Furthermore, a combination of minor oil spills and grease from vessels during container loading and unloading has contributed to the increased O&G values.

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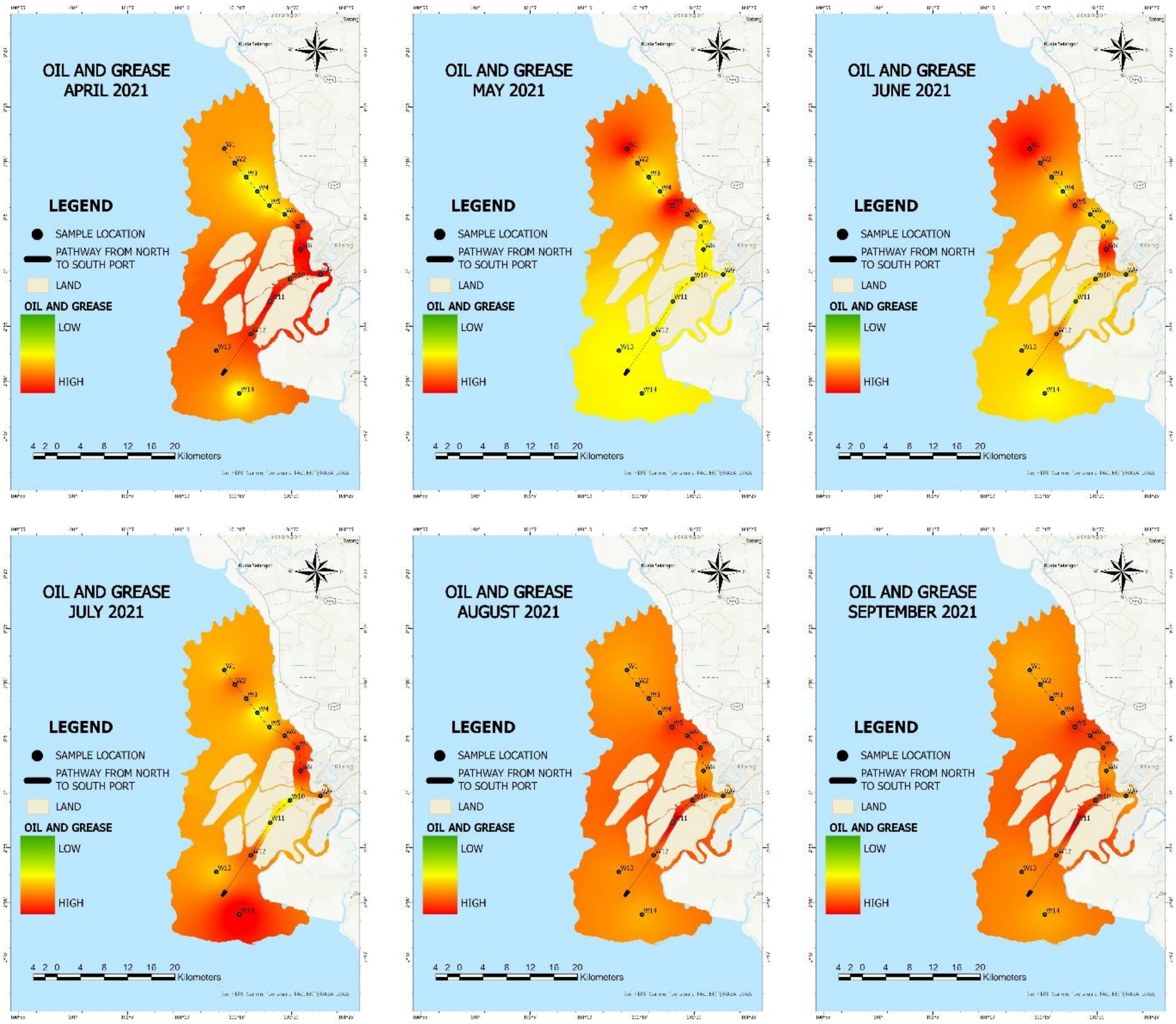

Figure 6. Spatial distribution of oil and grease from April to September 2021

Based on the data presented in figure 7, there is an observable decline in the concentration of oil and grease in the marine water of Port Klang. This decreasing trend indicates a positive development in water quality during the specified period. Several factors are likely responsible for this decline in oil and grease concentration. One key factor is the implementation of regulatory measures and pollution control initiatives. Increased awareness of environmental issues and stricter enforcement of regulations, along with the adoption of best management practices by industries and shipping activities, can effectively reduce the release of oil and grease into marine waters. The improvement of wastewater treatment systems, the implementation of measures to prevent and respond to oil spills, and the enhancement of port management practices are additional contributing factors to this downward trend.

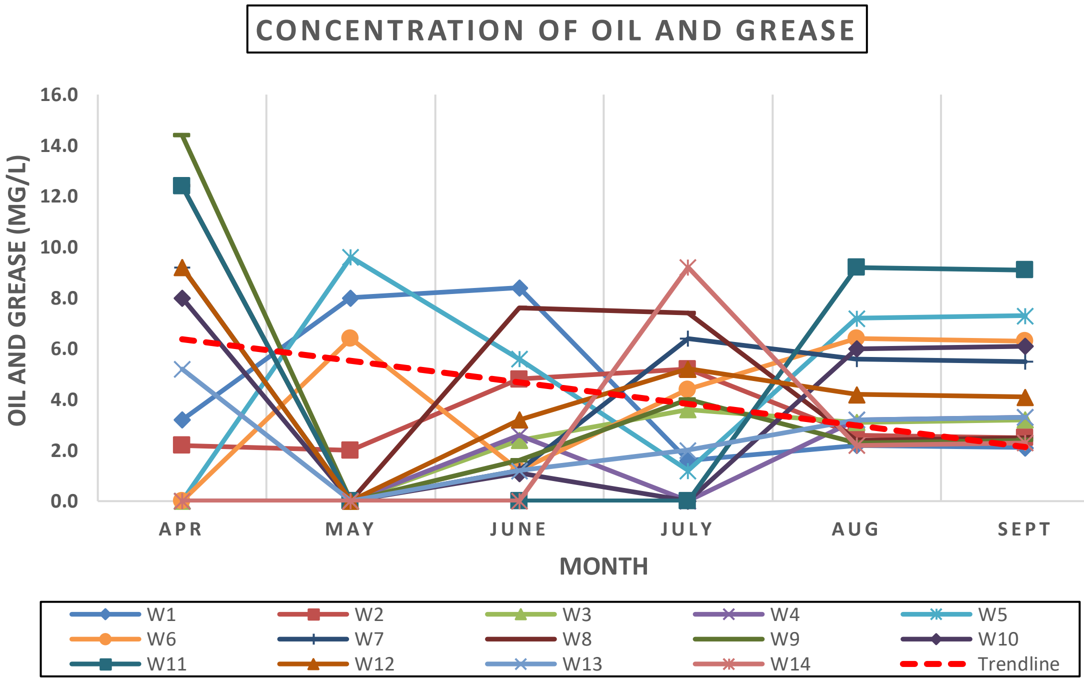

Figure 7. Temporal analysis of oil and grease

5. Conclusion

The integration of spatial and temporal analyses within a GIS database offers a comprehensive approach to managing marine water pollution. This approach allows for the integration and examination of diverse datasets, such as pollution sources, water quality parameters, coastal features, and land-use patterns. By considering these various factors together, a deeper understanding of the complex interactions between human activities and the marine environment can be gained. This understanding, in turn, facilitates the development of sustainable and informed management strategies.

In conclusion, the temporal analysis of marine water quality provides valuable insights into the dynamics and trends of water quality parameters. The examination of the decreasing trend in TSS concentrations from April to September 2021 reveals improvements in water clarity and sedimentation during the drier period. This trend suggests that reduced runoff and environmental management practices may have had a positive impact. Further investigation into the specific causes and implications of this decreasing TSS trend would enhance our understanding and help inform targeted interventions to sustain and enhance marine water quality.

Temporal analysis, as exemplified in this case, plays a crucial role in identifying patterns, assessing the effectiveness of management strategies, and serving as a foundation for evidence-based decision-making in marine water quality management. These findings emphasize the importance of continued environmental monitoring and management practices to safeguard the water quality of Port Klang. By implementing effective pollution control measures, enforcing regulatory standards, and promoting responsible waste management, further improvements can be achieved. Maintaining lower TSS and O&G concentrations not only benefits the marine ecosystem but also ensures a sustainable and healthier environment for both human and aquatic life.

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