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Oil and Grease Pollution in the West Coast of Sabah and Water Quality Index for the Conservation of Marine Biota

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ABSTRACT

Oil and grease (O&G) concentrations were determined on the West Coast of Sabah to identify pollution hotspots and to understand the extent of the issue. Triplicate seawater samples were collected at twenty-five stations during the northeast (November 2020 to February 2021) and southwest (July 2021 to September 2021) monsoons. QGIS software was used to create a map model, and water quality indexes were used to provide information on the status of the marine ecosystem and marine biota preservation. O&G concentrations were significantly higher ($p<0.05$) in certain areas of the West Coast of Sabah, ranging from 0.05 ± 0.03 mg/L to 39.34 ± 1.01 mg/L. According to the Malaysian Marine Water Quality Standards, O&G concentrations in the study area were categorized into Class 3, which is directly exposed to the discharge of effluent from anthropogenic activities. Hence, ecosystems in these areas were susceptible to some degree of deterioration. This suggests a potential source of pollution that requires further investigation and remediation efforts. However, the Water Quality Index revealed that the study areas were classified into moderate, acceptable, and medium status, which were still within the acceptable limit for the conservation of marine biota. The findings underscore the need for continued research and proactive measures to minimize O&G pollution and protect ecosystems in the study area. With increased awareness of oil spills, this favorable trend is projected to endure through effective management methods and effective actions to prevent O&G pollution along the West Coast of Sabah. Oil and grease pollution have the potential to endure in the environment for extended periods, ranging from years to even decades, resulting in enduring ecological harm, and hindering the restoration of ecological systems.

1. INTRODUCTION

The West Coast of Sabah is renowned for its abundant biodiversity, encompassing coral reefs, and mangrove forests. These areas serve as crucial reproductive sites, nurseries, and feeding grounds for a wide range of marine animals. However, the region is subject to various environmental impacts that have been documented by various studies and reports (Sabah Parks, 2023; SFD, 2023; BMRI, 2022; SEPD, 2021; SEDIA, 2020; MOAFIS, 2015). These impacts include pollution from industrial activities, such as oil spills and chemical discharges, which can harm marine ecosystems and biodiversity. Overfishing and destructive fishing can reduce fish stocks and harm coral reefs. Furthermore, overfishing is a significant concern in the region, leading to the depletion of fish stocks and disrupting the delicate balance of the marine ecosystem (SFD, 2023). This threatens the livelihoods of local fishing communities and undermines the sustainability of the fisheries sector (SEDIA, 2020). The construction of resorts, ports, and other infrastructure has encroached upon sensitive marine ecosystems, such as coral reefs and mangroves, leading to their degradation and

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destruction (SEPD, 2021). Coastal development and deforestation also contribute to sedimentation and runoff, leading to water pollution and habitat degradation. The discharge of untreated wastewater from coastal communities and industries has contributed to water pollution in the West Coast of Sabah waters (MOAFIS, 2015). This pollution, combined with oil spills from shipping and offshore activities, has had severe impacts on water quality, marine life, and the overall health of the ecosystem (Sabah Parks, 2023). Fossil fuel combustion is a significant contributor to CO_2 emissions, which in turn exacerbate global warming and its consequences, including rising sea levels, extreme weather occurrences, and ocean acidification (Perera, 2017).

O&G pollution can cause severe damage to these sensitive ecosystems, leading to the loss of biodiversity, degradation of habitats, and disruption of ecological balance. O&G is a significant marine pollutant that can potentially harm marine ecosystems due to its poor solubility and slow microbial breakdown (Bao et al., 2013). Oil spills from ships, illegal waste oil disposal, leaks from offshore oil and gas installations, and other factors can all contribute to this kind of pollution. The presence of O&G in the marine environment can have detrimental effects on the ecosystem, including the destruction of habitats, harm to marine life, and negative impacts on local communities that rely on coastal resources for their livelihoods. When it comes to marine biota, O&G pollution can have detrimental effects. These substances can coat the surfaces of marine organisms, impairing their ability to breathe, feed, and reproduce. When exposed to O&G, aquatic life suffers from decreased development, respiration rates, reproduction impairment, enlarged livers, detrimental effects on fish eggs, and larval survival (McNeill et al., 2012; Pilote et al., 2018). Moreover, O&G can contaminate the food chain, leading to the bioaccumulation and biomagnification of toxic substances in marine organisms. O&G pollution, which enters the food chain, may have a negative impact on human health and marine ecosystems, including mangroves and coastal wetland areas (Fahd et al., 2021). The primary source of contamination on beaches has been identified as sewage originating from the oil and gas industry (Schulz et al., 1994).

There are oil spillage cases reported around the West Coast of Sabah, especially offshore activity spillage (SECD, 2000). Oil discharges resulting from land-based activities have a negative impact on marine ecology, including coastal wetlands and mangroves. Additionally, the entry of these pollutants into the food chain poses a significant risk to human health (Fadzil et al., 2017). The researchers have documented the existence of aliphatic and polycyclic aromatic hydrocarbons in the sediment samples and have linked the occurrence of these substances to many sources, including port operations, shipping activities, accidental spills, and automobile emissions (Abdullah, 1995; Ching, 1996; Waheed et al., 2007; Annammala et al., 2013; Fadzil et al., 2017; Urzola et al., 2019).

Since 1976, the Department of Environment of Malaysia has conducted a monitoring program on marine water quality status (DOE, 2013; DOE, 2021). The Malaysian Marine Water Quality Criteria and Standard (MMWQS) is a tool used as a benchmark for water quality status in Malaysian marine waters. The Malaysian Department of Environment has been keeping an eye on O&G since 1976, one of the parameters in the MMWQS. MMWQS is divided into four classifications (Table 1). Besides, the Malaysian Marine Water Quality Index (MMWQI) is a quantitative and evaluative instrument used to determine the overall condition of water by considering a range of parameters, including physical, chemical, and biological attributes (DOE, 2013), and the O&G parameter is one of the seven total parameters included in the index. It produces a numerical value that measures the overall health of the water body and its appropriateness for supporting marine life (Table 2).

Table 1. Malaysia Marine Water Quality Standards (MMWQS) for the O&G concentration

Parameter (2012)	Class 1	Class 2	Class 3	Class E
O&G (mg/L)	0.01	0.14	5.00	0.14
Parameter (2019)	Class 1	Class 2	Class 3	Class E
O&G (mg/L)	0.01	0.14	5.00	1.00

Source: DOE (2021)

Table 2. Water Quality Indexes

Index	Acronym	Developed by	Equation	Classification	
Malaysian Water Quality Index proposed by DOE to reflect the marine water quality status and its category.	MWQI	Department of Environment (DOE), Malaysia	Equation 1	Excellent Good Moderate Poor	90-100 80-<90 50-<80 0-<50
Water Quality Index of Marine and Coastal Waters for the preservation of Marine biota	$ICAM_{PFF}$	The Marine and Coastal Research Institute José Benito Vives de Andréis (INVEMAR)	Equation 2	Optimum Adequate Acceptable Inadequate Poor	97-100 92-96 70-91 35-69 1-34
Water Quality Index developed in coastal area of Ha-Long Bay, Vietnam	WQI_{HL}	Loan, Nguyên, N.T., Hçi, N.	Equation 3	Excellent Good Medium Bad Very bad	97-100 92-96 70-91 35-69 1-34
Water Quality Index proposed by the Canadian Council of Ministers of the Environment	WQI CCME	Canadian Council of Ministers of the Environment	Equation 4	Excellent Good Acceptable Marginal Poor	95-100 80-94 65-79 45-64 0-44

The Water Quality Index (WQI) for marine biota considers specific parameters that are relevant to the health and well-being of marine life. These parameters may include dissolved oxygen levels, pH, temperature, turbidity, nutrient levels, and the presence of pollutants such as O&G. The WQI has been used for decades to simplify surface water physical, chemical, and microbiological properties into a single numerical number. This helps policymakers, scientists, engineers, non-scientists, and the public develop effective aquatic ecosystem and human well-being protection strategies. This article employs a water quality index to detect O&G pollution hotspots and causes in West Coast Sabah marine waters to conserve marine biota. This paper provides information about O&G concentration along the West Coast of Sabah and can be a guideline for local governments to manage marine ecosystems' sustainability by incorporating marine oil pollution concerns into policies related to the livelihoods of indigenous coastal fisheries and aquaculture communities, especially in combating oil spill pollution in the Sabah context.

By monitoring and assessing the WQI for marine biota, scientists and environmental agencies can identify areas of concern, implement appropriate measures to mitigate pollution, and protect the health and biodiversity of marine ecosystems. This helps to ensure the sustainable use of marine resources, the preservation of marine habitats for future generations, and their suitability for supporting marine life. Efforts are made to prevent and mitigate O&G pollution through strict regulations, monitoring, and response mechanisms to minimize the environmental and socio-economic impacts. O&G pollution on the West Coast of Sabah is a significant environmental concern that poses risks to the marine ecosystem and local communities. This region is home to diverse marine life and supports various economic activities such as fishing, tourism, and aquaculture. Efforts are being made to address these issues through conservation initiatives, stricter regulations, and community engagement to promote sustainable practices and protect the marine environment in the West Coast of Sabah waters. These environmental impacts highlight the urgent need for effective management strategies and sustainable practices in the West Coast of Sabah waters to mitigate further damage and ensure the long-term health and resilience of the marine environment (SBC, 2021).

2. METHODOLOGY

2.1 Sampling sites and water analysis

Sampling was taken along the coastal and river mouths of the West Coast of Sabah, Malaysia, which consists of 25 stations as shown in Table 3. Five significant locations were selected in consideration of the activities occurring on land, shore, and offshore (Figure 1). Sampling was conducted during the northeast (November 2020 to February 2021) and southwest (July 2021 to September 2021) monsoons, and triplicate seawater samples were collected using water sampler and kept in a 500 mL polyethylene bottle with caps. The concentration of O&G was measured following the standard partition gravimetric method (5520B). All samples were preserved by refrigerating at 4°C, extracted within seven days, and analysed as soon as possible. The Partition-Gravimetric method involves the extraction of dissolved or emulsified O&G from water through close contact with a mixture of trichloro-trifluoroethane and petroleum ether in a ratio of 40/60. Take approximately 500 mL of sample and mark the level in the bottle for later determination of sample volume. Acidity to pH2 or lower; often, 5 mL of HCl is sufficient. Transfer to a separate funnel. Carefully rinse the sample container with 30 mL of trichlorotrifluoroethane before solvent washing the separating funnel. Shake vigorously for two minutes. However, if stable emulsion is suspected, gently shake for 5-10 min. Allow the layer to separate, then drain it through a funnel containing solvent-moisturized filter paper into a clean, evacuated distillation flask. If a clear solvent layer cannot be formed, add 1 g Na_2SO_4, as needed. Extract twice more with 30 mL of solvent each time, but first rinse the sample container with solvent. Combine the extracts in an evacuated distilling flask and mash the filter paper with an additional 10 mL to 20 mL solvent. Use a water bath set to 70°C to distil the solvent from the distilling jar. As soon as the solvent has drained, put the flask on a water bath set to 70°C for 15 min and use a hoover to pull air through it for 1 min. It is possible to see water in the residue. To get rid of it, add 2 mL of acetone and let it evaporate on a water bath. Do this again and again until there is no more water visible. Let it cool for 30 min in a desiccator and then weigh it. The amount of O&G in the sample can be calculated as, O&G (mg/L) = (A-B) 1,000/volume of the sample, where A is the mass of the evacuated flask and residue (g), B is the mass of the evacuated flask (g), and the amount of O&G in the given water sample is in mg/L.

Table 3. Coordinate and selected area of the 25 sampling stations in the five chosen locations (A, B, C, D, and E) of the West Coast of Sabah

Location	Station	Area	Coordinate	
			Latitude	Longitude
A	S1	Pulau Tiga, Kuala Penyu	5°43’14.8”	115°39’00.6”
	S2	Menumbok Jetty	5°18’09.9”	115°22’28.2”
	S3	Sipitang (Tg Pagar Fisherman Jetty)	5°04’09.4”	115°32’38.7”
	S4	Sipitang (Merintaman Beach)	5°04’04.4”	115°31’59.3”
	S5	Sipitang (Mengalong River Mouth)	5°00’49.3”	115°28’00.3”
B	S6	Pimping Beach, Membakut	5°31’48.6”	115°41’22.9”
	S7	Kimanis River Mouth	5°37’08.3”	115°53’20.0”
	S8	Benoni River	5°38’56.2”	115°53’46.7”
	S9	Manis Beach, Papar	5°44’05.2”	115°53’46.4”
	S10	Diniwan Island	5°50’38.9”	115°59’30.9”
C	S11	Sepanggar Port	6°05’29.3”	116°07’37.8”
	S12	Putatan Shore	5°52’43.3”	116°02’60.0”
	S13	Gaya and Manukan Island (Coastal water)	5°59’32.5”	116°00’41.8”
	S14	Gaya and Sepanggar Island (Coastal water)	6°02’52.6”	116°03’39.0”
	S15	Likas Bay	6°00’28.8”	116°06’35.4”
D	S16	Dalit Beach (Mengkabong River Mouth)	6°08’34.2”	116°08’14.1”
	S17	Sabandar Beach, Tuaran	6°12’02.0”	116°10’34.4”
	S18	Tuaran River Mouth	6°14’09.6”	116°11’55.5”
	S19	Usukan Island	6°23’26.6”	116°20’03.6”
	S20	Manis Beach, Kg Sarang	6°35’03.2”	116°32’18.6”
E	S21	Teringai Beach, KM	6°43’16.1”	116°38’39.2”
	S22	Sikuati Beach (River Mouth)	6°53’17.0”	116°40’54.3”
	S23	Tip of Borneo	7°02’12.4”	116°44’27.9”
	S24	Bangi Island	7°06’31.7”	117°05’06.6”
	S25	Kudat Port	6°52’44.6”	116°50’44.3”

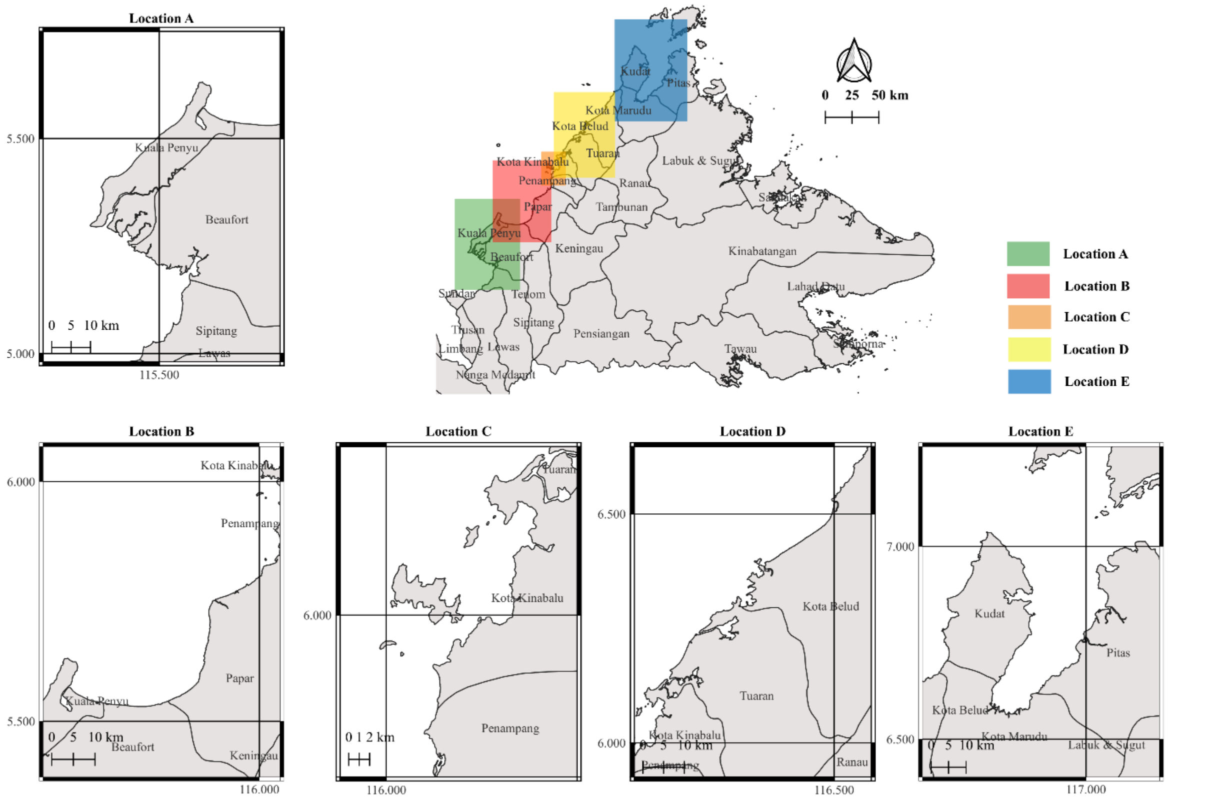

Figure 1. Five chosen locations (A, B, C, D, and E), at the West Coast of Sabah with each of the locations has five sampling stations

2.2 Marine Water Quality Standard and Water Quality Index

The Malaysian Marine Water Quality Standards (MMWQS) are environmental standards that focus on protecting and preserving the marine ecosystem, recognizing how important the ecosystem is to society, and doing so in a way that is cost-effective, useful, and socially appropriate. There are five classes classified in MMWQS (DOE, 2021). The use of the Marine Water Quality Standards (MMWQS) is predicated upon the established categorization of marine water based on its intended purpose within the ecosystem. Since 1985, the Department of Environment (DOE) has been engaged in the ongoing monitoring of marine water quality in Sabah. In addition, the Malaysian Marine Water Quality Index (MMWQI) serves as a comprehensive amalgamation of key marine water quality characteristics, with the objective of offering useful information on the status of marine water quality in a given water body. The index, denoted as Equation 1, is formulated by considering six distinct characteristics related to water quality (DOE, 2021). The MMWQI aggregate is measured on a scale ranging from 0 to 100, with a value of 0 representing low water quality and a value of 100 representing excellent water quality (Table 3).

$$MMWQI = qiDO^{0.18} \times qiFC^{0.19} \times qiNH^{0.15} \times qiNO^{0.16} \times qiPO^{0.17} \times qiTSS^{0.15} \quad (1)$$

The water quality indices for O&G concentrations in marine waters were determined by utilizing the sub-index curves of $ICAM_{PFF}$, as presented in Equation 2. These indexes were employed to assess the preservation of biota. The $ICAM_{PFF}$ index has been recognized for its ability to determine fatal values and establish a normalized curve for O&G based on acute toxicity studies that have been previously documented in scientific literature. These studies exhibit a stronger correlation with the observed concentrations of O&G in marine environments and their associated toxicity (Urzola et al., 2019). Nguyên et al. (2013) also devised the water quality index (WQI_{HL}) in line with the characteristics of the coastal zone. The authors proceeded to employ this index to evaluate the water quality in Ha Long Bay, Vietnam, as seen in Table 3. The estimation of the water quality index for the WQI_{HL} (Equation 3) utilizes a set of nine characteristics. These parameters are used to determine the water quality index, which is then classified into five categories ranging from 1 to 100. A value of 1 represents very poor water quality, while a value of 100 signifies exceptional water quality.

$$\text{ICAM}_{\text{PFF}} = \left[\prod_{1}^{n} X_i^{wi}\right]^{\frac{1}{\sum_1^n wi}} \quad (2)$$

$$\text{WQI}_{\text{HL}} = \left[\prod_{1}^{n} q_i^{wi}\right]^{\frac{1}{\sum_1^n wi}} \quad (3)$$

$$\text{WQI CCME} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right) \quad (4)$$

2.3 Modelling using QGIS and statistical analysis

QGIS software version 3.22 was used to create the map modeling for the area. The software functions such as shapefile and inverse distance weighting (IDW) interpolation were used to make the map layout and create the raster layer for concentration of O&G for specific areas based on the data. SPSS software 26.0 was used for the data and statistical analyses. The one-way analysis of variance (ANOVA) was employed to assess the statistical significance ($p<0.05$) of the differences in the O&G concentrations among the five locations of the 25 stations. A post-hoc analysis was performed to ascertain whether there was a statistically significant disparity among the various sites.

3. RESULTS AND DISCUSSION

3.1 O&G concentrations at the West Coast of Sabah

The range of O&G concentrations recorded at the West Coast of Sabah was 0.05±0.03 mg/L to 39.34±1.01 mg/L, respectively, at the S21 of location E and at the S9 of location B, as shown in Figure 2. The concentrations of O&G were significantly different ($p<0.05$) between the five locations, as shown by a one-way ANOVA (Figure 1). Figure 2 shows the highest O&G concentration was recorded at location B (Table 3), specifically at S9 (Manis Beach, Papar), followed by S8 (Sungai Benoni Station), and the lowest at S6 (Pimping Beach, Papar). Location C recorded the second highest O&G concentrations (mean±S.D.) with a range of 0.44±0.13 mg/L to 20.01±2.90 mg/L, followed by location D with a range of 0.38±0.02 mg/L to 17.86±5.97 mg/L, and the lowest was at location E with a range of 0.05±0.03 mg/L to 1.54±0.73 mg/L (Figure 2). Overall, Figure 3 shows interpolation O&G concentrations using QGIS at the coastal waters of the West Coast of Sabah.

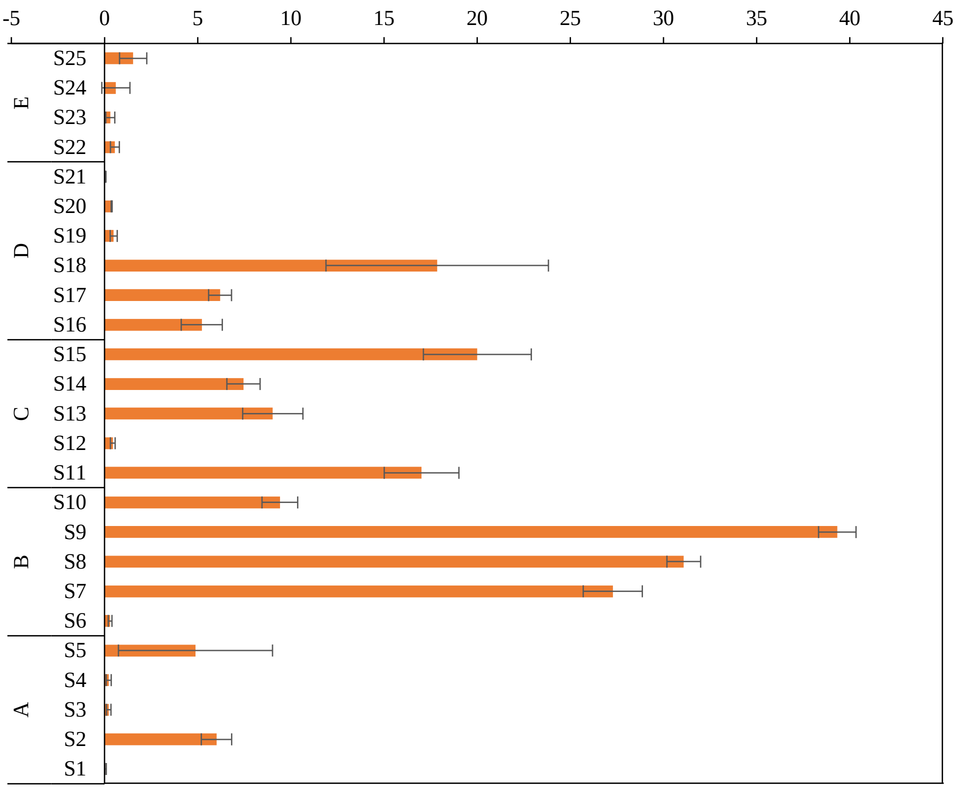

Figure 2. Means (±S.D.) concentrations of O&G at the 25 Stations of the West Coast of Sabah

Due to rapid activities and exploration from land, onshore, and offshore, there were high O&G concentrations at location B (Figure 1). The area of Manis Beach (S21) recorded 39.34±1.01 mg/L mean O&G concentration, which means it is critical erosion with immediate danger of damage or loss of values. The causes of the erosion are reclamation, dredging a navigational channel under construction, and a pipeline on the seabed that was observed at the location of Sabah Oil and Gas Terminal (SOGT) and was the main activity of the operational underwater pipeline transferring crude oil and gas to SOGT from the offshore platform. The increased shipping activities along the coastal water might be one of the main factors leading to higher O&G concentrations in location B (Figure 4). The boom of industrial activities within Kimanis Bay, such as palm oil estates and factory fabrication yards, power plants, timber processing factories, concrete plants, and the Sabah Agro-Industrial Precinct (SAIP) located along the Benoni River, and runoff oil spillage, are visible along the Benoni River (Figure 4).

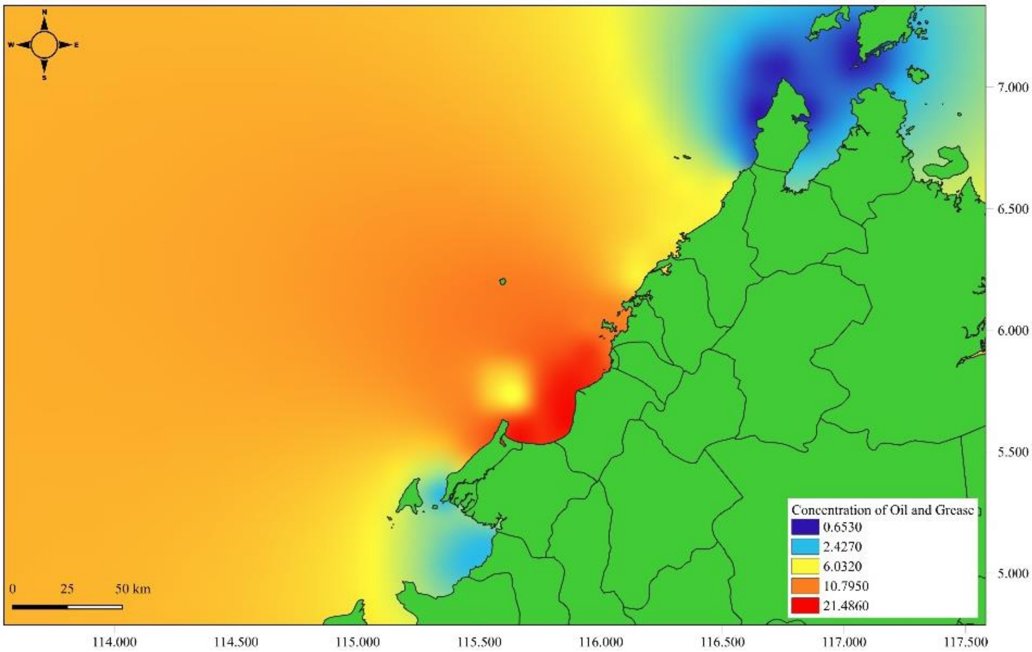

Figure 3. Distribution of O&G concentrations at the West Coast of Sabah

(a)

(b)

Figure 4. Trace of polluted water (a) and at the SOGT (b) of Sungai Benoni, Papar

3.2 Comparison of O&G concentrations with other studies

Table 4 shows the comparison of O&G concentrations between the present study and other research. It shows the O&G range concentrations were various. The O&G concentrations in the current study were marginally lower than those in the study by Annammala et al. (2013), which were 23.30 mg/L to 76.80 mg/L at the Manukan, Mamutik, and Sapi Islands of Sabah. They also reported that in the waters of Kota Kinabalu Port, the O&G concentration was 8.53 mg/L to 40.6 mg/L. However, the O&G concentrations in the present study were slightly higher compared to Fadzil et al. (2017) at the Kukup Island and Tanjung Piai coastal and estuary areas and Waheed et al. (2007) at the coastal and open sea of Brunei Bay (Table 4).

DOE (2013) reported that in the Malaysian waters of the Straits of Malacca coastal areas, the range of O&G concentrations was 1.45 mg/L (in Selangor waters) to 8.80 mg/L (in Penang waters), while Abdullah (1995) stated that the O&G concentrations in the Straits of Malacca coastal areas ranged from 0.40 mg/L (in Penang waters) to 3.50 mg/L (in Johor waters), as shown in Table 4. Abdullah (1995) also reported that in the South China Sea, the concentrations of O&G ranged from 0.30 mg/L to 2.40 mg/L. Those reported O&G concentrations were slightly lower compared to this study, which ranged from 0.05±0.03 mg/L (in location E) to 39.34±1.01 mg/L (in location B).

Table 4. Comparison of O&G concentrations in this study and other references

Location	Mean concentration (range) (mg/L)	References
Sipitang, Menumbok and Kuala Penyu (Location A) Membakut and Papar (Location B) Kota Kinabalu (Location C) Tuaran and Kota Belud (Location D) Kota Marudu and Kudat (Location E)	Location A: 2.265 (0.055-6.011) Location B: 21.486 (0.300-39.337) Location C: 10.794 (0.443-20.014) Location D: 6.099 (0.383-17.860) Location E: 0.809 (0.330-2.537)	Present study
Labuan (Manukan, Memutik and Sapi Islands)	43.3 (23.3-76.8)	Annammala et al. (2013)
Kota Kinabalu Port	24.6 (8.53-40.60)	Annammala et al. (2013)
Kukup Island Tg. Piai Coastal Sg Pulai Estuaries	Kukup Island: 0.44 (0.09-1.50) Tg Piai: 0.28 (0.13-0.45) Sg Pulai, Sg Pendas, and Sg Redan: 0.34 (0.06-0.90)	Fadzil et al. (2017)
Straits of Malacca Coastal Areas	Kedah: 2.79 (2.00-3.63) Melaka: 5.17 (5.00-7.00) P.Pinang: 4.38 (2.40-8.80) Selangor: 2.81 (1.45-5.60)	DOE (2013)
Brunei Bay Costal and Open Aea	0.63 (0.20-1.00)	Waheed et al. (2007)
Straits of Malacca	Perak: 0.51 (0.10-0.90) Selangor: 0.53 (0.30-1.00) N.Sembilan: 0.42 (0.10-0.60) Johor: 1.07 (0.30-3.50) Perlis: 0.75 (0.60-0.90) Melaka: 0.58 (0.50-0.60) P.Pinang: 0.86 (0.40-1.40)	Abdullah (1995)
South China Sea	Sarawak: 0.68 (0.10-1.50) Pahang: 1.70 (0.80-2.40) Terengganu: 0.97 (0.40-1.90) Kelantan: 0.77 (0.30-1.30) Sabah: 0.45 (0.40-0.60)	Abdullah (1995)

3.3 Marine Water Quality Standards and Water Quality Index

Based on the classification by the MMWQS, the concentrations of O&G along the West Coast of Sabah were categorized into class 3 (Table 1). Class 3 is the established benchmark for marine water that is subject to direct effluent discharge resulting from human activities. Therefore, ecosystems in various regions are susceptible to varying degrees of deterioration. Thus, the equivalent degree of protection is intended to preserve the remaining ecosystem's health and enhance the quality of water in the impacted region.

Table 5 shows the marine water quality status for the West Coast of Sabah according to the four indexes. It shows that the five locations of the West Coast of Sabah in the present study were in moderate status according to the MWQI, except for one station, respectively at location C and location D, and two stations at location E, which were in good status (Table 5). Besides, other indexes also showed that the five locations were in the acceptable ($ICAM_{PFF}$ and WQI_{HL}) and Medium (WQI CCME) statuses. The results proved that, according to the indexes, the five locations on the West Coast of Sabah were still in acceptable concentrations for the preservation of marine biota, according to the $ICAM_{PFF}$ (Table 5). Acceptable status requires the study area to monitor, bioassay, control, and manage the water body, evaluate physicochemical and toxic parameters, and develop a quarterly contingency plan to improve water quality and ensure discharge prevention measures help the ecosystem studied.

Table 5. Marine Water Quality Status for the West Coast of Sabah, according to the indexes

Area	Station	MWQI			$ICAM_{PFF}$	WQI_{HL}	WQI CCME
		2020	2021	This study			
Location A	1	Moderate	Moderate	Moderate	Acceptable	Medium	Acceptable
	2	Moderate	Moderate	Moderate	Acceptable	Medium	Acceptable
	3	Moderate	Moderate	Moderate	Acceptable	Medium	Acceptable
Location B	1	Moderate	Moderate	Moderate	Acceptable	Medium	Acceptable
	2	Moderate	Moderate	Moderate	Acceptable	Medium	Acceptable
	3	Moderate	Moderate	Moderate	Acceptable	Medium	Acceptable
Location C	1	Moderate	Moderate	Moderate	Acceptable	Medium	Acceptable
	2	Moderate	Moderate	Good	Acceptable	Medium	Acceptable
	3	Moderate	Moderate	Moderate	Acceptable	Medium	Acceptable
Location D	1	Moderate	Moderate	Good	Acceptable	Medium	Good
	2	Moderate	Moderate	Moderate	Acceptable	Medium	Acceptable
	3	Moderate	Moderate	Good	Acceptable	Medium	Good
Location E	1	Moderate	Moderate	Good	Acceptable	Medium	Acceptable
	2	-	-	Good	Acceptable	Medium	Good

4. DISCUSSION

O&G pollution on the West Coast of Sabah is a significant environmental concern that poses risks to the marine ecosystem and local communities. This region is home to diverse marine life and supports various economic activities such as fishing, tourism, agriculture, and aquaculture (BMRI, 2022; SBC, 2021; SEDIA, 2020; SEPD, 2021; SFD, 2023). The primary sources of O&G pollution in this area include oil spills from shipping activities, illegal waste oil dumping, gas facilities, and leakage from offshore oil. These incidents can result in the release of large quantities of O&G into the marine environment, leading to immediate and long-term impacts. Based on the observations, all the activities from land, onshore, and offshore could contribute to the O&G pollution in the area and harm the marine environment, but if they were controlled and managed well, the marine pollution could be avoided and the impact would be minimized. The amount of O&G in water can have a substantial impact on water quality, and it can be a critical criterion in establishing a body of water's Water Quality Index (WQI). The link between O&G and WQI is mostly due to the environmental and health hazards connected with these pollutants. According to Samsudin and Azid (2018), the use of WQI is a straightforward procedure that offers an appropriate assessment of water quality.

The lowest O&G concentration was recorded in the coastal waters of location E, as shown in Figures 2 and 3, due to the nature of location E's shallow coastal water, which makes it difficult to operate shipping activities. O&G concentrations were still within the MWQS range, and the water quality was in a "good" MWQI status, which means that the water is safe to use and is just slightly degraded from its ideal state. The marine operations in the area are mostly based on passenger ships, fishing, and recreational activities. Similar to the Teringai Beach in Kota Marudu (Table 3), the O&G concentration was still in the range of MWQS because the station is in a remote area, the condition of the gravel road is poor, and the location is not strategic, being quite far from the main road compared to the beaches in the coastal waters of Kudat. However, in the Bangi Island waters (Table 3), the O&G concentration was slightly higher because of tourism activity involving passenger ships, fishing activities, exploration of O&G operations, and residential areas.

The highest concentration of O&G in location B is due to the rapid and active activities from land, onshore, and offshore within the coastal water. The higher and faster the activity, the greater the risk of pollution. The concentration of O&G at location B is classified as class 3 according to the MWQS. This classification indicates that the discharge of effluent from human activities has had a direct impact on the area. Therefore, the ecosystems in these regions are prone to varying degrees of deterioration (DOE, 2021). Location B is also known as an active offshore activity. The location of the platform is approximately 100 to 500 km in Sabah Economic Exclusive Zone (EEZ) water, and the risk of marine pollution in this location is higher compared to the other locations. The highest cases of marine pollution from offshore, according to Department of Environment Sabah reports, demonstrate this. SOGT underwater pipelines connect to platforms from Sabah, Labuan, and Sarawak, which transport crude oil and gas. According to Schulz et al. (1994), offshore activities involving dredging, pipe-laying, and the establishment of support facilities result in the release of diverse contaminants into the maritime environment, therefore influencing its overall quality. According to DID (2012), the amount of oil and gas in location B is in category 1, which means that there is a high risk of damage or loss of value right away. This is because of the erosion and reclamation, construction of navigational channels, and pipelines on the seabed, especially close to the Sabah Oil and Gas Terminal (SOGT), Kimanis. Coastal erosion and siltation are two of the sources of marine pollution (Sarma, 2015). The exacerbation of siltation and coastal erosion has been attributed to the growth and modernization of ports, which involves the deepening of harbor channels (Sarma, 2015). Operative underwater pipelines transferring crude oil and gas to SOGT from the offshore platform made the shipping activities along Papar coastal water and might be one of the main factors that lead to marine pollution, as shown in the Nautical Chart of Malaysia version 2020. Underwater pipelines, which transport crude oil and natural gas, can have a variety of environmental implications both during construction and operation. The degree of these effects might vary based on factors such as the pipeline's location, the procedures used, and the efficiency of environmental control measures. Underwater pipelines, which transport crude oil and natural gas, can have a variety of environmental implications both during construction and operation.

There are a lot of industrial activities, including palm oil estates and factory fabrication yards, power plants, factories that process wood, concrete plants, and the Sabah Agro Industrial Precinct (SAIP) along the Benoni River. In 2015, there was a runoff oil spillage that caused a high reading of oil and gas and can still be seen in its tracks along the river (Figure 4).

The second highest concentration of O&G was recorded at location C (Figures 2 and 3). Land use activities are active in Kota Kinabalu (Table 3), especially coastal development, port activities, urbanization, tourism, and industrial activities. This can be seen along Likas Bay, which has the highest trace of O&G. Urbanization, commercial, tourism, residential, and industrial activities are leading to local development, which contributes to marine pollution in the environment (Vanderzwaag and Power, 2008). Sepangar Port became the hub for Sabah water, mostly container, oil tanker, chemical tanker, bulk container, and general cargo. Statistics are shown in Figure 5 from the Shipping Statistics and Notices from 2010-2019 of the Marine Department, Sabah. Kota Kinabalu coastal water is very active with the onshore activities from Kota Kinabalu Port, such as shipping operations involving de-ballasting, oil tank and cargo cleaning, fishing activities, and the maintenance of pipe lay barges on shore seabed water, which might cause a high density of traffic onshore. In the Straits of Malacca, one of Malaysia's busiest ports, industrial discharges are highlighted as the key contributions of O&G (Abdullah, 1995), and the situation is quite similar. Types of cargo and vessel operation are the main factors in identifying the potential for high risk in marine operations, and a high density of shipping traffic activities might cause marine pollution (Roy et al., 2006). Between 1990 and 2015, tanker cargo, oil tankers, and cargo vessels caused the greatest oil leak accidents, with crude oil, marine diesel, drilling fluids, and oily water accounting for over 80% (Maggi et al., 2014).

Tourism, fishing activities, and residence areas in Pulau Gaya, Pulau Manukan, and Pulau Sepanggar (Table 3) contribute to marine pollution from traffic from boats and ships. Illegal dumplings of oil were found at Pulau Sepanggar twice in 2017 and 2019, as stated in the DOE yearly reports, since the high traffic shipping onshore makes it difficult to trace who is accountable for the oil pollution. The high trace of O&G within coastal water between Pulau Gaya, Pulau Manukan, and Pulau Sepanggar proved that activities from land and onshore led to marine pollution (Annammala, 2013). Low concentration of O&G on the Putatan shore because of less activity onshore and offshore, based on the study observation.

The third highest O&G concentration was recorded at location D (Figures 2 and 3). From the observation, there are also many land use activities in the area, such as tourism, recreational, resorts, hotels, and jetties, which lead to marine pollution (Ching, 1996). Along the coastal water of Tuaran, there are resorts and hotels such as Karambunai hotel and villas, Rasa Ria Tuaran resort, and Mimpian Jadi resort. The area around the Mengkabong River Mouth, for example, is also a highly active area, with a few construction projects nearby and also villages (Figure 6), which may have impacted the coastal area and

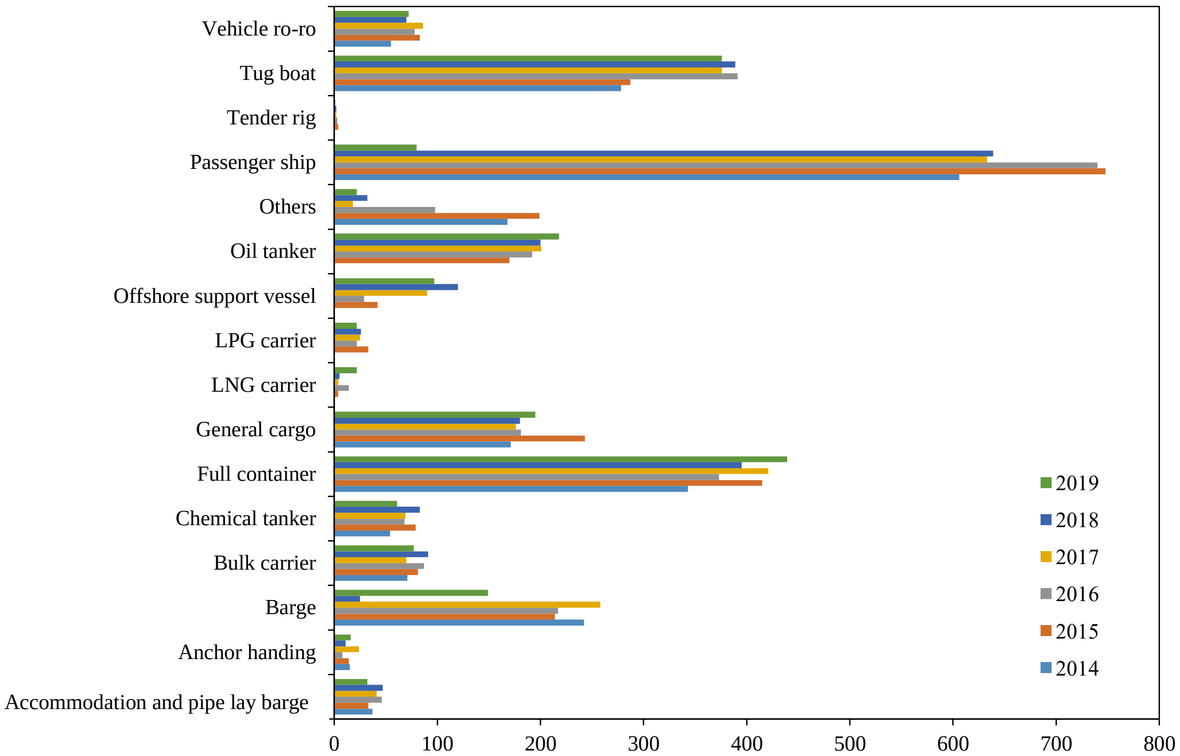

Figure 5. Data shown statistics of shipping activities in Kota Kinabalu, Sabah from year 2010-2019 (Source: Marine Department, Shipping statistics and notices, 2010-2019, Kota Kinabalu, Sabah)

(a) (b) (c)

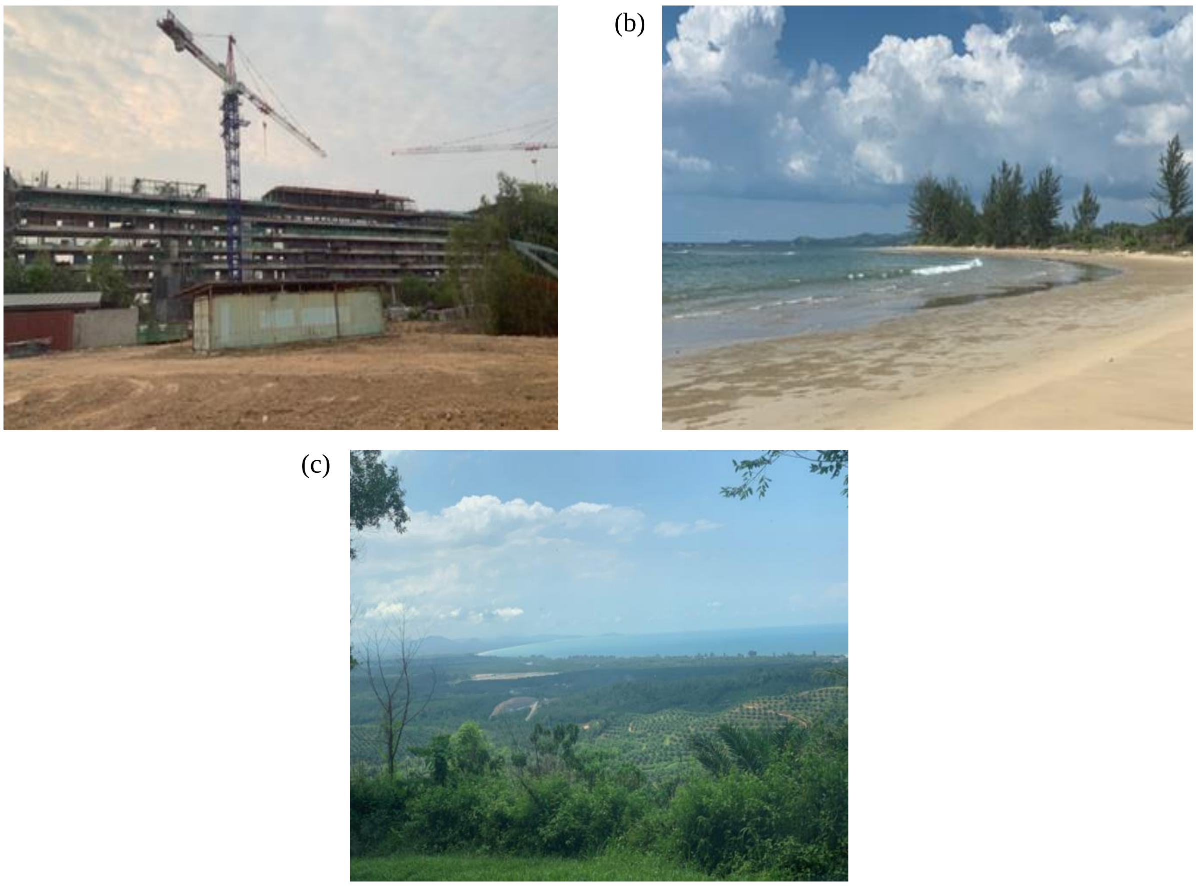

Figure 6. Construction of Alia Hotel, nearby the Sungai Mengkabong River Mouth, Tuaran (a) and Manis Beach, Kampung Sarang, Kota Belud (b), Teringai Beach, Kota Marudu view from Teringai Hill halfway from the main road (c)

caused O&G pollution. The Tuaran River was detected to be polluted by O&G pollution, which may be due to the industrial and aquaculture activities nearby the area and also tourism operations, which may have contributed to the marine pollution in the area. Schulz et al. (1994), have identified sewage O&G as a significant constituent of substances contributing to beach contamination. Mengkabong River Mouth, Sabandar Beach, and Tuaran River fall under Category 2, which is significant erosion with loss of value over five to 10 years (DID, 2012). Low traffic density onshore in location D because only boats and fishing gear are currently active and because of the shallow water around Tuaran and Kota Belud. Offshore activities are not active on the St. Joseph Platform since most offshore activities are shifted to location B because of the new oil field.

The concentrations of O&G at location A exhibited a range of 0.06±0.04 mg/L to 6.01±0.81 mg/L, positioning it as the fourth highest among the locations (Figures 2 and 3). The highest O&G concentration at location A was recorded at Menumbok Terminal. This may be due to the traffic from passenger ships, roro, and boats from Labuan, Brunei, and Sipitang, as well as the increasing number of ship operators between Menumbok and Labuan. Mengalong River Mouth at Sipitang was traced to a high O&G because nearby the area was located with Sipitang Oil and Sabah Ammonia Urea Terminal (SAMUR) and Sabah Forest Industries (SFI). The Department of Environment Sabah reported a spill of marine fuel oil (MFO) in the SFI terminal in 2015, which may have resulted in a higher concentration of O&G in the Mengalong River Mouth. The location of Brunei Bay as an anchorage area nearby the Sipitang coastal water area may also cause a high concentration of O&G due to the shipping traffic onshore, which became an anchorage area and hub for vessel bunkering activities and ship-to-ship activities involving oil transfer (Bao et al., 2013). Due to the fact that Sabah Parks manages and maintains Pulau Tiga and has designated it as a protected marine park, there is a low concentration of O&G nearby (Sabah Parks, 2023).

One of the immediate consequences of O&G pollution is the coating of marine organisms' surfaces, such as fish, corals, and seabirds. This coating can disrupt their natural functions, including respiration, feeding, and reproduction. The toxic components present in O&G can also cause physiological and biochemical changes in marine organisms, leading to reduced growth rates, impaired immune systems, and increased mortality. Furthermore, O&G pollution can have cascading effects on the entire marine food chain. Plankton and other small organisms are capable of absorbing O&G particles, which larger organisms then consume. This process, known as bioaccumulation, can lead to the concentration of toxic substances at higher trophic levels, including commercially important fish species. Consuming contaminated seafood can pose risks to human health as well.

Numerous actions are now being taken along the West Coast of Sabah in order to reduce the amount of pollution caused by O&G. These include the construction of reaction procedures to deal with any accidents as quickly as possible, frequent monitoring of water quality, and stringent rules and enforcement to avoid unlawful dumping and oil spills. Additionally, public awareness campaigns and education programs are conducted to promote responsible environmental practices among industries, communities, and individuals. Efforts are also made to enhance emergency preparedness and response capabilities to minimize the impacts of O&G pollution. This involves training personnel, developing contingency plans, and deploying appropriate equipment and technologies for containment, recovery, and cleanup operations. Through the efficient management and mitigation of O&G pollution along the West Coast of Sabah, it is plausible to safeguard the marine ecosystem, conserve biodiversity, and promote the sustainable use of coastal resources to cater to the needs of both current and future generations.

Oil pollution can result in the deterioration of habitats, contamination of water sources, and damage to marine creatures due to ingestion or entanglement. Polluted waters can have adverse effects on fishing enterprises, tourism, and public health by contaminating seafood and making recreational water activities unsafe for humans. This phenomenon also leads to the degradation of marine habitats, including coral reefs, mangroves, and seagrass beds, resulting in a decline in biodiversity and a decrease in marine ecosystem resilience. These factors can have adverse effects on the reproductive, feeding, and sheltering processes of marine organisms. As a result of habitat degradation, humans can experience adverse effects on coastal protection, fisheries, and tourism businesses that rely on the well-being of ecological systems.

5. CONCLUSION

The study revealed that O&G concentrations were significantly higher in certain areas of the West Coast of Sabah. This suggests a potential source of pollution that requires further investigation and remediation efforts. A map model was created using the QGIS software to show the hotspot and the extent of O&G pollution in the region. According to the MWQS, the concentrations of O&G found along the West Coast of Sabah were categorized as class 3. This classification indicates that the area is subject to the direct discharge of effluent resulting from human activities. Therefore, the ecosystems in these regions are susceptible to varying degrees of deterioration. However, according to the water quality index, the West Coast of Sabah was in moderate status (MWQI) and still within the acceptable limit for the conservation of marine biota ($ICAM_{PFF}$). With the increasing awareness of oil spills, it is expected that this positive tendency will persist through the implementation of efficient management strategies and the use of effective measures to reduce O&G pollution along the West Coast of Sabah. It becomes feasible to safeguard the marine ecology, conserve biodiversity, and promote the sustainable utilization of coastal resources, therefore benefiting both current and future generations.

Undertaking studies regarding O&G pollution is crucial for environmental conservation, human health protection, economic support, and the advancement of sustainable development. Collaborative efforts among researchers, policymakers, and stakeholders can effectively tackle the significant environmental issue of O&G contamination by comprehending its origins, consequences, and approaches to mitigation. Discover cutting-edge remediation technology to tackle O&G contamination in aquatic environments. The process involves examining the origins and routes of O&G pollution in aquatic settings. This process may require locating both point and non-point sources, such as urban runoff or natural seepage. Understanding the processes that control the movement and destiny of O&G in aquatic environments can aid targeted management initiatives. The study's scope and accuracy may be constrained by the limited availability or quality of data pertaining to maritime ecosystems and human activities. Subsequent investigations may prioritise the enhancement of data gathering methodologies, the augmentation of monitoring endeavours, and the facilitation of data sharing initiatives among academics and relevant stakeholders.

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