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Rapid Water Quality Assessment as a Quick Response of Oil Spill Incident in Coastal Area of Karawang, Indonesia

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The purpose of this study was to assess the effect of oil spills on seawater quality along the coastal waters of Karawang Regency. Several laboratories were involved in measuring water quality to get representativeness of the location of the exposed waters both spatially and temporally. The measurement of seawater quality was carried out *in situ* and in the laboratory. Seawater quality data were compared with quality standards and discussed descriptively. All key water quality parameters (total petroleum hydrocarbon, polycyclic aromatic hydrocarbon, phenol, MBAS, and oil and grease) were below the detection limit of equipment, and a number of metals generally met quality standards. Only shortly after the oil spill in the vicinity of the spill source, the Ni metal exceeded the quality standard. However, after some time, spatially and temporally Ni has met the quality standard. Parameters not related to oil spills such as total phosphate generally did not meet quality standards. This might be related to the high activity on land, such as waste from domestic, industry, and agricultural activities entering coastal waters. Based on intertemporal data, the effect of an oil spill on water quality was temporary. This shows that the handling of the impact of the oil spill has shown good results and the quality of seawater remained quite good. Oil spills that float on the ocean surface were picked up, and those that washed ashore were cleaned up and collected.

Keywords: oil spill, PAH, TPH, MBAS, oil and grease

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INTRODUCTION

The amount of oil entering marine waters worldwide is estimated as around 2.4 million tons per year. Sources of oil pollution are natural seepage and anthropogenic sources such as discharges from storage facilities and refineries, discharge of ballast water from tankers, borehole leaks, and ruptured pipelines, carry-over discharges, industrial and urban discharges, and atmospheric deposits (Tong et al., 1999; Lan et al., 2015). The cause of oil spills is estimated as around 30–50% due to human error either intentionally or unintentionally. Meanwhile, as much as 20–40% are caused by equipment failure or malfunction (Michel and Fingas, 2016).

The oil spill event from well drilling activity off the coast of Karawang that occurred at the end of July 2019 has the potential to have an impact on the condition of seawater quality in coastal waters. The dominant current pattern that leads to the west brings the oil spill to the west coast of Karawang Regency. Pertamina Hulu Energi Offshore North West Java (PHE ONWJ) as the company in charge of the well operations has conducted a number of prevention activities since the oil spill incident through the following steps (Stevens and Auraed, 2008; Xu et al., 2013; Singkran, 2014; Marzooq et al., 2019; Karbela et al., 2020; Haule and Freda 2021):

1) Predict the distribution of oil spills with the oil spill modeling program (MoTum).
2) Deploy a combat team that directly monitors and manages oil spills.
3) Conduct observations with UAVs (unmanned aerial vehicles) and helicopters to ensure that coastal areas are exposed to oil spills.
4) Interpret satellite image data with daily temporal resolution. The satellite images used are Sentinel-1A, Radarsat-2, Cosmo, and Skymed-1.
5) Conduct direct surveys to locations of coastal ecosystems exposed to oil spills.
6) Collaborate with universities to conduct impact studies on various environmental aspects.
7) Coordinate with relevant government agencies in the context of mitigating the impact of the oil spill.

Besides being used as an offshore oil and gas mining area, the coastal waters of Karawang Regency are widely used for various activities such as capture fisheries, aquaculture, marine tourism, and sea transportation. In addition to being the object of receiving the impact of an oil spill incident, various activities located on the coast can also have an impact on the condition of water quality. Therefore, in the impact mitigation activities, sampling of seawater quality is conducted in coastal waters and around river mouths (Stevens and Auraed, 2008; ITOPF, 2014).

Oil spills due to oil and gas exploration and production activities have often occurred in places, on both small and large scales. However, the effect of an oil spill on seawater quality may differ depending on the characteristics of the oil, current patterns, and mitigation and handling (Da Silva et al., 2009; Rout and Sharma, 2013). The aim of this study was to provide an overview of the impact of oil spills on water quality conditions in the coastal waters of Karawang Regency.

MATERIALS AND METHODS

Water quality data were obtained from the results of sampling conducted by Environmental Research Center (ERC) IPB and an accredited independent laboratory appointed by PHE ONWJ. In this study, the selection of key water quality parameters considers the following criteria: 1) having a quality standard value based on KepMenLH 51/2004, 2) related to the general characteristics of an oil spill, and 3) related to impact handling. The key parameters for assessing the impact of an oil spill are set, namely, polycyclic aromatic hydrocarbon (PAH), total petroleum hydrocarbon (TPH), phenol, oil and grease, and MBAS (surfactant) (Ewida 2014; ITOPF, 2014; Eljaiek-Urzola et al., 2019; Han et al., 2021). All key parameters were analyzed by the Indonesian standard of analytical method (SNI).

Sampling of seawater quality was carried out by team 1 from Intertek Laboratory, Syslab, and Bogor Labs under the coordination of PHE ONWJ (17 July–6 November 2019) and team 2 from ERC IPB University (15–17 August 2021). The division of the two teams took into account the wide study area and time. The location and time of sampling of seawater quality by Intertek Laboratory, Syslab, and Bogor Labs and ERC IPB Laboratory are presented in **Figure 1** and **Table 1.**

Sampling of seawater quality by Intertek Laboratory was carried out on 23 July–10 October 2019 at 16 locations starting from around the well (the source of the oil spill), seawaters around the well, to Sedari Beach. At several locations, repeated sampling was carried out to see changes in seawater quality conditions over time so that the total samples analyzed amounted to 25 samples. ERC IPB University conducted seawater sampling on 14–17 August 2019 at 12 points, starting from the Estuary of Tengkolak Beach, Sukakerta, along the west to Tanjung Pakis Beach.

At the beginning of the oil spill (17 July 2019), sampling was carried out at two locations, namely, at a distance of ±250 m southeast of the well (exposed seawater) and at a distance of ±11 km northwest of the well (seawater not exposed).

Water samples were taken from below the surface using a Kemmerer water sampler. The collected water quality data were analyzed spatially between the sampling and control locations, compared with the Ministry of Environment Decree (MoE Decree), No. 51 of 2004 Sea Water Quality Standards, for Marine Biota (attachment 3), and analyzed descriptively.

RESULTS AND DISCUSSION

In locations of seawater exposed to oil spills, TSS was found to reach 845 mg/L, when compared to that in the control area (TSS 4 mg/L), and the TSS quality standard was 20 mg/L. The high TSS is thought to be due to the rise of seabed sediments into the water column and surface layers along with the release of oil from leaking drilling wells (Ifelebuegu et al., 2017).

Data collected from team 1 show that BOD at the location of water exposed to oil spills is greater (5.8 mg/L) than that in the control location (<2.0 mg/L) but still meets the quality standard (20 mg/L). Other parameters that do not meet the quality standards of seawater quality for marine biota (MOE Decree, 2004) at the location of exposed water are total phosphate, copper (Cu), and nickel (Ni). At the control location, Cu also did not match the quality standard so that the Cu concentration at both locations could be considered a general condition.

Ni concentration at the location of water exposed to oil spill 0.12 mg/L has passed the quality standard (0.05 mg/L). This condition describes the water quality at the beginning of the incident because the sampling was conducted on 17 July 2021, when the oil spill was still around the source, not yet dispersed. At locations 1 km, 5–10 km, and 30 km from the source of the spill, Ni levels show concentrations that meet quality standards. Likewise, when sampling was conducted in August, September, and October 2019, Ni met the quality standard and even the concentration was below the detection limit. The presence of Ni may be related to the presence of this element in the fingerprint of YYA-1 well crude oil (0.9 mg/dry kg). However, this element in

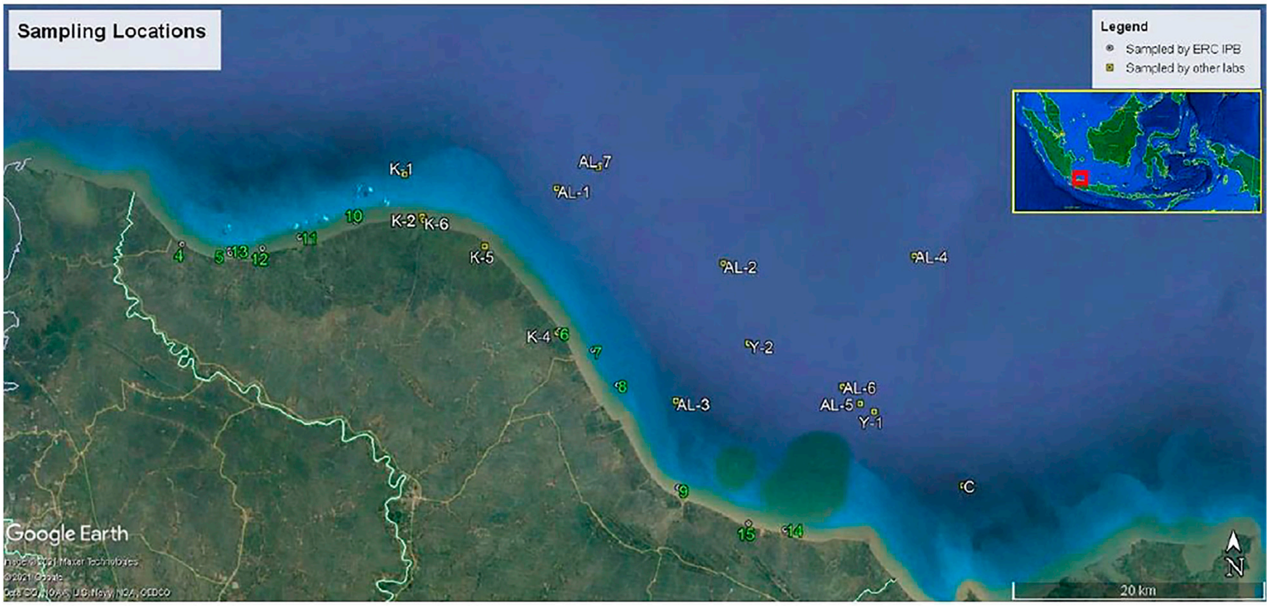

FIGURE 1 | Sketch of seawater quality sampling locations in Karawang Regency.

TABLE 1 | Water quality sampling site and time by Intertek Laboratory, Bogor Labs, and ERC IPB.

Cluster	Location code	Location	Sampling date
A. Intertek Laboratory, Syslab, and Bogor Labs (Team 1)			
1. Marine water at the source of oil spill inside YYA-1	Oil-exposed marine water	Distance ±250 m southeast of YYA-1	17 July 2019
	Non-exposed marine water	Distance ±11 km northwest of YYA-1	17 July 2019
	AL-1, AL-2, Al-3, Al-4	AL-1 (Coastal of Sedari), Al-2 (Coastal of Pantai Pelangi), Al-3 (Coastal of Pusaka Jaya), Al-4 (marine water, ±12 km northeast of YYA-1)	23 September 2019
	1 km of source	±1 km northwest of source	07 August 2019, 15 September 2019, 09 October 2019
	5–10 km of source	5–10 km west of source	07 August 2019, 16 September 2019, 09 October 2019
	30 km of source	Coastal of Pantai Sedari, 30 km west of source	07 August 2019, 16 September 2019, 11 October 2019
	Control (area outside oil spill distribution)	±10 km southeast of source	17 September 2019, 10 October 2019
2. Karawang Regency	Sedari (outside oil spill distribution)	3.7 km off Sedari Beach	06 August 2019, 28 September 2019, 20 October 2019
	Sedari 1 and Sedari 2 (within oil spill distribution)	250 m off Sedari Beach	06 August 2019, 28 September 2019, 20 October 2019
	Pantai Pelangi and Mouth Dobolan River	Pantai Pelangi and Mouth Dobolan River	05 November 2019
	Marine water of Sedari	Marine water of Sedari	06 November 2019
B. ERC IPB University (Team 2)			
3. Karawang Regency	4, 5	4 (Pantai Tanjung Pakis), 5 (Pantai Segar Jaya)	15 August 2019
	6, 7, 8, 9	6 (Estuary of Pantai Pelangi), 7 (Estuary of Sungai Buntu), 8 (Estuary of Pusaka Jaya), 9 (Pantai Ciparage)	16 August 2019
	10, 11, 12, 13	10 (Pantai Cemara), 11 (Pantai Sedari), 12 (Pantai Tambak Sari), 13 (Pantai Tambak Sumur)	15 August 2019
	14, 15	14 (Estuary of Pantai Tengkolak, Sukakerta), 15 (Pantai Pasir Putih, Sukajaya)	17 August 2019

seawater is immediately diluted and scattered by ocean currents spatially and temporally.

Based on seawater quality data around the oil spill source, it is known that the presence of an oil layer was observed by Intertek Laboratory, Syslab, and Bogor Labs at a location 1 km to the northwest from the well on 7 August 2019 and 15 September 2019. This is an indication that there is an oil spill that has escaped the obstruction of the oil boom installed around the source of the oil spill. However, based on the results of laboratory analysis from the sampling location, it can be assessed that the presence of an oil layer on the sea surface has no significant effect on the overall water quality condition because all parameters related to oil such as PAHs, TPHs, phenols, detergents (MBAS), and oil and grease meet quality standards, and even the concentration is below the detection limit.

The parameter that may be affected by the presence of an oil layer is the dissolved oxygen (DO) content. The results of *in situ* measurements showed a DO concentration of 4.4 mg/L on 7 August 2019 at a sampling location 1 km from the source, when at this location a layer of floating oil was also found on the surface. However, at the same location and time, the brightness (9 m) and turbidity (0.7 NTU) were still in the good category, meeting the quality standard. On the contrary, the results of measurements on 15 September 2019 at a sampling location of 1 km showed a relatively good DO content (5.75 mg/L), 3 m brightness, and low turbidity (<0.5 NTU). Similar phenomena were found by Chen et al (2017) who studied the impact of two oil spill events on the water quality along the coastal area of Kenting National Park, Taiwan.

Observing the phenomena that occur, the effect of an oil spill on DO parameters, turbidity, and brightness is highly dependent on the thickness and area of the oil layer on the water surface. The thicker the oil layer, the lower the penetration of sunlight into the water column, which can continue to disrupt photosynthesis by plankton so that it indirectly causes the dissolved oxygen level in the water to become low (González et al., 2009). The oil layer directly can also cause the dissolved oxygen level in the water to become low due to the obstruction of the diffusion process from the air (Ifelebuegu et al., 2017). In this incident, oil spills were intercepted by oil booms and skimmers and immediately picked up periodically, so that there were not many oil spills that escaped from the oil boom barrier, only in the form of lumps that were not continuous, and were washed away by currents to the west from the source of the spill.

Parameters of seawater quality around oil spills that do not meet quality standards generally indicate contamination from domestic waste, namely, relatively high levels of nutrients, especially total phosphate. In almost all sampling times and locations, total phosphate did not meet the quality standard (0.015 mg/L). The presence of phosphate in water is generally caused by anthropogenic pollution such as the use of detergents, run-off from agricultural fertilizers, industrial waste, and domestic waste (Daneshgar et al., 2018). Sampling locations are more dominant on the coast, so that the influence of river flows that carry untreated domestic wastewater is visible, supported by high turbidity. Seawater quality data from sampling in early October 2019 (after the well was successfully closed at the end of September 2019) also still show total phosphate concentrations that do not meet the quality standards, thus confirming that this condition is not due to an oil spill.

The characteristic of volatile oil is indicated by the presence of odor in the air around the well. However, at all times and locations of sampling carried out by the Intertek Team, no significant odor was recorded from the presence of an oil layer on the surface of water because the proportion of oil that was washed away was much less than the proportion of oil that was captured, collected, and brought to the mainland for further handling. This condition can also be related such that offshore waters are open and air circulation tends to be better than that on the coast, so that the smell of the oil layer does not feel significant.

In addition to water quality sampling, Intertek Laboratory also measures air quality around platforms and residential areas on the coast. The results of ambient air quality measurements at the well location on 15 September 2019 showed that the hydrocarbon content in the ambient air was 537 μg/Nm^3. This concentration exceeds the ambient air quality standard based on PP 41 of 1999, which is 160 μg/Nm^3. The hydrocarbon content is much greater than the results of sampling at the same location on 9 October 2019 or after the well leak was successfully handled, which is <50 μg/Nm^3. The hydrocarbon concentration in the ambient air can strengthen the explanation that the well oil tends to be volatile or undergoes evaporation. There are a number of volatile oil fractions which are short chains. The long carbon chain oil fraction was carried by ocean currents away from the spill source. The lower carbon numbers are gases, intermediate compounds are liquids, and higher members of the series are solids (Nolan, 2019). Evaporation is the process of weathering the oil with the largest portion. Evaporation reduces significantly the volume of oil remaining in the air or soil after a spill (Lindgren and Lindblom, 2004). Fate of oil contamination in the marine environment includes spreading and advection, evaporation, dissolution, dispersion, emulsification, photo-oxidation, sedimentation and shoreline stranding, and biodegradation (Stevens and Auraed, 2008; Gong et al., 2013; Passow and Overton, 2021).

The results of observations from Intertek Laboratory, Syslab, and Bogor Labs in the waters of Sedari Beach (**Table 2**) in August–October 2019 did not find the presence of an oil layer on the sea surface, both in the exposure area and outside the exposure. The content of PAH, MBAS, phenol, and oil and grease was all below the detection value. Likewise, the dissolved metal parameters all meet the quality standards. Seawater quality parameters that do not meet the quality standards are generally an indication of the influence of domestic, industrial, and agricultural wastewater contamination which is characterized by high concentrations of total phosphate and nitrate.

The parameters of seawater quality that are the main concern by team 2 (ERC IPB University) are focused on parameters directly related to oil spills such as the presence of an oil layer on the surface, odor, TPH (total petroleum hydrocarbon), PAH (polycyclic aromatic hydrocarbon), phenol, MBAS, oil and grease, and metals. In addition to turbidity, in general the

TABLE 2 | Coastal water quality of Karawang (ERC IPB University).

No.	Parameter	Unit	Standard[a]	Coastal of Tanjung Pakis (4)	Coastal of Segar Jaya (5)	Estuary of Pantai Pelangi (6)	Estuary of Sungai Buntu (7)	Estuary of Pusaka Jaya (8)	Coastal of Ciparage (9)
Physical Characteristic									
1	TSS	mg/l	80	40	27	25	36	29	36
2	Turbidity	NTU	<5	9.04	23.5	9.22	1.46	2.16	2.16
3	Transparency	cm	300	5	5	5	44	47	50
4	Oil film	—	Nil	Nil	Nil	Nil	Nil	Nil	Nil
5	Color	—	—	Brown	Grayish brown	Brown	Greenish brown	Brown	Light brown
6	Odor	—	Natural	No odor	No odor	No odor	No odor	No odor	No odor
Chemical Characteristic									
1	pH	—	7–8.5	7.87	7.98	7.8	7.83	7.88	8.02
2	Salinity	psu	Natural	30	31	34	31	31	34
3	Phenol	mg/l	0.002	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
4	Oil and grease	mg/l	1	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
5	MBAS (surfactant)	mg/l	1	0.09	0.11	0.18	0.08	0.17	0.05
6	PAH	mg/l	0.003	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
7	TPH	mg/l	-	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
8	Cu	mg/l	0.008	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
9	Cd	mg/l	0.001	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
10	Pb	mg/l	0.008	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
11	Hg	mg/l	0.100	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
12	As	mg/l	0.012	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
13	Zn	mg/l	0.050	0.14	0.1	0.03	0.04	0.05	0.1
14	Ni	mg/l	0.050	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
15	Cr(VI)	mg/l	0.005	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
No.	**Parameter**	**Unit**	**Standard[a]**	**Coastal of Cemara (10)**	**Coastal of Sedari (11)**	**Coastal of Tambak Sari (12)**	**Coastal of Tambak Sumur (13)**	**Coastal of Tengkolak Sukakerta (14)**	**Coastal of Pasir Putih Sukajaya (15)**
Physical Characteristic									
1	TSS	mg/l	80	27	23	35	37	31	23
2	Turbidity	NTU	<5	7.28	1.81	3.22	3.4	8.51	7.28
3	Transparency	cm	300	8	8	7	7	7	25
4	Oil film	—	Nil	**Present**	Nil	Nil	Nil	Nil	Nil
5	Color	—	—	Brown	Brown	Brown	Brown	Light brown	Light brown
6	Odor	—	Natural	Odor	No odor	No odor	No odor	No odor	No odor
Chemical Characteristic									
1	pH	-	7–8.5	8.05	8.09	8.07	8.08	7.94	7.91
2	Salinity	psu	Natural	33	33	33	33	33	31
3	Phenol	mg/l	0.002	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
4	Oil and grease	mg/l	1	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
5	MBAS (surfactant)	mg/l	1	0.07	0.2	0.08	0.07	0.1	0.2
6	PAH	mg/l	0.003	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
7	TPH	mg/l	—	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
8	Cu	mg/l	0.008	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
9	Cd	mg/l	0.001	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
10	Pb	mg/l	0.008	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
11	Hg	mg/l	0.100	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
12	As	mg/l	0.012	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
13	Zn	mg/l	0.050	0.04	0.02	0.01	0.01	0.02	0.01
14	Ni	mg/l	0.050	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
15	Cr(VI)	mg/l	0.005	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl

[a]*Quality standard (MoE Decree No. 51/2004 Marine Biota). Bdl, below detection limit.*

observed seawater quality parameters meet the quality standards (MOE Decree, 2004). TSS in all observation locations ranged from 22 to 42 mg/L, was still classified as moderate, and met the quality standard (80 mg/L). Turbidity levels vary, in some coastal locations and river mouths. Turbidity >5 NTU, exceeding the quality standard, was seen at nine observation locations, namely, Muara Pantai Pelangi, Tanjung Pakis, Pantai Segar Jaya, Pantai Cemara, Pantai Sedari, Tambak Sedari, Pantai Pasir Putih, dan Muara, and Pantai Tengkolak. Turbidity is related to the condition of coastal sediments which are generally fine muddy and muddy sand that is easily stirred due to waves and currents.

Physical parameters, pH, and salinity are not affected by oil spills. A similar phenomenon was encountered by Ewida (2014) who conducted research on the Nile River and also found no effect on the physical parameters of waters due to oil spills.

Based on the concentration of phenols, oil and grease, surfactants (MBAS), PAHs, TPHs, and dissolved metals, overall they were low and even undetectable (**Table 2**). Indications of contamination were seen at Pantai Cemara, due to the presence of a layer of oil in the waters and the smell of oil at the time of observation (16 August 2019). However, seawater quality in general is not affected by oil spill events because all concentrations of seawater quality parameters related to oil meet the quality standards.

This condition can be attributed to the rapid response efforts in the form of prevention by installing oil booms and skimmers since the occurrence of the oil spill in the vicinity of the leaking oil well. This effort can significantly reduce the volume of oil that reaches the surrounding coastal waters. Given the nature of oil which has a relatively high paraffin wax content (29.32%Wt), it tends to be in the form of small lumps of oil that float on the surface and do not mix or dissolve in water. Biodegradation can remove up to 60% of spilled oil. The photochemical process can convert an amazing oil by up to 50%. Some of the oil on the surface that is undergoing weathering will be washed up along the coastline (Passow and Overton, 2021). High air temperatures and sea breeze speeds can increase the weathering of oil (Lindgren and Lindblom, 2004). This natural process can reduce the volume of oil spilled in seawaters (Wang et al., 2016).

CONCLUSION

Some of the key parameters for assessing the impact of an oil spill are PAH, TPH, phenol, oil and grease, and MBAS (surfactant). All key water quality parameters and a number of metals generally meet the quality standards. Just moments after the oil spill in the vicinity of the spill source, the Ni metal exceeds the quality standard. However, after some time, spatially and temporally Ni has met the quality standard.

Parameters that are not related to oil spills such as total phosphate generally do not meet the quality standards. This may be related to the high activity on land, such as waste from domestic, industrial, and agricultural activities entering coastal waters.

Based on intertemporal data, the effect of an oil spill on water quality is temporary. This shows that the handling of the impact of the oil spill has shown good results and the quality of seawater remained quite good. Oil spills that float on the ocean surface are picked up, and those that washed ashore are cleaned up and collected.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

HE as the first author contributed to the whole process of manuscript writing. Mursalin and SH were responsible for the planning of sampling, GIS analysis, and data interpretation.

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