An Evaluation of the Environmental Impact of Oil Pollution from Maritime Transportation

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Maritime transportation, which has a growing share in global transportation, and especially ships with large carrying capacities, increases the risk of marine environment pollution. The fact that maritime transport takes place not only in the open seas, but also in coastal waters, narrow waters with high navigational risk, and sea areas in the vicinity of ecologically sensitive zones necessitates prediction and calculation of this risk, as well as taking precautionary measures. This study seeks to identify optimal intervention strategies and determine where and when interventions should take place to minimize the adverse effects of potential oil pollution on the marine environment, utilizing a simulation model based on the example of Istanbul's Tuzla shipyard region. The Potential Incident Simulation and Evaluation System (PISCES) decision support system, which predicts the spread of pollution based on the behavior of oil in water, was used in the simulation. As oil weathering processes, which result in evaporation, emulsification, and dispersion, vary depending on the type of oil, weather, and oceanographic conditions, their seasonal average values were obtained from the relevant institutions and entered into the simulation. In the dispersion of oil, the surface current structure, which plays the most pivotal role, has been established by PISCES, based on the reference vector obtained from the relevant institute.Given that, once the oil disperses, starts to submerge and sedimentation occurs, intervention becomes impossible, leading to long-lasting negative impacts on the marine ecosystem, timely response to marine pollution caused by ships is of utmost importance. Intervention strategies should be selected based on dispersion time and quantity, as well as the duration of the interaction of oil with the coast. Another consequence is that oil pollution can affect not only the marine environment but other areas as well, such as adjacent environmentally sensitive areas, causing devastation to the marine habitat.

KEY WORDS

~ Maritime transportation
~ Marine environment
~ Oil pollution
~ Simulation
~ Oil spill intervention

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doi: 10.7225/toms.v13.n01.w15

Received: 10 May 2023 / Revised: 14 Nov 2023 / Accepted: 28 Feb 2024 / Published: 15 Mar 2024

1. INTRODUCTION

Increasing global trade volume, combined with the growing need for the maritime transportation of goods between production and consumption points, poses a risk to the environmental balance of the marine environment. The environmental effects of maritime accidents and subsequent oil pollution experienced in the past years have been identified in studies and administrative measures to prevent their recurrence in the light of the lessons learned have been established by international conventions. Based on this experience, numerous technological devices have been developed to reduce intervention time. However, even advanced intervention systems that have been developed so far remain at a primitive level in the face of enormous environmental damage caused by the interaction of oil with seawater.

Despite advancements in maritime safety, there are still accidents at sea and in ports that result in substantial costs, trade disruptions, environmental damage, and, at times, loss of life. The marine environment, particularly in the light of issues like oil spills, has been gaining increasing attention. Shipping accidents are recognized as significant contributors to the deterioration of aquatic ecosystems due to the release of harmful chemicals. Beyond the potential consequences for human beings and the environment, maritime incidents can also have severe economic ramifications. Trade interruptions and the costly replacement of equipment and property, both at sea and in ports, contribute to economic challenges associated with such accidents (Lloyd’s List Intelligence, 2023).

Based on the statistics of The International Tanker Owners Pollution Federation Limited (ITOPF) for the last five decades, the number of 7+ ton tanker spills has decreased considerably, as shown in Figure 1. The average annual number of spills in the 1970s was 79. The number has since dramatically dropped by over 90%, to mere 6 spills in the 2010s, and has sustained a comparable level in the present decade (ITOPF, 2022).

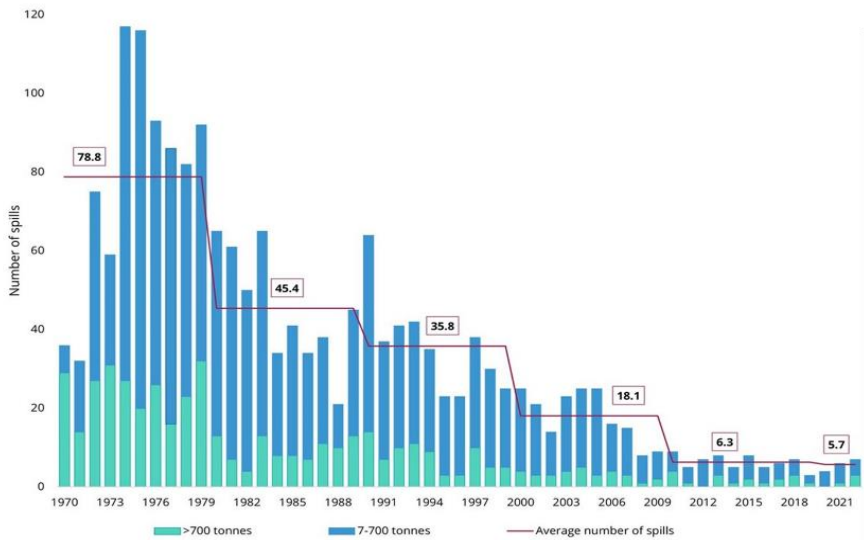

Figure 1. Number of medium (7-700 tons) and large (>700 tons) oil spills, 1970-2022 (ITOPF, 2022).

In tandem with the decline in the occurrence of spills, there has been a noteworthy reduction in the volume of oil discharged over successive decades, as shown in Figure 2. In the 2010s, an approximate loss of 164,000 tons of oil was recorded from tanker spills bigger than 7 tons, reflecting a substantial 95% decrease since the 1970s. In this decade, three-year data give us the recorded figure of 26,000 tons (ITOPF, 2022).

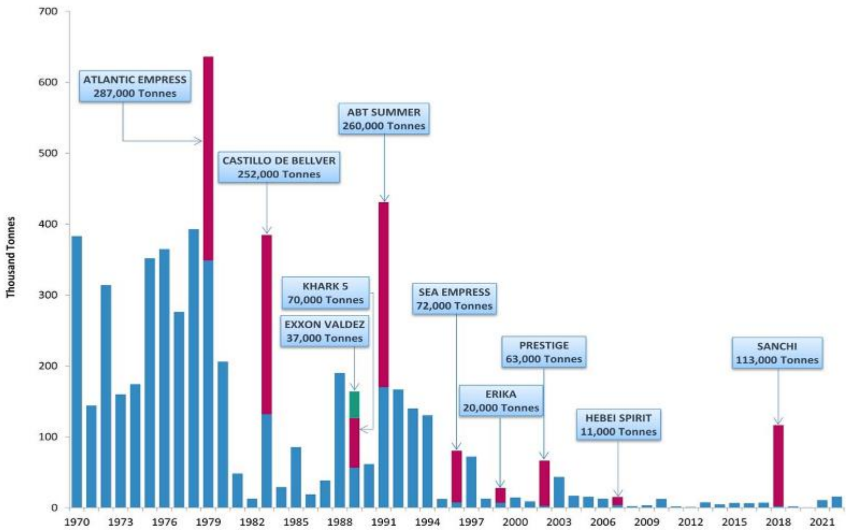

Figure 2. Number of tanker oil spills bigger than 7 tons, 1970 - 2022 (ITOPF, 2022).

Despite the observed decrease in the frequency and volume of oil pollution over the years, the increasing dependence of global trade on maritime transportation, the diminishing natural resources derived from marine environments, and the growing sensitivity to environmental balance suggest that even a small-scale oil pollution incident could result in significantly greater economic losses and environmental damage compared to the past. For example, the accident and subsequent pollution in the East China Sea involving Iranian-flagged tanker Sanchi and Hong Kong-flagged cargo ship CF Crystal on January 6, 2018, is the most recent major marine pollution. The Sanchi transported a quantity of natural gas condensate that exceeded 111,300 tons. An indeterminate portion of the Sanchi's condensate is believed to have contributed to the fires that ensued following the collision. The combustion and gaseous emissions around the tanker caused death and injury to phytoplankton, as well as birds, marine mammals, and fish present in the area at the time of the ignition (Carswell, 2018). The environmental impact was further discussed in Mullany (2018)'s article issued by the New York Times, which stated that the area in the East China Sea where the spill occurred is a significant location for the spawning of edible fish during that specific season and also serves as a migratory route for whales.

The quantification of the precise financial implications of an oil spill remains elusive; nonetheless, experts rely on historical analyses of significant spills to approximate associated financial risks. A 2012 study by the Fisheries Centre with the University of British Columbia, appraising the potential economic ramifications of a tanker spill on ocean-based industries in British Columbia, gives some estimations. According to this study, a medium-sized spill on the north coast of British Columbia would entail an economic cost of up to $189 million, with cleanup expenses reaching $2.4 billion. The projected economic impact of a large spill on the regional economy would escalate to $308 million, necessitating a cleanup expenditure of $9.4 billion (Hotte and Rashid Sumaila, 2012). Drawing on historical data compiled by ITOPF from diverse sources including the shipping press, specialized publications, vessel owners, insurers, and ITOPF's firsthand experience with incidents, spills are typically classified into three size categories: <7 tons, 7-700 tons, and >700 tons, with the specific spill volume documented (ITOPF, 2022). Given that an oil spill exceeding 700 tons is considered a large-scale pollution event, the possibility that the volume reaches several thousand tons necessitates proactive measures and the formulation of contingency plans by all stakeholders before pollution occurs.

Oil spill modeling systems, integral to the response to incidents like the Sanchi accident, play a crucial role in supporting decision-making authorities. These systems contribute significantly to the preparation of emergency response plans, which should be established proactively before the onset of pollution. Additionally, they facilitate choosing post-pollution response strategies and the organization of spill recovery tactics (Perkovic and Sitkov, 2008). As the leading response measure to the growing impact of oil pollution, decision support and simulation systems play a crucial role in minimizing pollution-related losses and damage. Simultaneously, predicting real life circumstances while simultaneously considering potential human responses is difficult (Delgado et al., 2006). These oil pollution models and response forecasts are vital to minimize the negative impact of delay on the marine environment. Predicting oil pollution spread by exploring case scenarios and creating an intervention plan shorten pollution response time and especially allow the recovery of oil while it is still on the sea surface, before it sinks into the water column and interacts with the shore (Fingas, 2013), (PISCES II, 2008).

These kinds of systems can provide decision-makers with a modeled picture of the incident area in search and rescue and pollution response operations after maritime accidents by continuously updating and modeling oceanographic and meteorological variables. The variables taken into account by such models can include weather and sea conditions, surface currents, coastal structure, depth, ecologically sensitive areas, intervention equipment, and other relevant values. Based on these variables, decision support systems generate outputs that describe the behavior of sea pollution over time, including when it will sink from the sea surface into the sea column, disperse and harm marine life, when and how much it will strand on the coast, and to what extent it will harm the habitat, etc. Authorities responsible for maintaining a sustainable balance between protecting and utilizing natural resources rely on these systems to create emergency response plans to prevent pollution that may disrupt this balance.

The most critical points in responding to marine pollution, especially oil pollution which causes severe damage, are when the oil sinks from the sea surface into the sea column, making intervention impossible, and when it reaches the coastline, making cleanup much more difficult. These two values, namely the timing of the dispersion and the moment of coastal impact, are particularly taken into consideration when developing pollution response strategies, including decision-making on timing, deployment locations of intervention equipment, and intervention methods.

This study aims to describe the spread of oil pollution from ship accidents and its potential environmental impacts, on the example of the shipyards region located in Tuzla/Istanbul, as shown in Figure 3, using a decision support system, Potential Incident Simulation and Evaluation System (PISCES), which also includes an oil spill simulation module.

Figure 3. Shipyard region Tuzla/Istanbul/Turkiye (Google Maps, 2023).

2. LITERATURE OVERVIEW

The interaction of oil with seawater, varying according to oil type, induces structural changes and makes intervention more difficult over time. In this context, the short duration of intervention aimed at the elimination of pollutants is crucial to minimize the negative impact on environmental balance. In this respect, research on oil pollution spread in the sea, its impact on the marine environment, and studies addressing pollution detection, monitoring, and intervention have been examined.

In accordance with the research conducted by Walker et al. (2019), marine transportation is responsible for adverse impacts on the marine environment, which include air pollution, greenhouse gas emissions, the discharge of ballast water containing aquatic invasive species, the historical use of antifoulants, oil, and chemical spills, releases of dry bulk cargo, garbage disposal, underwater noise pollution, ship collisions with marine megafauna, and the potential risks of ship grounding or sinking. Additionally, the study highlights the prevalent sediment contamination of ports during transshipment or ship-breaking activities. The research gives a comprehensive overview of the environmental repercussions of marine transportation and outlines the existing measures, both mitigative and legislative, as well as environmental performance strategies aimed at improving the global management of these challenges.

Sidorovskaia et al. (2016) propose a novel method for calculating the impact of humankind on the marine animal population. The results of a case study of regional population dynamics trends following the Deepwater Horizon oil spill disaster, obtained from passive acoustic-monitoring data collected in the area of the event before and after the oil spill, pertain to sperm and beaked whales. The study proved significant changes in the feeding habits and hunting grounds of marine mammals residing in the area following the incident.

Jung et al. (2013) conducted a study on the repercussions of the Hebei Spirit tanker accident in December 2007, which resulted in an oil spill that contaminated the Yellow Coast of South Korea. The study focused on assessing the respiratory effects of the spill on children residing along the Yellow Coast. Among the 662 children in the affected area, 436 (65.9%) participated in the study. All subjects completed a modified version of the questionnaire prepared in the framework of the International Study of Asthma and Allergies in Childhood. The study involved a comprehensive medical examination, consisting of a skin prick test, pulmonary function test, and methacholine bronchial provocation test (MBPT). The conclusive findings indicated that exposure to an oil spill is a substantial risk factor for asthma in children.

The European Union (EU) Horizon 2020 research initiative “GRACE (Integrated Oil Spill Response Actions and Environmental Effects)” was presented by Jørgensen et al, (2019) a study that adopts a comprehensive approach to examining and understanding the hazardous consequences of oil spills, as well as the environmental effects and advantages of a range of marine oil spill response technologies in the icy climate and ice-laden regions of the North Atlantic and the Baltic Sea. In the project, highly sensitive biomarker methods were employed to evaluate the effects of naturally and chemically dispersed oil, residues from *in situ* burning, and non-collected oil on fish, invertebrates and macro-algae. Also, specific methods for the rapid detection of oil pollution impact on biota were developed. In addition, the awareness on oil spill response has improved due to novel online sensors on various platforms used to observe, monitor, and predict oil movements in the sea. Real-time data transfer into operational systems is facilitated, thereby improving information accuracy regarding oil spill location, and contributing to more effective oil spill response strategies.

Bayazit and Kaptan (2023) created a list of ship operations prone to causing marine pollution and their interrelationships were determined based on expert opinions and literature overview. Subsequently, the Fuzzy Bayesian Network approach was employed to compute the probabilities associated with each ship operation contributing to marine pollution. The Bow-tie approach was then used to determine the extent of response operations based on the level of marine pollution. Notably, the study identified procedures that cause funnel gas emissions as posing the highest risk. This research is of practical and strategic significance for professionals engaged in safety and environmental management in the maritime transportation sector, helping them make informed decisions.

Amir-Heidari et al. (2019) advocate the necessity of establishing a standardized method for assessing risks associated with diverse shipwrecks. Their research introduces a state-of-the-art model for spatial and stochastic risk assessment of oil spills from wrecks. This model offers a systematic approach to incorporating intricate factors influencing risk values. A notable aspect of the model is its specific emphasis on uncertainty, enabling the probabilistic computation of total risk as the integral expected sum of numerous potential consequences. To illustrate the application of the model, a case study was conducted in the Kattegat region at the entrance to the Baltic Sea, aiming to determine the risk posed by a wreck nearby Sweden.

Asif et al. (2022) give an analysis of the susceptibility of shorelines to the effects of oil spills, given the influence of seasonal variations on the natural degradation of oil. The study provides an extensive overview of monitoring techniques, that include Global Information System tools and remote sensing, and allow oil spill tracking and mapping. The research included a comparative analysis of various remote sensors, and established that laser fluorosensors are capable of detecting oil on diverse substrates, including snow and ice. The study emphasizes challenges in oil spill management, including concerns about the scarcity of monitoring data, the necessity for integrated decision-making systems, and the imperative development of rapid response strategies to optimize shoreline protection from oil spills.

In their study, Garello and Kerbaol (2017) emphasize the challenge of detecting oil spills, which show as dark patches on Synthetic Aperture Radar (SAR) images. They emphasize the complexity of this task due to the influence of various factors altering sea surface conditions, including wind, waves, and currents. In their opinion, for a prevention system that goes beyond mere oil spill detection and tracking to be effective, it is imperative to identify vessels responsible for oil discharges. To this end, they used a synergistic approach that integrates radar imaging data with weather and oceanographic information, and utilizes ship identification systems, such as the Automatic Identification System (AIS). The authors stress the significance of their endeavor, noting that the majority of these pollutions occur in coastal zones which are home to 80% of the global population.

Keramea et al. (2021) give a comprehensive review of transportation and oil weathering processes, focusing on parameterization. The authors critically assess eighteen state-of-the-art oil spill models, evaluating their capability to simulate these processes, account for oil release from surface or submerged sources, utilize real-time field data for model initiation and parameter adjustment, and quantify prediction uncertainties. Their review identifies spreading, advection, diffusion, evaporation, emulsification, and dispersion as the most addressed oil weathering processes in existing models. However, a notable limitation in the majority of these models is not taking into account crucial physical processes like oil dissolution, photo-oxidation, biodegradation, and vertical mixing. The study highlights a deficiency in the timely response aspect of the latest oil spill models. It stresses the need for modeling improvements, emphasizing a more comprehensive parameterization of oil dissolution, biodegradation, entrainment, and the prediction of oil particle size distribution following wave action and well blowouts.

Bukin et al. (2019) discuss the outcomes of their efforts in innovating techniques and technical apparatus for deploying small-sized unmanned aerial vehicles (UAVs) in the ecological monitoring of the environment, aligning with the MARPOL 73/78 international convention. The paper details the creation of a hardware-software complex designed for the recognition of oil spills, incorporating elements of artificial intelligence. Laboratory experiments are elucidated, specifically those involving the identification of oil spills through laser-induced fluorescence (LIF) methods and the recording of the spectrum of upward solar radiation.

In the research conducted by Soares et al. (2020), a novel online interface was created, integrating a dynamic Hazardous and Noxious Substances (HNS) database with a chemical numerical dispersion model to improve predictions regarding the behavior and environmental risk of HNS spills in marine ecosystems. The potential impacts on pelagic organisms were characterized by linking model outputs with toxicity risk ratios. Additionally, a straightforward population model was devised to anticipate environmental level impacts. The amalgamation of these developed tools established a framework, with the overarching goal of refining predictions related to the behavior of HNS plumes and the potential hazards to the marine environment and its associated ecosystem services.

Aşan et al. (2020) ran a simulation of the 1994 M/T Nassia accident that occurred in the Istanbul Strait on the PISCES-II Simulator. The aim was to juxtapose response actions at the time with current capabilities and explore strategies to mitigate the adverse effects of an oil spill accident. The study included two distinct response scenarios for the same oil spill incident, effectively simulating the accident. The findings stress the need for specialized consideration of sea conditions and associated assets in oil pollution response, particularly in areas with strong currents such as the Istanbul Strait.

Can (2007) ran a simulation of oil pollution following potential tanker accidents in the Istanbul Strait, calculating oil spill trajectory in the Strait. The calculations for four different regions of the Strait were done using a multiphase model and the finite volume method. In time-dependent solutions incorporating turbulence, the study not only examined oil spread but also took into account surface currents. The results indicated that in points where current circulation is high, especially in bays, the oil takes longer to leave the region. Some areas became more vulnerable in adverse wind conditions. According to these findings, the study identified specific points where precautionary measures should be taken in the event of tanker accidents in these areas. Can anticipates that the study will contribute to the emergency response plan for the Istanbul Strait.

The number of maritime accidents, which result in significant economic losses and have great environmental impact, has been decreasing over the years. However, sensitivity to potential pollution incidents has inversely increased. In this context, anticipating potential pollution, preparing emergency response plans, and establishing goals for plans through scenario simulations in a controlled environment have become essential. Based on its aim, this study focuses on establishing the criteria for environmental impact caused by pollution, with a specific focus on coastline impact and dispersion times. In contrast to other studies, it sheds light on the formulation of intervention strategies by identifying criteria in intervention plans that should be emphasized to minimize environmental impact.

3. METHODOLOGY

In line with the purpose of this study, a scenario of a tanker accident and subsequent large-scale oil pollution on the sea was created in the Tuzla shipyards area. This scenario was ran in the Potential Incident Simulation, Control and Evaluation System (PISCES) simulation program to determine oil spill spread over time. The parameters of the oil that is likely to spill and weather data obtained from the General Directorate of Meteorology (GDM) of the Ministry of Environment, Urbanization, and Climate Change of the Republic of Turkiye, and oceanographic conditions obtained from “DenAr Marine Research Corporation, Tuzla Shipyard Area Marine Research Project Hydrographic, and Oceanographic Study Report” for the fall season were entered into the simulation. Ecologically Sensitive Areas, the most vulnerable part of the processes, propounded by “EKOGEN Public Health and Environmental Consulting Treble. LLC., Ecological Evaluation Report within the Scope of Tuzla Shipyard Area Emergency Response Plan”, were also entered into the system. After the spill, the oil spread, evaporation, dispersion, emulsification, and coastal interaction processes were identified depending on the time elapsed. When it comes to intervention in oil pollution, it is essential to respond while the oil is still on the sea surface, before it hits the shore. Based on these considerations, when the outputs of the scenario created were analyzed, dispersion commencement time and time of oil reaching the shore were emphasized, and intervention commencement periods recommended.

4. POTENTIAL INCIDENT SIMULATION AND EVALUATION SYSTEM - PISCES

PISCES is a marine incident response simulator designed to create and execute both virtual and on-scene exercises. The application was developed to support exercises focused on responding to search and rescue including oil pollution incidents. Therefore, the mathematical model of the application was created that took into account not only environmental factors, such as the coastal area, sea surface currents, weather, sea conditions, ice conditions, and ecologically sensitive areas, but human intervention activities as well. The program presents the coastline as a series of closed polygons automatically obtained from vector-based sea charts. The surface current area is created using a time-dependent interpolation of an established basic current vector. Surface current velocity at a particular point on the field is determined using linear interpolation of base vector values on a triangle mesh based on the Delaunay principle.

Ecologically sensitive areas are presented as polygons consisting of a certain number of groups. The Lagrangian method was used for oil spread modelling, in which numerous particles that model the oil layer move under the combined effects of wind, current, and diffusion (Delgado et al., 2006). PISCES serves as a responsive simulator designed to prepare and execute command center exercises and area drills related to oil spill response. It possesses communication capabilities with essential assets, including ship-handling simulators comprising Vessel Traffic Service, Search and Rescue modules, communication stations, engine room simulator, and cargo handling simulator. Additionally, the PISCES simulator is furnished with operative stations tailored for civil protection entities, such as port authorities, marine police, navy, and environmental agencies. This simulator functions not only as an educational tool but also provides practical assistance in the event of an oil spill (Perkovic and Sitkov 2008).

4.1. Weather and Oceanographic Conditions

The most powerful factors that affect the spread of oil pollution in the sea are current and wind strength. In particular, air temperature is an important factor in determining the amount of oil evaporation. In the scenario, the fall season was considered and for this purpose, wind, air, and seawater temperature data for the region between 1980-2022 were obtained from the General Directorate of Meteorology (GDM) of the Ministry of Environment, Urbanization and Climate Change of the Republic of Turkiye. As a result of the evaluations, it was assumed that the average air temperature is 16.5 ^{o}C, dominant wind in the Tuzla Shipyards Area in the fall season is the Northeasterly (NE) with an average speed of 5 knots, and the average sea water temperature is 14°C. Given that the shipyard area is sheltered, sea conditions were entered as "0" and seawater density was assumed to be 1014 kg/m^3 (GDM, 2022).

According to the studies conducted to determine the direction and speed of surface currents in the Tuzla Shipyards region, the dominant current regime in the region was found to be dependent on weather parameters and show local deviations in shallow areas. The average current velocity is 0.067 m/s - 0.1 knots (kts) and the dominant current structure in the bay is generally clockwise direction from southeast (SE) to southwest (SW) (DenAr, 2021). Figure 4 illustrates wind and current structure in the area.

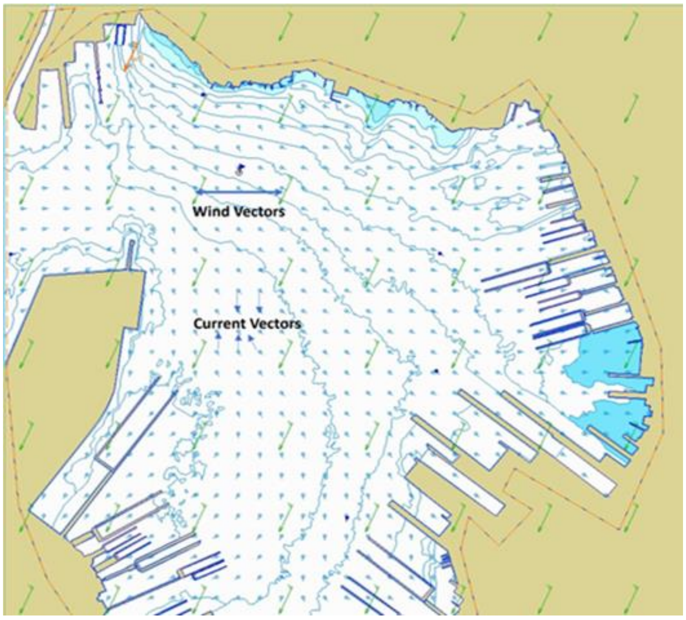

Figure 4. Wind and current structure in the area.

An examination of the factors affecting oil dispersion revealed that current velocity in the area remained low against the prevailing wind conditions and did not affect the surface spread.

4.2. Ecologically Sensitive Areas

Looking at sensitive areas in the vicinity of the Tuzla Shipyards area, the most important areas that may come into interaction with pollution are the Kamil Abdus Lake (Fish Lake), shown in Figure 5, and the Sakiz Island Natural Site Areas located just west of it. The land boundary between the Kamil Abdus Lake, Sakiz Island Natural Site Areas, and the Tuzla Shipyard Area is approximately 100 meters wide, and the two areas are separated by the Tuzla Road, which can be considered an artificial barrier.

Figure 5. Kamil Abdus lake and Sakiz island (Google Maps, 2023).

Although separated by this barrier, potential ecological interactions may occur between these two areas via both terrestrial and marine pathways and should not be overlooked (EkoGen, 2021). These areas may be endangered if timely or adequate intervention is not made in case of an oil pollution in the Tuzla Shipyards Region.

4.3. Potential Fuel Types and Spillage Quantities

Ships coming to the shipyards in the Tuzla Shipyard Area have fuel oil for main engines and diesel oil for generators in their fuel tanks. They are allowed to enter the shipyard with the fuel they have on board. Fuel oil is denser and has lower viscosity than diesel oil and causes more environmental pollution when spilled into the sea. Therefore, fuel oil was used in the pollution scenario with the following characteristics: Viscosity: 805×10^{-6} m²/s, Density: 945 kg/m³, Pour point: -12.0 °C, Flashpoint: 87.2 °C.

When creating scenarios, the size of ships arriving to the Tuzla Shipyard Area was considered, and the largest ship that could come to the area was estimated to be approximately 400 m long, with the average fuel capacity of approximately 1,500 tons. A ship of this size was assumed to have about 150 tons of fuel in each of its ten separate tanks, and the simulation was based on the assumption that in the worst-case accident scenario, all the fuel from one of these tanks, i.e. 150 tons, would be discharged into the sea.

5. OIL POLLUTION INSIDE THE TUZLA SHIPYARD AREA

To assess environmental pollution caused by maritime transportation, a ship-related accident scenario was conducted in the shipyard area, which is a stakeholder in the sector. In this context, oil pollution was modeled at the M1 location in the general north-northwest of Istanbul, the Tuzla Shipyard Area. Pollution status 10 minutes after the incident is shown in Figure 6, and 1 hour later in Figure 7.

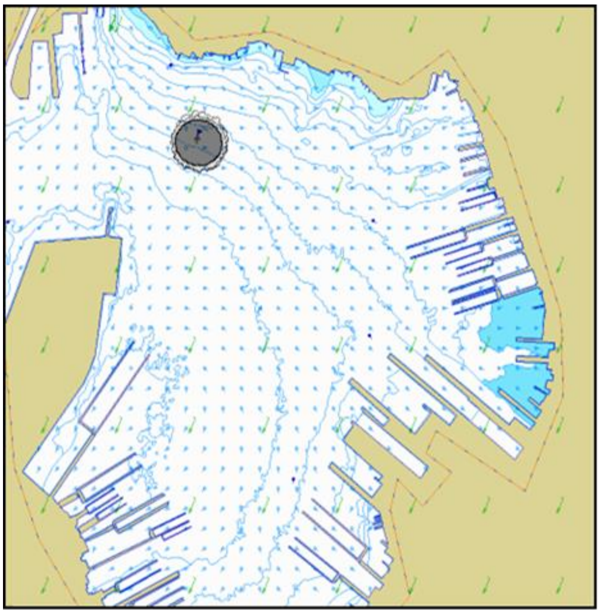

Figure 6. Oil pollution – after 10 minutes.

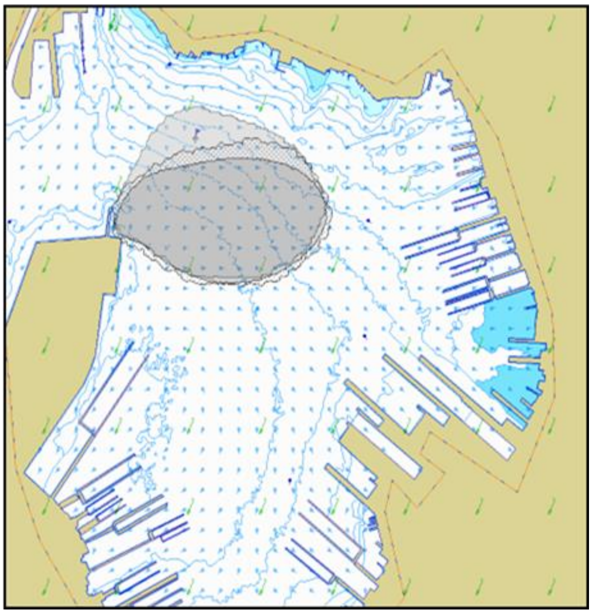

Figure 7. Oil pollution – after 1 hour.

The results show that oil pollution at the M1 location would hit the coast in the western dock area of the Tuzla Shipyard Area after 1 hour and 4 minutes. The main factors affecting time are low current velocity (0.1 kts.) and low wind speed (5 kts.). Pollution status 3 hours after the incident is shown in Figure 8, and 6 hours after the incident in Figure 9. In this case, oil was predicted to accumulate in the southern part of the Tuzla Shipyard Area after 5 hours and 50 minutes.

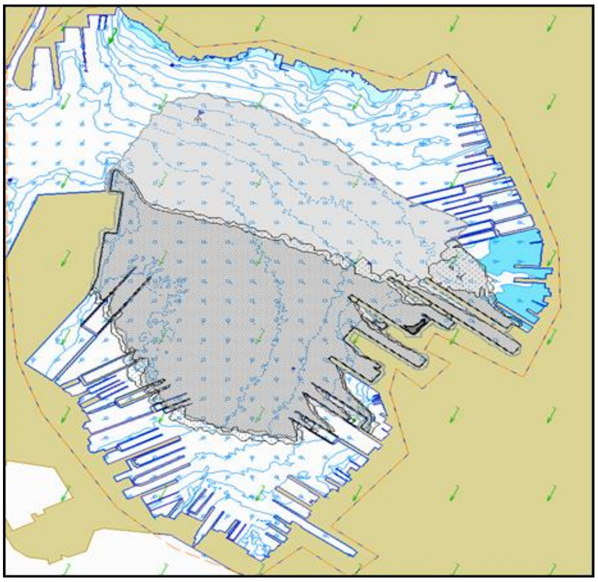

Figure 8. Oil pollution – after 3 hours.

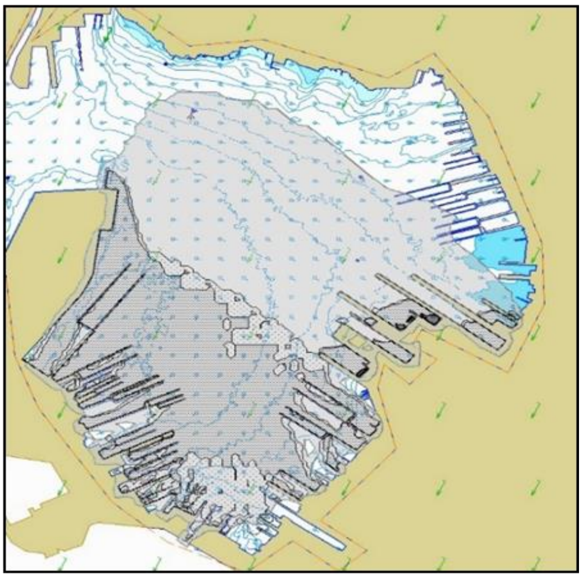

Figure 9. Oil pollution – after 6 hours.

Oil pollution behavior pattern parameters for a 6 hour period are shown in Table 1.

Time	Amount spilled (ton)	Amount floating (ton)	Amount evaporated (ton)	Amount dispersed (ton)	Amount stranded (ton)	Amount floating mixture (oil + water) (ton)	Maximum thickness (mm)
00:15	150	150	0	0	0	152	1.2
00:30	150	150	0.1	0	0	155	1.2
00:45	150	150	0.1	0	0	158	1.3
01:00	150	150	0.2	0	0	161	1.5
01:15	150	150	0.3	0	0.1	163	0.9
01:30	150	149	0.5	0	0.2	166	1.8
01:45	150	149	0.6	0	0.2	168	2.1
02:00	150	149	0.8	0	0.3	170	2.6
02:15	150	148	1.1	0	0.8	171	2.9
02:30	150	147	1.3	0.1	1.3	172	3.7
02:45	150	146	1.6	0.1	1.9	173	4.7
03:00	150	145	1.9	0.1	2.7	174	4.1
03:15	150	144	2.1	0.1	3.9	174	4.5
03:30	150	142	2.4	0.1	5.1	173	4.9
03:45	150	141	2.6	0.1	6.2	173	5.1
04:00	150	140	2.8	0.1	7.2	173	5.6
04:15	150	139	3	0.1	8	173	5.3
04:30	150	138	3.2	0.1	8.8	173	5.5
04:45	150	137	3.3	0.1	9.4	173	5.9
05:00	150	137	3.4	0.2	9.8	173	5.5
05:15	150	137	3.4	0.2	9.9	174	4.6
05:30	150	136	3.5	0.2	10	175	5.1
05:45	150	136	3.6	0.2	10.1	175	5.8
06:00	150	136	3.6	0.2	10.1	176	5.9

Table 1. Behavior parameters of oil pollution over a 6 hour period.

Table 1 shows that within 6 hours after pollution, 3.6 tons of spilled oil evaporated, the thickness of the oil on the water surface reached a maximum of 5.9 mm, while 10.1 tons of oil stranded to the coast. The dispersion of the oil from the sea surface started 2 hours and 30 minutes later, and a total of 0.2 tons of oil dispersed.

Mild air and sea water temperature increased the amount of evaporation of sea surface oil, with oil thickness reaching a maximum of 5.9 mm. The increased thickness and specific gravity of the oil caused it to disperse after 2 hours and 30 minutes. Due to the initial location of the incident being in the north and the wind blowing from the north-east direction, the oil spread over an area of approximately 1.5 nautical miles towards the south, allowing water molecules to penetrate the oil molecules more effectively and causing the oil to disperse.

Based on the above, a barrier should be used in the northwest region at least 1 hour before oil hits the coast, and oil containment and collection should commence at least 2 hours and 30 minutes before it begins to disperse. As stated in the Ecological Assessment Report, potential marine pollution in the area south of the Tuzla Shipyards, separated from the Kamil Abduş Lake and Sakiz Island Natural Sites, where the road can be considered an artificial barrier, could have a negative environmental impact on both the land and the marine environment (EkoGen, 2021). Therefore, pollution must be contained and prevented from spreading to the south by means of barriers installed before the specified time.

6. CONCLUSION

This study attempted to identify the potential negative environmental impacts of maritime transportation through a simulation of ship-sourced oil pollution in the shipyard area located in Istanbul Tuzla, a sector stakeholder. Maritime transportation, with its shipyards, ports, narrow waterways, and large-capacity vessels carrying significant amounts of hazardous cargoes, stands out with its potential to cause a large-scale environmental disaster in case of an accident.

Oil pollution, which has the most detrimental impact on the marine environment, has the potential to inflict damage not only on the sea but also on other ecologically sensitive areas surrounding it. As soon as it spreads, oil pollutes not only the sea surface, but also contaminates the airspace above if it ignites, and becomes much more difficult to intervene in coastal areas once it has stranded. As time passes, the specific gravity of oil molecules increases, which can be explained by emulsification, where water molecules penetrate the oil molecules that are spilled into the sea. When it disperses into the seawater column and sediments, intervention becomes impossible, leading to irreversible negative effects on the entire marine ecosystem for years to come.

As stated in the study, in the case of oil pollution it is crucial to intervene within 2 hours and 30 minutes from the moment the oil spills on the sea surface, as this would significantly reduce the magnitude of environmental pollution caused by dispersion. When deciding which oil pollution intervention method to choose, the identified dispersion initiation time must be taken into consideration as a reference value, based on environmental conditions. Likewise, the time required for the oil to reach the shore should be another criterion in emergency response plans.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship and publication of this article.

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