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Research Article

Modelling of the Oil Spill in M/V LADY TUNA Accident and the Evaluation of the Response Operation in Simulated Condition with PISCES II

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Abstract

Oil pollution from ships is an important source of marine pollution and becomes an important problem all over the world. For this reason, every effort should be made to prevent oil spills and to remove them effectively as soon as pollution has emerged. In this respect, various computer simulations are used to get well informed about the fate of spilled oil on the seawater. In this study, the grounding accident of ship M/V Lady Tuna causing 75 tons of fuel spills into the sea on December 18, 2016, close to the coast of Çesme in Turkey, was investigated. The aim of the study is to investigate the oil spill accident and evaluate the response operation of M/V Lady Tuna. To achieve this aim, firstly the reports related to the accident were examined and the response operation was evaluated by modelling of the M/V Lady Tuna accident with PISCES II (Potential Incident Simulation, Control and Evaluation System) simulator. Within this scope, two scenarios were prepared by using PISCES II. The first scenario was created without any response resources to observe the movement direction of the oil slick after the accident. The second scenario was reconstructed with the possible response resources after the oil spill. Through simulation, it was possible to obtain the oil spill/pollution statistics; such as the recovered oil rate, the amount of stranded oil to the coast, the amount of floating oil rate, and other oil spill parameters. As a result, it was evaluated that the oil pollution in the M/V Lady Tuna accident could be responded more effectively and the pollution could be much less. It is assessed that the study will contribute to organizations involved in oil spill response operations.

Keywords: Oil Spill, Oil Spill Response Operation, M/V Lady Tuna, PISCES II.

Introduction

Oil pollution in the marine environment is one of the most important threats all over the world due to major oil spill disasters. When an oil spill occurs in the marine environment, all efforts must be made by governments and other organizations to prevent oil pollution. The best way to control the oil spill will take place if the response operations and emergency response strategies are already planned to prevent oil spillage as soon as possible. More recently, the advanced mathematical models have been created which are integrated with computer simulation to better predict oil's behavior and to take the best decisions for response operations by minimizing the environmental effect. For example; the OILMAP (Oil Spill Model and Response System, GNOME (General NOAA (National Oceanic and Atmospheric Administration) Operational Modelling Environment) and ADIOS (Automated Data Inquiry for Oil Spills) are computer programs which provide rapid predictions of the movement of spilled oil by entering both environmental and hydrodynamic data and specifying a spill scenario in the marine environment.

However, previous modeling studies of oil spills were based on experimental observations and the use of simple formulations to predict the spread of oil to seawater. The notable pioneer studies explaining fate of the spilled oil and physical process in the spread of oil on a water surface were improved by Fay (1969 and 1971), Mackay et al. (1980), Lehr et al. (1984), Delvigne at al. (1988), Güven et al., (2006), Doğan et al. (1998) and Fingas et al. (1996). Nowadays, it is widely used to make approaches that utilize advanced technology detection systems and various models in relation to oil accidents (Şeker, et al., 2013; Papila, et al., 2018; Abdikan, et al., 2018; Gazioğlu, et al., 2016, 2017; Gazioğlu, 2018). These studies take account of empirical measurements of spreading rates and analytical and theoretical studies of the physical processes.

PISCES II (Potential Incident Simulation, Control and Evaluation System II) is one of the computer software programs based on the mathematical modelling of an oil spill in marine environment. The simulation program predicts the oil spill behavior in water depending on spill parameters, the type of oil source, and environmental condition after the spillage. In addition, unlike many other programs, it is possible to manage the response operations in real time on the sea following the spillage. (PISCES II Manual, 2008)

Many processes control the behavior and condition of oil in marine environment. The properties of spilt oil change on the seawater over time, so it is important to know physical, chemical and weathering process of the oil when prediction behavior of the oil (ITOPF, 2002).

The movement of oil in the marine environment usually takes place in two directions. The movement in the horizontal direction occurs as a spread and causes the sea surface to be covered with oil or stranded to shoreline. The movement in the vertical direction occurs when the oil disperse or dissolute in the seawater. As a result of the movement, the oil sinks towards the bottom and becomes part of the sediment on the seabed.

The weathering process (spreading, evaporation, dispersion, emulsification, oxidation, biodegradation, dissolution and sedimentation) occurs when oil is exposed to environmental conditions such as in sea system (Fig. 1) (ITOPF, 2002).

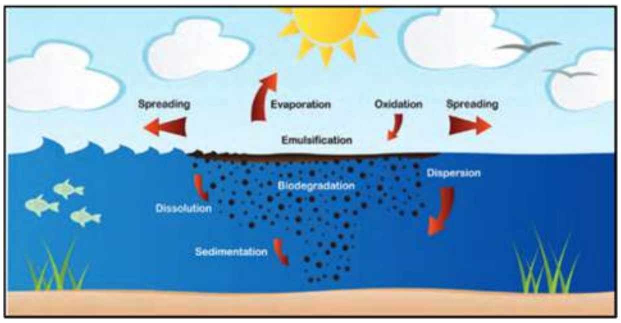


Figure 1. Weathering Processes Affecting Oil at Sea (ITOPF, 2002).

As shown in Fig. 2, the ratio of the weathering processes takes place at different rates and at different times. For example, spreading, evaporation, dispersion process takes place immediately in hours or days, but biodegradation, emulsification process takes place slowly over months or years.

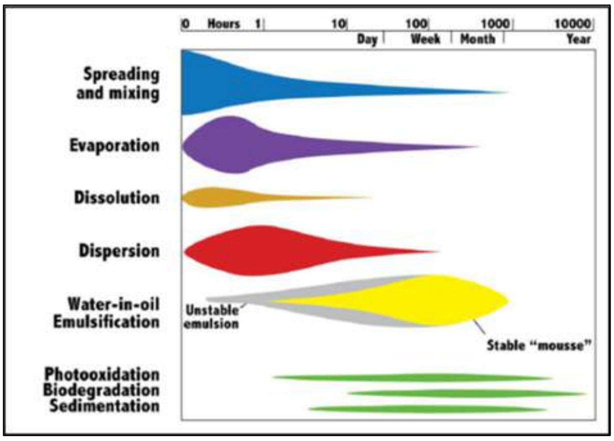


Figure 2. Weathering Processes (Boufadel et al., 2015).

The exception of petroleum products which have a higher density than sea water, they usually float on the surface when the oil enters in the marine environment and begin to spread. The viscosity of the oil and the amount of spilled oil affect the spreading speed of the oil on the sea. (ITOPF, 2002)

The effects of winds and currents significantly affect the spread of oil and resulting movement that can be calculated with sum of two vectors shown in Fig. 3 (Hault, 1972; Fingas, 2013). The wind-sourced current speed is assumed as 3% (1%–6%) of wind velocity (Soltanpour et al., 2013).

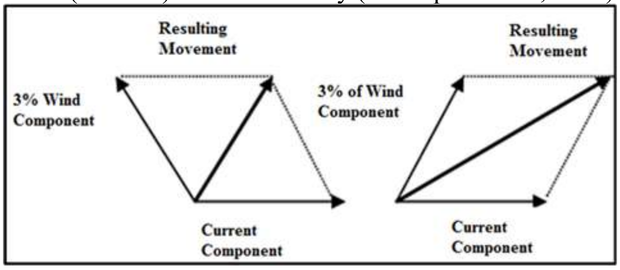


Figure 3. Oil Movement (Fingas, 2013).

Materials and Methods

In this study, firstly the reports related to the accident were investigated and then the response operation was evaluated by modelling of the M/V Lady Tuna accident with PISCES II simulator. In this concept, two scenario models were conducted for the study in simulated condition. The objectives of the scenarios are to illustrate possible response operations on the sea surface before the oil reaches the coast. The process steps applied in the study are shown in Fig. 4.

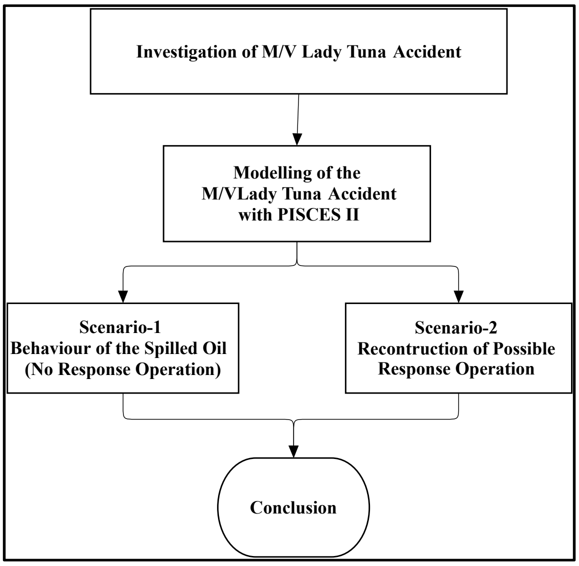


Figure 4. Flow chart of the Study

The information related to the incident data was obtained from the Investigation Report of M/V Lady Tuna marine accident. The reports are given as below:

• Marine Accident Investigation Report on the grounding of M/V Lady Tuna prepared by Accident Investigation Board (AIB) (32/DNZ-04/2017), the Ministry of Transport, Maritime Affairs and Communications, 2017.

• The Expert Report of M/V Lady Tuna was submitted to the Republic of Turkey Çeşme Civil Court of the First Instance by Sunlu, Kayacan and Küçükgül, 2017.

The environmental data was obtained from archive document of Meteorological Data Information Sales and

Presentation System, Turkish State Meteorological Service (MEVBIS, 2017). The environmental data (air and water temperatures, wind direction and speed, sea state, the density of water and surface current) were manually put into the model.

Investigation of the "M/V Lady Tuna" Accident

M/V Lady Tuna, a Panamanian flagged vessel that came to make fish harvest from the tuna farms in the Ildır Bay which is under the administrative responsibility of Çeşme Port Authority, completed loading her cargo on 18.12.2016 and while she was proceeding to the anchorage area for custom clearance formalities at 13:30 LT. When the vessel was under way, master saw three small fishing vessels on starboard bow side of the vessel and altered the course to port side so as to avoid the collision. But, master could not realize the shallow waters on their port side and the vessel grounded at 13:36 LT on the shoal west of Ufak Island position while she was still under way at a speed of 11.7 knots. Master ordered to stop the engines at 13:42 LT. Soon after, the chief officer of the ship reported a fuel oil leak from the ship to the master at 13: 55 LT. The information about the vessel, navigation and accident are presented in Table 1. (AIB, 2017)

Table 1. Information about the Vessel, Navigation and Accident (AIB, 2017).

Ship Name	M/V LADY TUNA
Flag	Panama
Class Society	NKK
IMO Number	9453438
Type of Ship	Fish Processing Vessel
Gross Tonnage	4538 GT
LOA	120, 75 m
Last Port of Call	Ildır Bay /Turkey
Destination Port	Port Said / Egypt
Cargo on Board	1223 MT Processed Tuna Fish
Number of Crew	33 persons
Type of Sea Passage	High Seas
Date/Time of Accident	18.12.2016 / 13:40 LT (GMT +3)
Type of Accident	Very Serious Marine Casualty
Location of Accident	Ildır Bay /Çeşme -İzmir
Injured/Fatality/Loss	None
Oil Pollution	Fuel oil (IFO 180) approximately 75 cubic meters.

Gulf of Ildır is located between Karaburun Peninsula and Çeşme Canal in the west of Turkey. North coastal strip of Ildır Gulf is very narrow and shows a sudden deepening structure (Meriç et al., 2012). The accident happened near Fener Island in the Ildır Bay district of Çeşme province of İzmir (Lat: 38° 23.26' N - Long: 026° 25.42' E) is shown in Fig. 5.

İstikbal and Erkan (2018), in their article, point out that this coast area surrounded by the fish farms are usually a kind of high-risk marine environment because of shallow waters and islands that are difficult to the navigation of the large tonnage vessels.

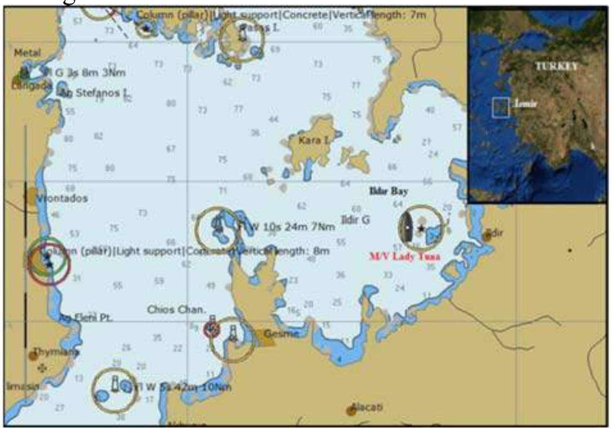


Figure 5. Position of the Accident (CPN, 2018).

As a result of the oil spills event, Ministry of Transport, Maritime Affairs and Communications, General Directorate of Marine and Inland Water Regulatory Affairs, has canceled the authority certificate of 9 of the 12 companies which were authorized by the Ministry. (Numbered: 36712415-160.03.02-E. 12358 dated 09.02.2017) (Notification to the Emergency Response Firms, 2017). Most Maritime and Environmental Services and Mare Marine Cleaning Services, managed the pollution response operation of the M/V Lady Tuna, were among the companies whose license has been canceled by the Ministry.

Events at the Aftermath of the Accident

After the accident, the master of the ship informed to the agency about the oil pollution and reported that response operation was necessary urgently. There was no attempt by the ship to prevent oil pollution. After the soundings were taken from the tanks by the crew, it was determined that there were damages to fore-peak tank, No.1 center ballast tank, No.1 center fuel tank, No.2 port and starboard fuel tanks. There was leakage from the fuel tanks to the sea. Damaged parts of the ship on the Transverse Plan are shown in Fig. 6. (AIB, 2017)

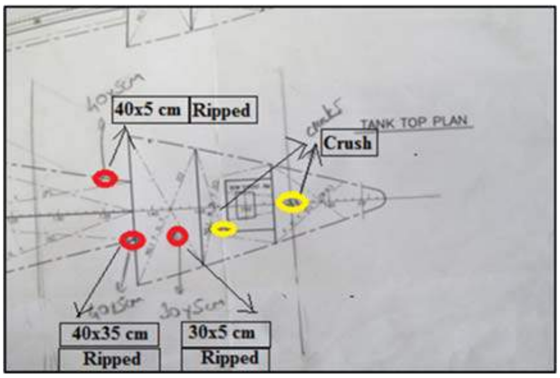


Figure 6. Damaged Parts of the Ship (AIB, 2017).

At 15.00 LT (1,5 h after the accident), ship's agent called the pollution response company Most Maritime and Environmental Services which was based at Ulusoy Port, in the administrative responsibility area of Çeşme Port Authority, to make the necessary preparations. Çeşme Port Authority ordered the ship's agent to start necessary pollution response activities at 17:30 LT (4 h after the accident). Most Shipping started to encircle the fish farms with barriers at 20:30 LT and they completed to encircle the ship to the containment of pollution with barriers with two skimmers at 22:30 LT (Fig. 7) (9 h after the fuel oil leakage from the ship). As of 12:00 LT on 19th December 2016 (about a day after the accident), another company "Mare Marine Cleaning Service Company" started to work for pollution response. (AIB, 2017)

However, according to the captain's statement, the time of the accident was recorded in the ship's logbook at 13:30 LT. The insufficient boom was encircled to the ship at 00:30 LT on 19 December 2016 (11 h later) to control the pollution arising from the ship. Because of the bad weather condition, the second barrier was encircled 20 h after the spillage. (Sunlu, Kayacan and Küçükgül, 2017)

It shows that there are differences and inconsistencies in the documents of the official institutions about how fuel oil pollution started in the events and how they manage the response operation following the spillage from the ship.

Figure 7. Containment of Spilled Oil by Barriers (www.seanews.com.tr, 2017).

Distance from the Ulusoy Çeşme Port to the accident position is about 12 nautical miles (NMs) by the sea and about 20 km by the land road (Fig. 8). The accident position is very close to the other international ports (Port of İzmir, Alsancak and Nemrut) by the seaway and land road. It means the response equipments could be delivered to the accident area quickly.

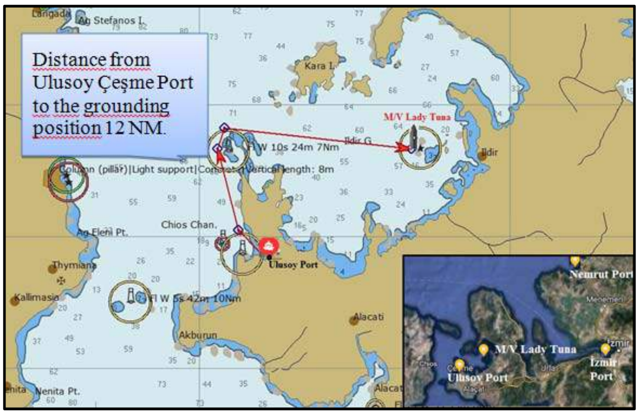
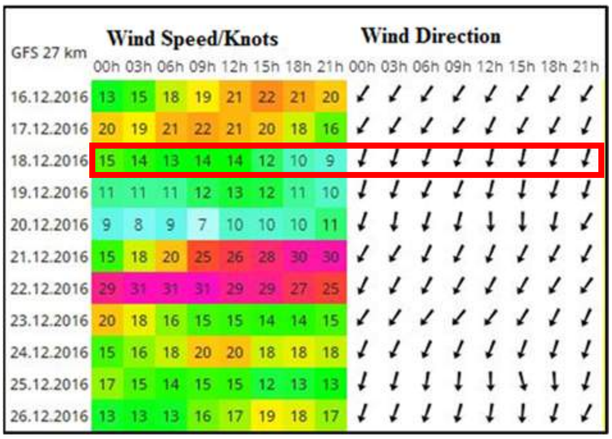


Figure 8. Distance from Ulusoy Çeşme Port to the Grounding Position (CPN, 2018).

On 24th December 2016 (6 days after the accident), tanker ship Petrol-1 (Fig. 9) came alongside M/V Lady Tuna in order to discharge the fuel in her damaged parts. The discharging operation was completed on 26th December 2016 (8 days after the accident). Salvage operations were started at 09:00 LT on 27th December 2016, 9 days after the accident. (AIB, 2017)

Figure 9. Transfer Operation (AIB, 2017).

The weather report of the Ilıca/Çeşme Weather Station is presented in Fig. 10. It shows that the violent storm occurs after the accident when the fuel oil continued to spill into the sea from M/V Lady Tuna. It has been thought that the physical insufficiency of the barrier placed around the ship and the extreme weather conditions increased the volume of the spilled oil.



GFS 27 km	Wind Speed/Knots 00h	03h	06h	09h	12h	15h	18h	21h
16.12.2016	13	15	18	19	21	22	21	20
17.12.2016	20	19	21	22	21	20	18	16
18.12.2016	15	14	13	14	14	12	10	9
19.12.2016	11	11	11	12	13	12	11	10
20.12.2016	9	8	9	7	10	10	10	11
21.12.2016	15	18	20	25	26	28	30	30
22.12.2016	29	31	31	31	29	29	27	25
23.12.2016	20	18	16	15	15	14	14	15
24.12.2016	15	16	18	20	20	18	18	18
25.12.2016	17	15	14	15	15	12	13	13
26.12.2016	13	13	13	16	17	19	18	17

Figure 10. Wind Speed and Direction (www.windguru.cz, 2018).

Modelling of the Oil Spills in M/V Lady Tuna Accident with PISCES II

PISCES II program is used to control and predict the propagation of oil spills based on the mathematical modelling. The simulation program also provides planning of the response operation in real time to prevent oil pollution on the seawater.

Fig. 11 shows the general appearance of chart view of the control panel and the scenario checklist window in PISCES II. The "Scenario Checklist" window displays a list of parameters to be specified and actions to be performed to prepare the scenario.

The tasks in the list are divided for convenience into several categories:

- Specification of the impact area,
- Specification of environmental conditions,
- Pollution parameters,
- Response resources.

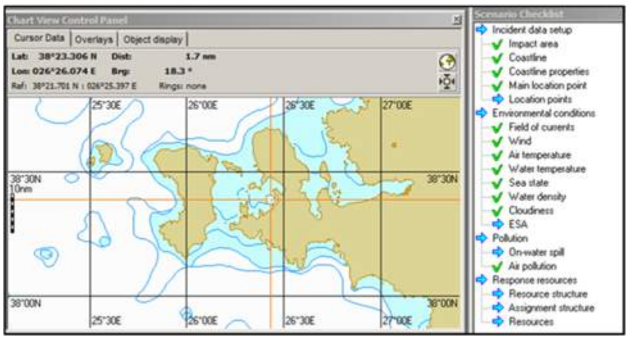


Figure 11. The Scenario Checklist Layout.

Scenario-1: Behaviour of the Spilled Oil on Seawater (No Response Operation)

The Scenario-1 was started at 10:40 UTC on 18 December 2016 and ended 22:40 UTC on 19 December 2016 (36 h) in simulated condition with PISCES II (UTC +3 to convert local time in the 2016 year). The information about scenario duration was presented in Table 2.

Table 2. The Duration of Scenario-1 with PISCES II.

Scenario	Time (UTC)	Date	Time from Scenario Start
Begin	10:40	18.12.2016	36 h
End	22:40	19.12.2016	

The characteristics of fuel oil "IFO 180" used in the experiment are presented in Table 3.

Table 3. Characteristics of the IFO 180, (PISCES II Manual, 2008).

Name of the product	IFO 180
Type	Refined
Group	IV
Density	968 kg/m^3
Viscosity	2324 cP (centipoise)
Maximum content of water	25 %
Emulsification constant	0 %
Pour point	-10 ºC
Flash Point	91 ºC

The effects of wind and currents significantly affect the drifting of the oil at the sea surface. The direction and speed of the surface current for the moment of the accident in Ildır Bay have not been measured by Turkish State Meteorological Service.

The general pattern of current varies depending on meteorological conditions and wind direction in considerable duration affect the surface current on the sea.

To know more about the dominant wind direction of Ildır Bay, wind statistics for Çeşme were displayed in Fig. 12. So, the general direction of the surface currents was adopted towards SW (225°) under the effect of the regional wind from NE and NNE direction.

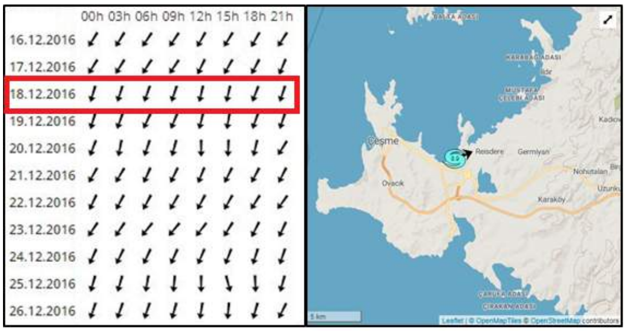


Figure 12. Wind Direction of Ilıca/Çeşme and Station Position (www.windguru.cz, 2018).

In the real case, the flow rate of the oil spillage (per hour) from the ship could not be determined. Considering the damaged parts of the ship, the amount of the oil spill rate was assumed as 5 tons/per hour.

The environmental data were manually placed in the model and then the software simulation started with the combining of other related components. Thus, the simulation was performed on the following data:

i. Incident Data Set-up:

- Date of accident; 18th of December 2016, 13:40 Local Times (GMT +3),
- Accident position; Lat: 38° 23, 26′ N / Long: 026° 25, 42′ E,
- Impact area was defined,
- Coastline properties,
- Main location points and location points were set near the accident point.

ii. Environmental Conditions:

- Field of current: Direction 225° (towards SW), speed 0,16 kts,
- Field of wind: Direction from NE,
- Air temperature: 9 °C,
- Water temperature: 13,9 °C,
- Sea state: 3 feet,
- Seawater density: 1029 kg/m3,
- Cloudiness: 0.

iii. Pollution-on Water Spill:

- Type of oil: IFO 180,
- Amount spilled: 72.5 tons (75 m3),
- Rate: 5 tons/ per hour.

In the first scenario, no response resources were used during the simulation. When the oil spilled, it immediately began to spread on the surface of the sea. The fate of spilled oil water movement rapidly breaks up oil films, which drift on the water surface. The movement of the oil slick after the accident was towards SW direction which drifts in response to the wind and the current (Fig. 13). The pollution and spillage parameters after 6 h from the accident are presented in Table 4.

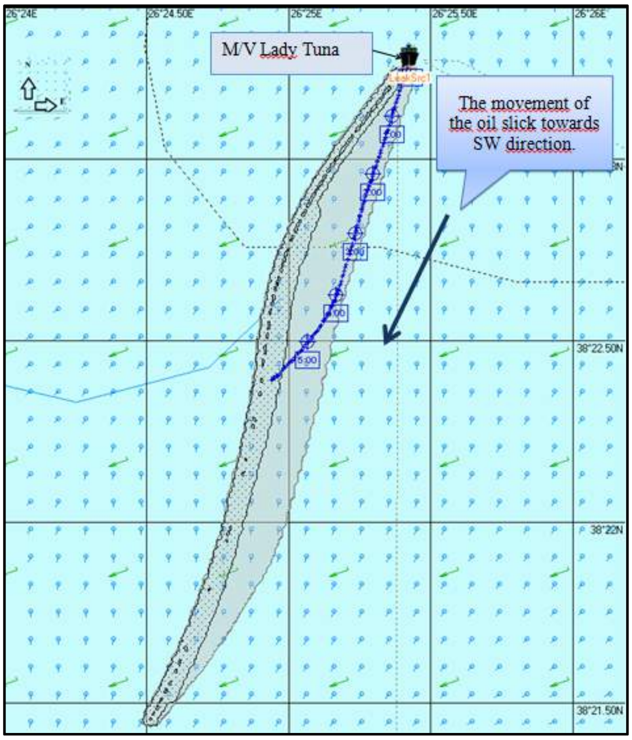


Figure 13. Movement Direction of the Oil Slick (Δt: 6 h).

Table 4. Oil Spill Parameters of Scenario-1 after 6 h.

Oil	Parameter	Percentage (%)
Amount spilled	30,0 tons	100
Amount floating	29,8 tons	99,4
Amount evaporated	0,2 tons	0,52
Amount dispersed	0,0 tons	
Amount stranded	0,0 tons	
Amount floating mixture	35,6 tons	
Max thickness of slick oil	1,4 mm	
Slick area	0384882 m^2	
Viscosity of slick oil	2149 cP	

The rate of dispersion is largely dependent upon the nature of the oil (the viscosity) and the sea state. The dispersion started at a very low rate about 11 h from the spillage because of the high viscosity rate of the fuel oil in the model and the gentle-moderate weather condition.

The area shown in gray color indicates the area where oil is spreading for up to 12 h from the beginning of the scenario (spilled oil; 60 tons) (Fig. 14). The program shows the information “Oil impact on land” on the window screen. The oil reached on the Paşalimanı coast (0,02 %) about 12 h later following the spillage (Table 5).

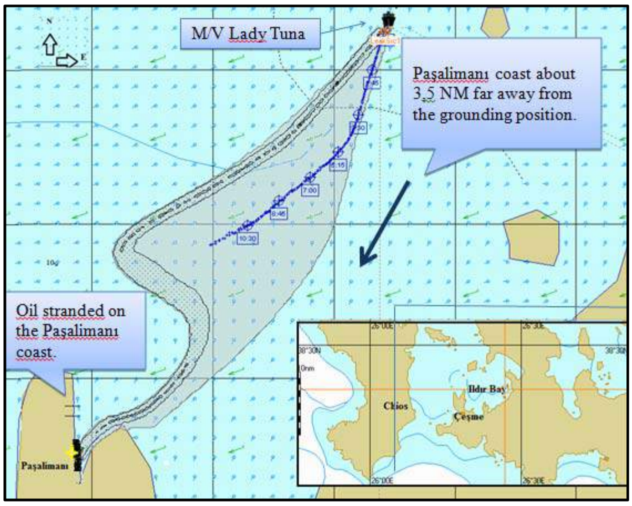


Figure 14. Scenario-1: The Oil Stranded on the Paşalimanı Coast (Δt: 12 h).

Table 5. Oil Spill Parameters of Scenario-1 after 12 h.

Oil	Parameter	Percentage (%)
Amount spilled	60,0 tons	100
Amount floating	59,0 tons	98,5
Amount evaporated	0,8 tons	1,41
Amount dispersed	0,1 tons	0,09
Amount stranded	0,02 tons	0,02
Amount floating mixture	73,9 tons	
Max thickness of slick oil	0,8 mm	
Slick area	129276 m^2	
Viscosity of slick oil	2685 cP	

As a result of the scenario, the movement direction of the oil slick after 36 h from the accident is shown in Fig. 15. It is clearly seen that the oil was stranded at Paşalimanı coast, the Boyalık Bay, the Setur Çeşme Marina, the Radisson Blue Resort Hotel beach, the Ilıca Hotel beach, the Yıldızburnu coast, Sherotan Hotel beach and the Ilıca public beaches. The pollution and spill parameters (after 36 h) are presented in Table 6.

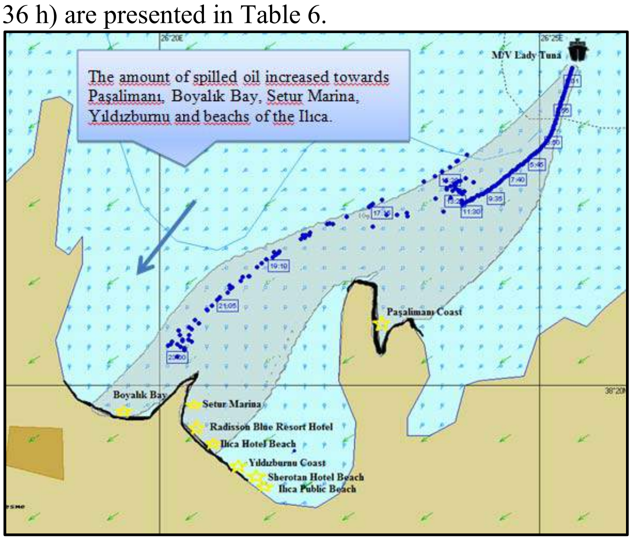


Figure 15. Scenario-1: The Movement direction of the oil slick (Δt: 36 h).

Table 6. Oil Spill Parameters of Scenario-1 after 36 h.

Oil	Parameter	Percentage (%)
Amount spilled	72,5 tons	100
Amount floating	18,4 tons	25,4
Amount evaporated	2,3 tons	3,18
Amount dispersed	0,4 tons	0,51
Amount stranded	51,4 tons	70,9
Amount floating mixture	24,9 tons	
Max thickness of slick oil	17,4 mm	
Slick area	5705 m^2	
Viscosity of slick oil	4010 cP	

As a result of the study, it was available to determine and compare the spill and pollution statistics occurred after the incident in the simulated condition as graphically (Fig.16). So, the following results are obtained in the Scenario-1;

• After 14 h and 30 minutes following the accident, 72,5 tons fuel oil leaked from the ship's tanks (5 tons/per hour).
• The amount of stranded oil (which began about 12 h after the spillage), is 51,4 tons (70,9 % of the spilled oil) as well as the floating oil amount is 18,4 tons (25,4 % of the spilled oil).
• The remaining amount of the spilled oil were dispersed (0,51 %) and evaporated (3,18 %). It means the evaporation and dispersion rate is very low due to the nature of the oil (IFO 180, the heavy fuel oil) as well as the moderate sea state.
• The amount of floating oil increased until 14 h following the accident. After this time the floating oil rate decreased because the oil reached on the coast as well as the fuel leakage ended after 14 h and 30 min.
• The spilled oil on the surface of the sea spreads depending on the environmental conditions, the properties and amount of the spilled oil.

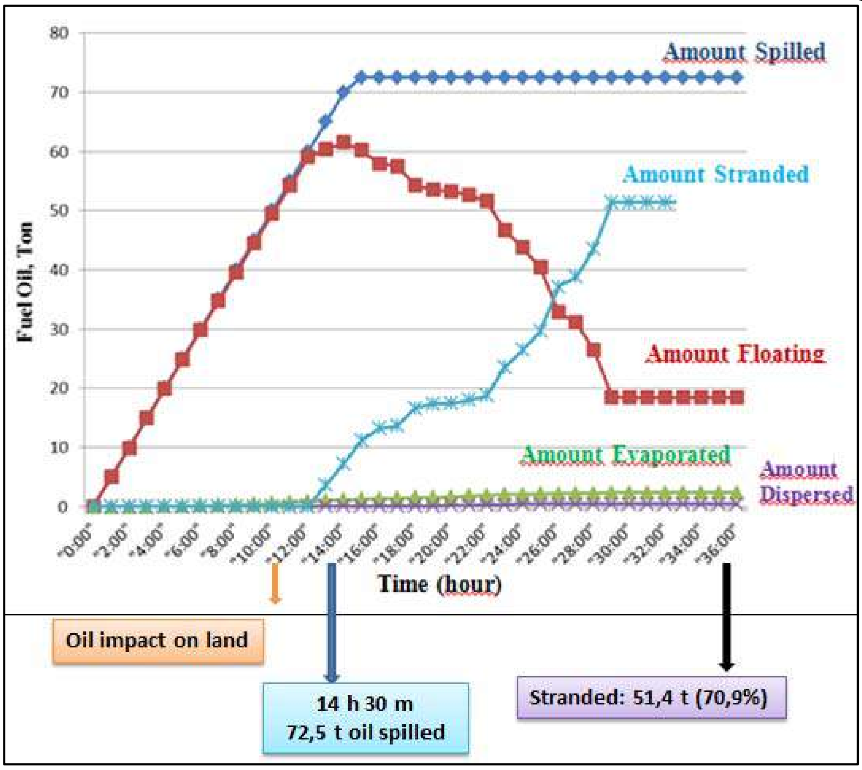


Figure 16. The Graphic of the Spill/ Pollution Statistics of the Scenario-1.

Table 7. Duration of the Scenario-2 with PISCES II.

Scenario	Time	Date	Time from Scenario Start
Begin	10:40	18.12.2016	15 h
End	01:40	19.12.2016	

Table 8. Parameters of the Response Resource Equipments (PISCES II Manual, 2008).

Model Data of the Skimmer Type		Model Data of the Boom Type		Features of the Boat	
Type	Oleophilic Skimmer	Type	Open Water Boom	Type	Oilfield Supply Vessel
Storage Capacity	11 m^3	Height	1.97 ft.	Max Speed	14 kts.
Recovery Rate	3,54 tons/hour	Depth	3.61 ft.	Draft	1 m.
Sea factor	0.0, 1.0; 0.8, 1.0; 1.3, 0.5	Slack	5 %	LOA	20 m.
Recovery Radius	20 m.	Absorb Capacity	0 m^2	Range	200 NMs

Scenario-2: Reconstruction of Possible Response Operation with PISCES II

The Scenario-2 was reconstructed with the possible response resources after the oil spill. The simulator PISCES II provides an illustration of the possible response operation on seawater. The information about the Scenario-2 duration (Table 7) is presented as above.

During the oil recovery operation, the parameters of the response equipment were presented in Table 8 (above).

The oil skimmers remove the floating oil from the point they are located. Model selection of the skimmer determines the rated capacity of the skimmer and the dependence of oil skimming efficiency on the oil viscosity and the wave height. Table 9 shows the characteristics of the Oleophilic skimmer presented in PISCES II. The wave height of the sea at the time of the accident is adopted as 3 feet. The viscosity of the oil IFO 180 is 2324 cP in the program.

Table 9. The Characteristics of the Oleophilic Skimmer (PISCES II Manual, 2008).

Skimmer Model	Dependence of oil skimming efficiency on the wave height		Dependence of oil skimming efficiency on the oil viscosity	
	Wave height (feet)	Efficiency (%)	Viscosity (cP)	Efficiency (%)
Oleophilic	0	100	0	10
	2.62	100	500	40
	4.27	50	1500	90
	5.91	0	2500	60
			5000	10
			10000	0

The incident data, the environmental conditions and the amount of spillage on seawater are the same as in the first scenario. The only difference was that the response resources created to containment and recovery of an oil spill during the simulation. These were an open water Boom-1 for the oil containment, an open water Boom-2 arranged J shape formation for the oil collection by trawling, three Oleophilic skimmers and three oilfield supply vessels. The event log of the recovery process is presented in Table 10.

Table 10. Event Log of the Recovery Process.

Time (UTC) 18.12.2016	**The Response Resources**
10:40	The fuel oil began to leak.
3 h after spillage 13:40	The Oil Containment Boom Formation-1 Deployed; Oleophilic Skimmer-1 and Skimmer-2; An Oilfield Supply Vessel.
5 h after spillage 15:40	J Shape Boom Formation-2 Deployed; Oleophilic Skimmer-3; Two Oilfield Supply Vessels.
7 h after spillage 17:40	Oleophilic Skimmer-1 and Skimmer-2 exceed storage capacity (11 m^3); Oleophilic Skimmer-1 and Skimmer-2 Rearranged.

The accident occurred at 10:40 UTC (13:40 LT) on 18 December 2016. The open water Boom-1 and the Oleophilic skimmers were placed on the sea at 13:40 UTC (3 h after spillage). The deployed oil containment Boom Formation-1 prevented spreading of the oil slicks. The Oleophilic Skimmers-1 and Skimmer-2 removed the floating oil from the point they located in the boom formation. An oilfield supply vessel assisted the operation. Before the response resources started to the task, about 15 tons oil had spilled to seawater in three hours.

The one J shape Boom Formation-2 was placed on the scene with the Oleophilic Skimmer-3 and two Oilfield supply vessels as a single unit at 15:40 UTC (5 h after the spillage). Movement of the J shape Boom Formation-2 was controlled by two Oilfield supply vessels and it allowed the oil collecting by trawling (Fig. 17). J shape Boom Formation-2 (300 m open water boom) was adjusted in the direction of the oil leak and moved with an Oleophilic skimmer towards the leakage source. The Response Operation with Oil Containment Boom Formation-1 and J Shape Boom Formation-2 were presented in Fig. 18.

At 17.40 UTC (about 7 h after the spillage), the Oleophilic Skimmer-1 and Skimmer-2 (combined with the containment boom-1) removed the floating oil and exceed the storage capacity which is 11 m3. Therefore the Oleophilic Skimmer-1 and Skimmer-2 were rearranged as combined with the Boom Formation-1.

At the end of the 9 h, the skimmers removed the floating oil from the point they located, about 31,5 tons oil on-water was recovered (69,7 % of the spilled oil) in simulated condition. Oil spill parameters after 9 h from spillage are presented in Table 11.

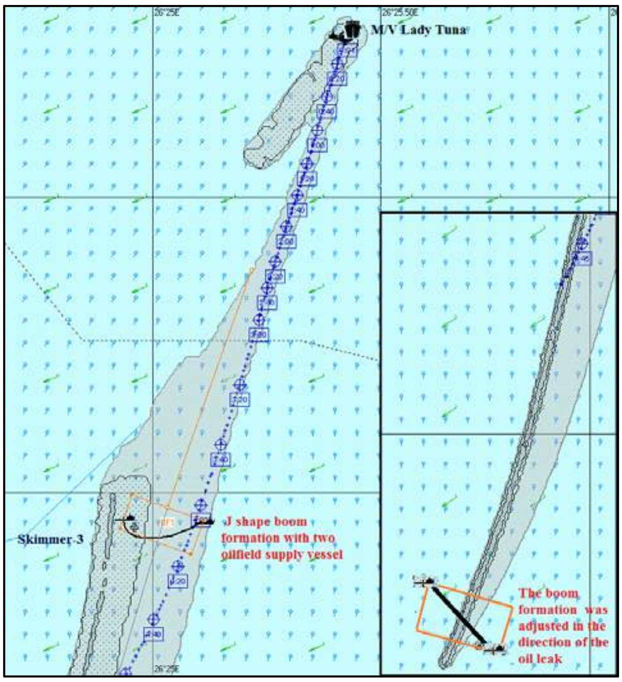


Figure 17. The Movement of the J Shape Boom Formation-2 with the Skimmer-3.

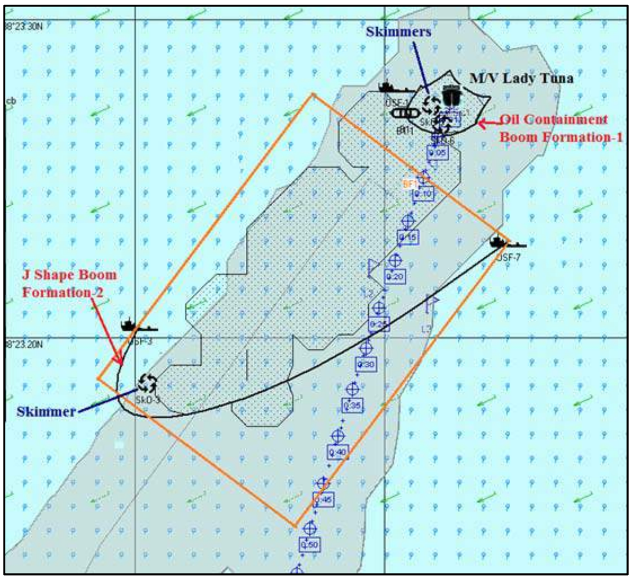


Figure 18. The Response Operation with Oil Containment Boom Formation-1 and J Shape Boom Formation-2.

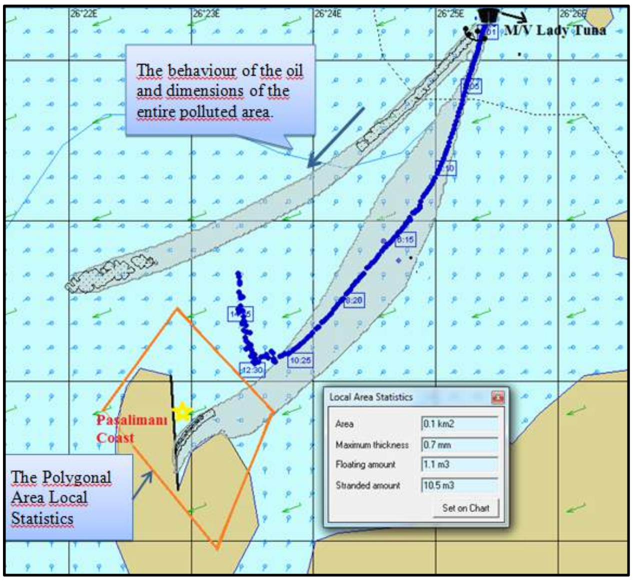


Figure 19. The Behavior of the Spilled Oil and Local Area Statistics (Δt: 15 h).

Table 11. Oil Spill Parameters of Scenario-2 after 9 h.

Oil	Parameter	Percentage (%)
Amount spilled	45,2 tons	100
Amount floating	13,5 tons	29,8
Amount evaporated	0,2 tons	0,48
Amount dispersed	0,01 tons	0,03
Amount stranded	0 tons	0
Amount recovered	31,5 tons	69,7
Amount floating mixture	17,8 tons	
Amount recovered mixture	31,9 tons	1,17
Max thickness of slick oil	0,8 mm	
Slick area	378042 m^2	
Viscosity of slick oil	2783 cP	

Table 12. Oil Spill Parameters of Scenario-2 after 15 h.

Oil	Parameter	Percentage (%)
Amount spilled	72,5 tons	100
Amount floating	3,3 tons	4,6
Amount evaporated	0,4 tons	0,55
Amount dispersed	0,02 tons	0,03
Amount stranded	10,0 tons	13,7
Amount recovered	58,8 tons	81,1
Amount floating mixture	4,5 tons	
Amount recovered mixture	59,3 tons	0,81
Max thickness of slick oil	0,8 mm	
Slick area	388922 m^2	
Viscosity of slick oil	2918 cP	

The “Local Area Statistics” window shows statistics for the polygon area. The local statistics of the the area was presented in Fig. 19, which displayed maximum thickness and area of the patch, amount of oil product afloat and stranded oil. It displayed pollution statistics of the Paşalimanı coast where is the first impacted coast from the oil spill (about 3,5 NMs far away from the accident position).

The display of oil pollution in gray color indicates the size of the entire polluted area from the start of the scenario until 15 h following the spillage. After using the resources of response on the sea, it is observed that the direction of oil has changed.

In the second scenario, when the response resources were organized in simulated condition, 58.8 tons oil was recovered. So, the amount of the oil which reached the shore reduced after the response operation. The illustrated response operation allowed making a conclusion about the pollution/spill parameters of M/V Lady Tuna accident is displayed in Table 12.

The main objective of the Scenario-2 is to illustrate actions to response oil pollution on the sea surface before it reaches the shoreline where it will create the most amount of destruction.

The simulation PISCES II showed a significant influence on the efficiency of oil spill recovery from the surface of the sea. Results of the spill/pollution statistics are graphically presented in Fig. 20. So, the following results are obtained in the Scenario-2;

- After 14 hours and 30 minutes following the accident, 72.5 tons fuel oil leaked from the ship’s tanks. The oil stranded on the Paşalimanı coast (3,5 NMs far away from the accident) about 12 h after the spillage.
- Because the containment Boom-1 with two skimmers was deployed around the ship after 3 h following the spillage, the only 15 tons of oil spread to seawater in three hours.
- The J shape Boom Formation-2 with one Oleophilic skimmer was placed on the scene and recovered about 5 tons oil on the sea by trawling. But, 10 tons oil reached the coast. Because, the oil slick area was more than the booms' radius; the effectiveness of the

skimmer reduced due to floating oil-water emulsification process and the Oleophilic skimmer has 20 m recovery radius which restricted removing of the floating oil.
- Thanks to the response operation, the amount of the oil which reached the shore reduced. The spill statistics presented that 81,1 % of the spilled oil (58.8 tons) was recovered when the oil spill response actions was taken without losing time.

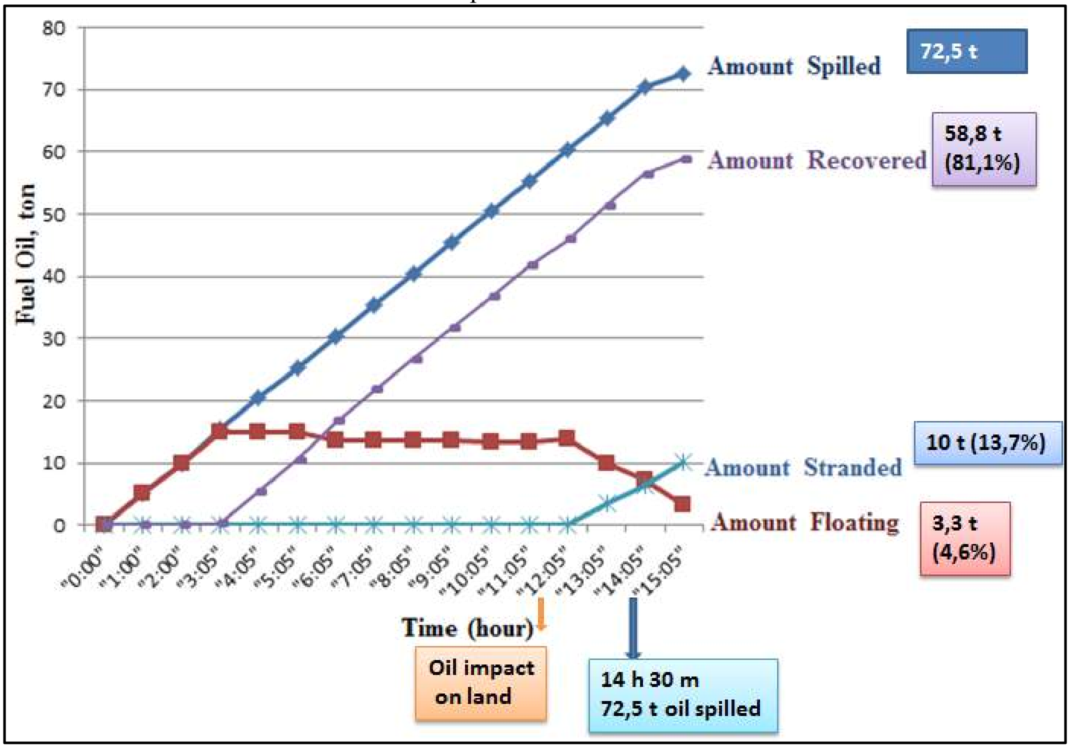


Figure 20. The Graphic of the Spill/Pollution Statistics of Scenario-2 by Creating the Response Operation.

Results

The following results were obtained by examining the reports about the accident and the news obtained from the press.

- Even if, the right after the accident, ship's Captain reported the pollution to the ship's agent that an immediate action/response was necessary, the response operation was started late following the accident. Therefore, the spilled oil amount from the ship increased the marine pollution.
- According to the accident investigation report on the grounding of M/V Lady Tuna, the response company started to encircle the ship with a barrier about 9 h after the oil leakage in order to control the pollution arising from the ship. On the other hand, according to the captain's statement from the court report, the insufficient boom (barrier) was encircled to the ship 11 h after the spillage. This situation shows that the differences and inconsistencies in the documents of the official institutions about when the response company started the operation to control pollution.
- The response company reached the accident region 7h after the accident, but firstly they began to encircle the fish farms with barriers. About 9 h after the spillage, they began to encircle the ship around with a barrier (which is not efficient in high sea condition). However, first of all, they should have started the response operation against the leak source. As a result, the response operation was delayed at least 2 h. This caused more than 10 tons of the fuel to spill.
- The response company "Most", which is based at Ulusoy Port, in the administrative responsibility area of Çeşme Port Authority was managed the response operation. Distance from the Ulusoy Çeşme Port to the accident position is about 12.00 NMs by the sea. It is a distance that can be taken within one hour by the supply vessel loaded with response resources. However, the response company reached the accident region 7 h after the accident.
- According to the report, 9 h after the spillage, the ship was encircled with a boom as well as the two skimmers removed the floating oil from the point they were located. But, in 9 h, 45 tons of fuel spilled into the sea and moved away from the ship towards the southwest direction due to the wind and the current in the region. At the end, the oil remained on the ship was only 27,5 tons. It means the response operation was focused on the remained oil. Therefore, 45 tons of spilled oil stranded towards the Ildır coast.
- On 24th December 2016 (6 days after the accident), the tanker ship discharged the fuel in her damaged tanks and discharging operation was completed on 26th December 2016. The weather report shows that the violent storm increased three days after the accident. It created a greater danger to the damaged ship and the environment. The discharge operation of the fuel on the ship normally should be made shortly after the accident.

- As a result, many inconsistencies have been observed with regard to the response activities of the M/V Lady Tuna; these are deficiencies in the implementation of the response plans, inadequacy of the available response resources, delays in the collection and distribution of response resources as well as communication and coordination problems between institutions and authorities.

In the other phase of the study, the M/V Lady Tuna grounding accident was modelled with PISCES II and the following results are achieved:

- The trajectories of the spilled oil after accident showed that the oil spread under the effect of the SW wind direction and surface current on the sea.
- After 14 h and 30 min. following the accident, 72.50 tons fuel oil leaked from the ship's tanks. Firstly, the oil stranded on the Paşalimanı coast (3.50 NMs far away from the accident) about 12 h later following the spillage. There is the nearest the coast towards SW the direction of the current and wind. And then, the oil slick continued to spread towards the Paşalimanı coast, the Boyalık Bay, the Setur Çeşme Marina, the Radisson Blue Resort Hotel beach, the Ilıca Hotel beach, the Yıldızburnu coast, Sherotan Hotel beach and the Ilıca public beaches.
- The spill statistics revealed that the evaporation and dispersion oil amount were very low rate dependent upon the nature of the oil (IFO 180, the heavy fuel oil) as well as the moderate sea state. Therefore the most of the oil slick on the sea stranded towards the Ildır coast.
- The main objective of the response operation following the oil spill incident is not to allow the oil to reach the coastline where it creates the most destruction to the environment. Therefore, one open water boom and two Oleophilic skimmers were deployed around the leak source after 3 h from the spillage by one oilfield supply vessel. But, the spilled oil (about 15 tons) spread to seawater in three h before the response resources deployed on the sea. So, the one J shape boom formation was deployed in the direction of the oil leak and moved with one Oleophilic skimmer towards the leakage source. The movement of the J shape boom formation was controlled by two oilfield supply vessels and it allowed the oil collecting by trawling.
- The simulation PISCES II showed a significant influence on the efficiency of oil spill recovery from the surface of the sea. The spill statistics revealed that 81.10 % of the spilled oil (58.80 tons) was recovered and the stranded oil was limited to 10 tons after the response operation was managed without losing time. Thus, the spilled oil did not spread on the sea and cause less damage to the marine environment.
- Before the response operations are planned, the nature of the spilled oil, the effectiveness of the response resources and sea condition should be considered during the operation.
- So, the Oleophilic skimmers and Open Water Boom models were selected dependent upon the high viscosity of the spilled oil (IFO 180) and the sea state after the accident.
- In the case of early response to the oil spill following the accident; the response resources can be prepared by professional personnel within 1 h after the accident notice.

The response resources (the booms, the skimmers) can be reached the accident area by the supply vessels within one hour and the resources can be deployed on the sea within one hour. It means the response process can begin at the latest in 3 h under the ideal conditions.

Conclusion

Turkey should take more serious steps concerning with response operation and preparedness for eliminating oil pollution in emergency incidences. The officials and the response operation companies should also consider the following:

- Transparent coordination and communication should be between the organizations and officials.
- It is necessary to urgently assess the situations like the behavior of the oil on seawater, the shoreline area impacted by oil and response strategies to take early action to prevent oil pollution.
- The transfer operation of the remained oil in the ship and salvage operation of the ship should be conducted as soon as possible.
- The personnel involved in the response operation should be professional and trained.
- To avoid delays in collection and distributing sources of response, they must be properly checked to assess their suitability and performance.
- Nowadays, it is widely used to make approaches that utilize advanced technology detection systems and various models in relation to oil accidents. Autonomous decision support systems that are responsive to situational awareness and equipped with machine learning, which can respond faster in spatial analysis, will be used more intensely in environmental disasters such as oil pollution.
- The PISCES II and the other software programs are important for the coordinators managed the response operation. The simulation program has the most advantage of documenting pollution/spill statistics, the stranded oil amount to the shoreline, the time to oil reach the coast, efficiency rate of the response equipment.

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