The 22nd IAMUC
Batumi, 21-22 Oct 2022

Proceedings of the
International Association of Maritime Universities Conference

Preventing pollution of Adriatic Sea: Oil spill trajectory model using Pisces II scenarios and effects of incident on marine environment using multiple regression

Maja Čović [1, *]

[1] *University of Split, Faculty of Maritime Studies, Croatia*
[*] *Corresponding author: mcovic@pfst.hr; Tel.:* +385-91-155-7467.

Abstract: Oil spill is the release of a liquid petroleum hydrocarbon such as crude oil, refined petroleum such as gasoline or diesel fuel into the environment due to human activity, which can cause devastating impact to marine ecosystem. According to International Maritime Organization (IMO), oil tankers transport approximately 2900 million tons of crude oil and oil products per year. The quantity of oil spilled annually into oceans exceeds one million metric tons and oil spills have large impact on wildlife and economy as well. This paper presents the simulation of oil spill trajectory on water surface in the Kaštela Bay (in the Adriatic Sea) created by PISCES II simulator. The Kaštela Bay is semi-enclosed basin with cargo port and terminal for petroleum products distribution.

The scenarios determinate processes with oil spill in marine environment: the trajectory of oil spill, chemical changes of oil and persistence of oils in the air, water column and sediment. The result of two different scenarios are shown in order to give an insight into potential oil spills impact on marine environment in this sensitive location. Furthermore, observing through whole linear multiple regression model (F=2.734; R=0.517; p=0.097) variable height of wave was identified as significant predictor of speed at which oils spread in (b=1.965; p=0.047). The paper presents different scenarios of oil spill from ships incident scenarios in particular sensitive area and gives the as well as correlation between relevant predictors and speed at which oil spreads. It can also serve as starting point for risk assessment analyses of the incidents in order to minimize the negative impact of oil spills on marine environment..

Keywords: oil spill, marine environment, scenario, PISCES II, the Kaštela Bay

1. Introduction

Oil spill is the release of a liquid petroleum hydrocarbon such as crude oil, refined petroleum such as gasoline or diesel fuel into the environment due to human activity, which can cause devastating impact to marine ecosystem.

According to International Maritime Organization (IMO), oil tankers transport approximately 2900 million tons of crude oil and oil products per year. The quantity of oil spilled annually into oceans exceeds one million metric tons and oil spills have large impact on wildlife and economy as well.

This paper presents the simulation of oil spill trajectory on water surface in the Kaštela Bay (in the Adriatic Sea) created by PISCES II (Potential Incident Simulation, Control and Evaluation System) simulator.

Pisces II has been used for spill trajectory in this research. In this paper, multiple regression is used to determinate how predictors such as currents speed, salinity, air temperature, height of wave, water temperature, and wind speed impact on the speed of oil spreading.

2. Literature review

Spreading of oil layer is dominant process in spillage process. According to Fay (1971), it is possible to examine spread motion in three stages. The beginning one covers effects of gravity and inertia forces. The second stage involves gravity and viscosity as dominant forces, and the third stage occurs when slick disperse and is expressed by the balance between surface tension and layer. While spreading, spill undergoes chemical as well as physical changes. Processes is termed 'weathering'. Some of these processes, like the natural dispersion of oil into water, lead to the removal of the oil from the sea surface and facilitate its natural breakdown in the marine environment. Spilled oil is usually eliminated from the marine environment through the long-term process of biodegradation (Saadoun, 2015). Time interval needed for the biodegradation depends on numerous factors, such as weather and sea conditions at the time of incident, volume of spilled chemicals, and the type of ecosystem (Farrington, 2014). The numerical modeling technique calculating weathering processes of oil with mathematical methods has proven its validity with outputs that have a high degree of accuracy provided in real cases. Estimation reliability of such models is highly subject to the data quality of accident and the model performance (Hodges et al. 2015). To minimize pollution effects, there are numerous conventions. The most important convention for preventing marine environment pollution from ships oil spills is the International Convention for the Prevention of Pollution from Ships (MARPOL), The aims to eliminate intentional and accidental pollution of marine environment.The International Convention Relating to Intervention on the Hight Seas in Cases of Oil Pollution Casualities (INTERVENTION) confirms the right of coastal states to take measures on high sea aimed at preventiong, reducing or eliminating the threat for the coast as a result of oil pollution caused my marine incident, and International Convention on Oil Prepardeness, Response and Cooperation (OPRC). (G. Jelić et al., 2020) This Convention calls Parties to establish national system for responding promptly to oil pollution and to establish oil response equipment (IMO, 2010).

3. Methodology

In the paper, multiple regression method was used for studying the relationship between a single dependent variable and one or more independent variables. Multiple regression provides possibility to combine many variables to produce optimal predictions of the dependent variable. For causal analysis, it separates the effects of independent variables on the dependent variable so it is possible to examine the contribution of each variable (Alison, 1999). Multiple regression is used to determine how predictors such as currents speed, salinity, air temperature, height of wave, water temperature, and wind speed impact on the speed of oil spreading. Additionally, to reduce non-significant variables from regression model, forward stepwise variable selection algorithm is applied.

Other method used in this paper is Pisces II simulation, to determine the worst-case scenario for possible oil leakage, and to get input for further risk assessment. The PISCES II is an incident response simulator designed to simulate processes in an oil spill on the water surface. The application is developed in order to enhance oil spill response. Program provides information based on mathematical modeling of oil spill. The Pisces II spill model simulates processes in oil spill on the water surface: transport by currents and wind, spreading, evaporation, dispersion, emulsification, viscosity, variation, burning, and interaction with coastline. In the mathematical model, factors such as environmental parameters, physical properties of spilled oil, and human response actions were taken into consideration. Environmental parameters included coastline, field of currents, weather, wave height and water density. Physical properties of spilled oil included observing specific gravity, surface tension, viscosity, distillation curve and emulsification characteristic. Human response actions include booming, on – water recovery ND application of chemical dispersants (Gucma et al., 2011)

3.1. Pisces II trajectory simulation

Simulations were created for 18 different scenarios. Oil spill is positioned in the Adriatic Sea (Kaštela Bay, 43˚31.983'N, 016˚27.555'E) in August, when the density of tanker traffic is the highest in this semi-closed water body. The Kaštela Bay is semi-enclosed basin with cargo port and terminal for petroleum products distribution.

Data was obtained by Croatian Meteorological and Hydrological Service, for period from 2002 to 2022. Absolute maximum and minimum and mean value were observed. Data included; air temperature, sea temperature and wind force. Current speed simulations were created using this data in order to determinate, which scenario presents the highest risk in the case of oil spill pollution. Data was also used as predictors in linear multiple regression model to determinate significant predictor of speed at which oils spread (Table 1).

Table 1. Pisces II parameters used as predictors in multiple regression model

PREDICTORS	CURRENTS SPEED	SALINITY	AIR TEMPERATURE	HEIGHT OF WAVE (m)	WATER TEMPERATURE	WIND DIRECTION	WIND SPEED
SCENARIO 1	0,5	37,2	26,2	0,3	24,4	135°	2,1
SCENARIO 2	0,5	37,2	26,2	0,3	24,4	45°	2,1
SCENARIO 3	0,2c	37,21	28,3	0,2	22,1	135°	1,8
SCENARIO 4	0,2	37,21	28,3	0,2	22,1	45°	1,8
SCENARIO 5	1	37,23	23,3	0,4	26,9	135°	2,6
SCENARIO 6	1	37,23	23,3	0,4	26,9	45°	2,6
SCENARIO 7	0,5	37,24	36,8	0,3	22,1	135°	2,1
SCENARIO 8	0,5	37,24	36,8	0,3	22,1	45°	2,1
SCENARIO 9	1	37,25	42,2	0,4	26,9	135°	2,6
SCENARIO 10	1	37,25	42,2	0,4	26,9	45°	2,6
SCENARIO 11	0,2	37,26	32,6	0,2	22,1	135°	1,8
SCENARIO 12	0,2	37,26	32,6	0,2	22,1	45°	1,8
SCENARIO 13	0,5	37,27	16	0,3	24,4	135°	2,1
SCENARIO 14	0,5	37,27	16	0,3	24,4	45°	2,1
SCENARIO 15	1	37,28	18,6	0,4	26,9	135°	2,6
SCENARIO 16	1	37,28	18,6	0,4	26,9	45°	2,6
SCENARIO 17	0,2	37,29	13	0,2	22,1	135°	1,8
SCENARIO 18	0,2	37,29	13	0,2	22,1	45°	1,8

4. Results

In eighteen simulations run through PISCES II, the worst-case scenario was scenario 13 (Table 1) when the longest coastal part was polluted. Incident occurred at 12:46, and oil spill reached the coast at 14:26. Oil spill volume was 1440 tonnes, wind direction 135° and wind speed 2.1 bofors. The length of coastline polluted by oil spill was 5683 m, slick area 105712 m^2 and maximum thickness of slick 212 mm (Figure 1).

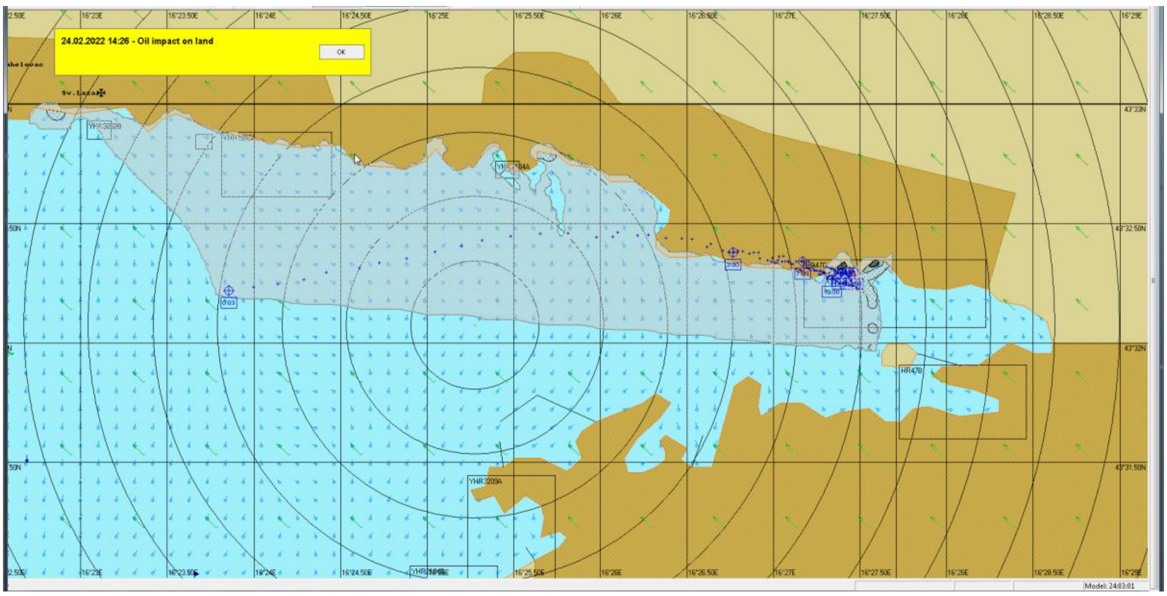

Figure 1. Scenario 13 oil footprint

In scenario 18, incident occurred at 12:46, and oil spill reached the coast at 23:12. Oil spill volume was 1440 tonnes, wind direction was 45° and wind speed 1.8 bofors. The length of coastline polluted by oil spill was 637 m, slick area 567911 m2 and maximum thickness of oil slick was 45.5 mm. Of 1440 tonnes of spilled oil, 82.2 tonnes of oil evaporated. Maximum slick area 567911 m^2 and viscosity 3.2 cSt.

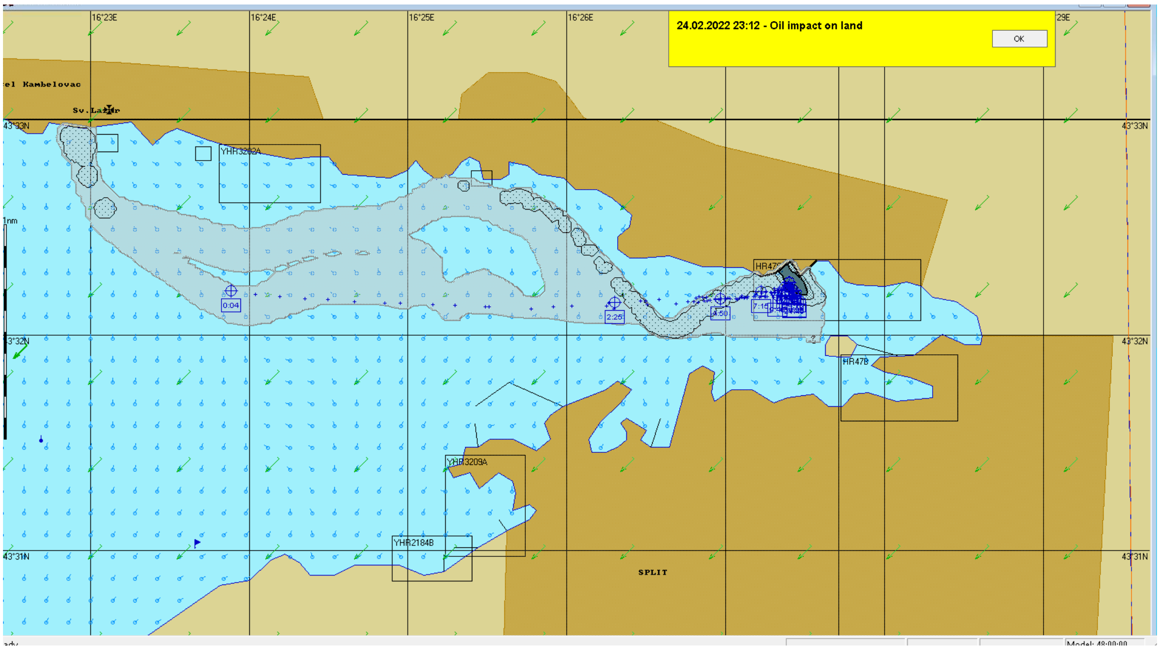

Figure 2. Scenario 18 oil footprint

Spill statistics included data on coastline pollution, slick area, amount of oil evaporated, maximum thickness, volume of dispersed oil and oil viscosity for Scenario 13 and Scenario 18, after 24 hours of running simulation (Table 2).

Table 2. Spill statistic

SPILL STATISTIC	COASTLINE POLLUTION (m)	SLICK AREA (m^2)	AMOUNT EVAPORETED (t)	MAX THICKNESS (mm)	AMOUNT DISPERSED (t)	VISCOSITY (cSt)
SCENARIO 13	5683	105 712	23,0	212	32.4	1.7
SCENARIO 18	637	567 911	82,2	45.5	63.5	3.2

One of scenarios shows large coastline pollution, and another one demonstrates large slick area in this sensitive location. Since bay is semi-closed, and in vicinity of terminal for petroleum products distribution, it is necessary to prevent incidents, and to make further simulations of worst case scenarios, to ensure equipment which would be required to prevent or minimize damage in case of oil leak, collision or some other incident in this area. There is option of providing necessary number of different skimmers and tanks that can float on water and tanks that are placed on land, thus ensuring all the pollution that may come. Pisces II incident response simulator provides possibility of running different scenarios with different kind of equipment necessary to minimize pollution, to determinate which solution would be optimal for different possible outcomes. Parameters currents speed, salinity, air temperature, height of wave, water temperature, and wind speed were used as variables in the analysis (Table 3).

Table 3. Descriptive analysis parameters of all observed variables

Variable	AS±SD	Confidence ±95%	Min - Max	Coef.Var.
Cureents speed	0.57±0.34	0.40-0.74	0.20-1.00	59.92
Salinity	37.25±0.03	37.23-37.26	37.20-37.29	0.08
Air temperature	26.33±9.44	21.64-31.03	13.00-42.20	35.86
Height of wave (m)	0.30±0.08	0.26-0.34	0.20-0.40	28.01
Water temperature	24.21±2.16	23.14-25.28	22.10-26.90	8.91
Wind speed	2.17±0.34	2.00-2.34	1.80-2.60	15.67
Speed	0.29±0.12	0.23-0.35	0.11-0.54	42.80

Table 4 shows that regression analysis identified Height of Wave as significant predictor of speed of oil spread. Forward stepwise algorithm removed all variables from regression model, except Height of the Wave and Water temperature**.**

Table 4. Results of multiple regression analysis with forward stepwise algorithm (β – regression coefficient if variables are standardised, Se(β) – standard error of β coefficient, b – regression coefficient if variables are not standardised, Se(b) – standard error of b coefficient, t(15) –t-test value; p – level of statistical significance)

	β	Se(β)	b	Se(b)	t(15)	p
Intercept			1.16	0.61	1.90	0.08
Height of Wave (m)	1.34	0.62	1.97	0.91	2.16	0.049
Water Temperature (ºC)	-1.06	0.62	-0.06	0.04	-1.71	0.11
			R=0.52; R2=027; F2,15=2.73; p=0.097			

Conclusion

The scenarios determinate processes with oil spill in marine environment: the trajectory of oil spill, chemical changes of oil and persistence of oils in the air, water column and sediment. The result of two different scenarios are shown in order to give an insight into potential oil spills impact on marine environment in this sensitive location: the worst-case scenario for both coastal and sea pollution.

In eighteen simulations run through PISCES II, the worst-case scenario was Scenario 13 when the longest coastal part was polluted. Incident occurred at 12:46, and oil spill reached the coast at 14:26. Oil spill volume was 1440 tonnes, wind direction 135° and wind speed 2.1 bofors.

The length of coastline polluted by oil spill was 5683 m, slick area 105712 m^2 and maximum thickness of slick 212 mm. Of 1440 tonnes of spilled oil, 23 tonnes evaporated and viscosity was 1.7 cSt.

In scenario 18, 82.2 tonnes of oil evaporated. Maximum thickness of oil slick was 45.6 mm, slick area 567911 m^2 and viscosity 3.2 cSt. Wind direction was 45°. Polluted part length (m) is 637. (Figure 2).Although one of them showed substantially better results for coastline pollution, slick area was significantly larger than in other case. Therefore, both cases are extreme.

Furthermore, observing through whole linear multiple regression model (F=2.734; R=0.517; p=0.097) variable height of wave was identified as significant predictor of speed at which oils spread in (b=1.965; p=0.047). The obtained results can also serve as starting point for risk assessment analyses of the incidents in order to minimize the negative impact of oil spills on marine environment.

References

[1] Akhtar, J, Bjørnskau, T & Jean-Hansen (2012) V. Oil spill risk analysis of routeing heavy ship traffic in Norwegian waters. WMU J Marit Affairs 11: 233–247

[2] Allison P (1999) Multiple regression: A primer, Pine Forge Press

[3] Chapter:2 Fundamentals of Risk Assessment, Risk of Vessel Accidents and Spills in the Aleutian Islands: Designing a

[4] Comprehensive Risk Assessment - Special Report 293 (2009) National Academies of Sciences, Engineering, and Medicine. Washington, DC: The National Academies Press

[5] Clark, RB (2002) Marine pollution, Oxford University Press

[6] Farrington, J (2014) Oil Pollution in the Marine Environment II: Fates and Effects of Oil Spills, Environment: Science and Policy for Sustainable Development, 56:4, 16-31

[7] Gucma L, Marcjan K (2012) Incidents Analysis on the Basis of Traffic Monitoring Data in Pomeranian Bay. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, Vol. 6, No. 3, 377-380

[8] Guide to Oil Spill Exercise Planning (1994) IMO/IPIECA Report Series Volume Two, London

[9] International Maritime Organization (2016) Operational guidelines on Sunken and Submerged Oil Assessment and Removal Techniques. IMO, London

[10] INTERREG CRO-ITA (2022) Protecting the Enclosed Parts of the Sea in Adriatic from pollution - Testing of pilot location and development of risk models and plans for cases of sudden sea pollution - Kaštela Bay, Croatia

[11] International Tanker Owners Pollution Federation Limited (2022) Oil tanker spill statistic. ITOPF, London

[12] Jelić Mrčelić G, Mandić, N, Petrinović, R. (2020) International Legislative Framework // Environmental Impact of Ships. University of Cambridge, Cambridge 329-351

[13] International Maritime Organization (2010) Manual on Oil Spill Risk Evaluation and Assessment of Response Preparedness. IMO, London

[14] Saadoun IM (2015) Impact of oil spills on marine life. Emerging pollutants in the environment. IntechOpen, London

[15] The International Tanker Owners Pollution Federation Limited, Effects of oil pollution on the marine environment, London

[16] The International Tanker Owners Pollution Federation Limited. London (2022) ITOPF Handbook. ITOPF, London

[17] Walker, RT, Adebambo O, Del Aguila M., Elhaimer E.F., et al (2019) Chapter 27 - Environmental Effects of Marine Transportation, an Environmental Evaluation, Academic Press, 505-530

[18] Wiens JA (2013) Oil in the Environment, Legacies and Lessons of the Exxon Valdez Oil Spill. Cambridge University Press, Cambridge

[19] Xu, J (2006) Theoretical framework of economic analysis of law governing marine pollution. WMU J Marit Affairs 5: 75–94