Chapter

Introductory Chapter: Issues with Oil Spills and Remote Monitoring

Maged Marghany

1. Introduction

The oil spill is a popular topic for pollution discussion because of the extent of the environmental harm it can produce. Additionally, it may have a variety of negative effects on ecosystems and economies, ranging from immediate extinction of species and habitat destruction to long-term water contamination effects. These outcomes can be disastrous and can include everything from long-term water pollution to irreversible changes in species populations and habitat destruction. This introductory chapter would be demonstrated a variety of other concepts in addition to oil spills, in the author's opinion.

1.1 What is meant by an oil spill?

What exactly is oil? In line with the basic definition, oil is an organic compound that is soluble or readily soluble in water but not readily soluble in other liquids and is found in crude oil. An oil spill occurs when oil floats on the surface of bodies of water and is carried by the wind, currents, and tides [1–5].

The most visible source of oil pollution in the marine environment is operational oil discharges and spills from ships, particularly tankers, offshore platforms, and pipelines. Take the Amoco Cadiz oil tanker as an example (**Figure 1**). In 1978, this tanker ran aground off the French coast, causing 68.7 million gallons of oil to spill.

Figure 1.
Sinking oil tanker Amoco Cadiz.

Large spills like these are unusual occurrences. Additionally, an oil transfer accident caused the oil tanker Mega-Borg (**Figure 2**) to spill 5.1 million gallons of oil [1, 6].

Ixtox 1 exploration well blowout in 1979. In 1980, when workers were able to stop the blowout, 140 million gallons of oil were estimated to have leaked into the ocean (**Figure 3**). Only the intentional oil spills that put an end to the Kuwait-Iraq war in 1991 are smaller than this, making it the second-largest spill in history (**Figure 4**).

Figure 2.
Explosion of tanker mega-Borg.

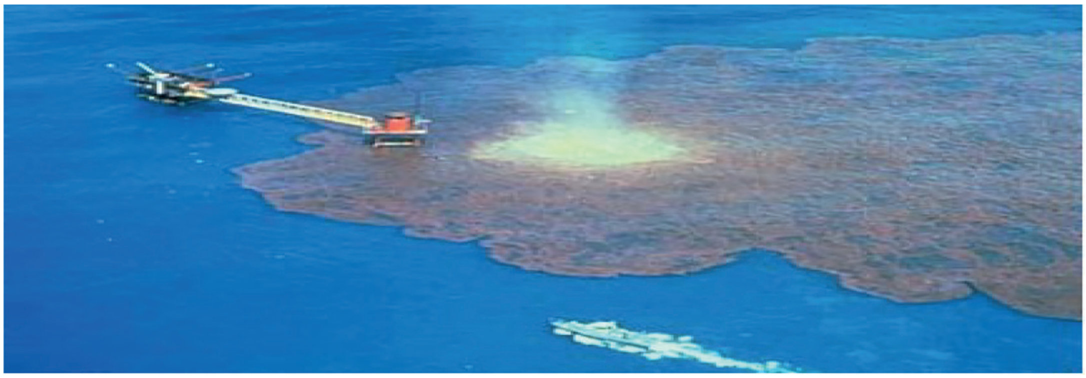

Figure 3.
Exploratory well Ixtox 1 in 1979.

Figure 4.
Exploratory of oil wells during the Kuwait-Iraq war of 1991.

In fact, during times of conflict, one nation may choose to pour tons of oil into the oceans of the opposing nation [1, 4, 6, 7].

2. Oil spill behavior in marine environments

The environmental impact of an oil spill will depend on how quickly it spreads. The majority of oils have the propensity to spread horizontally, leaving a "slick"—a smooth and slick surface—on top of the water. Surface tension, specific gravity, and viscosity are factors that influence how easily an oil spill can spread. The degree of attraction between a liquid's surface molecules is measured by surface tension. The likelihood that an oil spill will continue increases with the surface tension of the oil [6–10]. Even without the aid of wind and water currents, the oil will spread if its surface tension is low. Oil is more likely to spread in warmer waters than in extremely cold ones since increased temperatures can reduce a liquid's surface tension [1–8, 11–15].

The density of a substance as compared to the density of water is known as its specific gravity. Most oils float on top of the water because they are lighter than water. However, if the lighter components of the oil evaporate, the specific gravity of an oil spill may rise. Animal fats, vegetable oils, and heavier oils may interact with sediments or rocks at the bottom of a body of water, sink, and form tar balls. The measure of a liquid's flow resistance is its viscosity. The tendency of the oil to settle in one place increases with its viscosity [1, 6, 8, 16].

3. Problem of technical methods for oil spill detection

Recent advancements in remote sensing technology have made them an important tool for surveying and detecting marine pollution, which helps to better detect oil spills. Ships, aircraft, and satellites are some of the many tools available to detect and monitor oil spills [17, 18]. When ships are outfitted with navigation radars, they can detect oil spills at sea, say in restricted areas of 2500 m × 2500 m (**Figure 5**). As an alternative, the main methods for observing oil pollution in the ocean are aircraft and satellites [1, 3, 19–21].

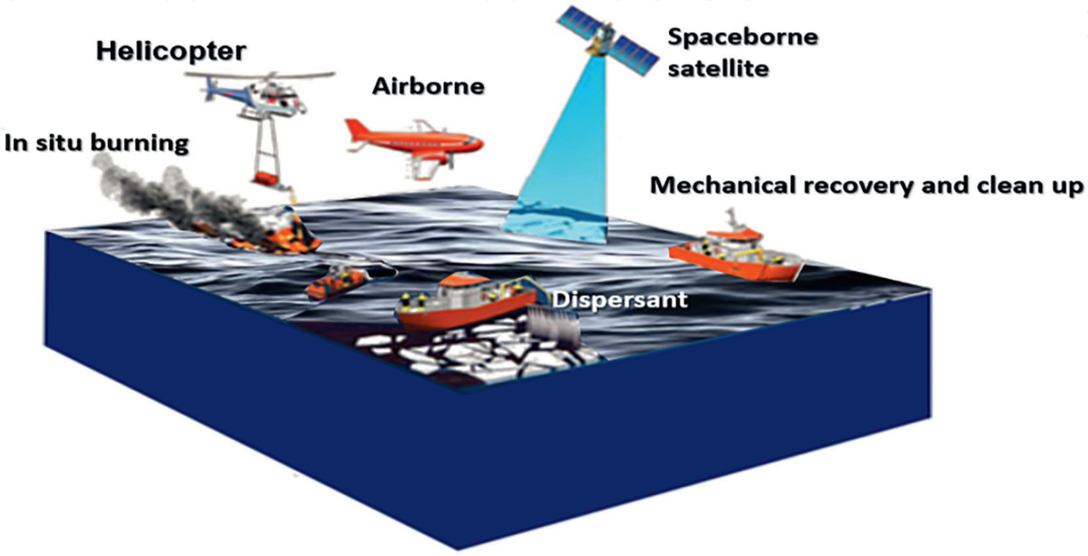

Figure 5.
Different tools for oil spill detectionz.

4. Monitoring an oil spill with optical remote sensing: potential

Research on the utilization of remote sensing technology for oil spill pollution detection has been ongoing for more than a decade. Optical and microwave sensors have been examined in several studies for oil spill detection and monitoring in several coastal water. Because of its wide area coverage and day and night all-weather capabilities, SAR deployed on satellites is now an essential instrument in oil spill monitoring. However, the majority of research on airborne remote sensing methods is not included. Although there have been a few attempts to use optical data, the main satellite or airborne data source primarily used for oil spill detection is the microwave sensor [1, 6, 22].

The most popular technique for remote sensing is optical. Due to their low cost and availability as commercial-off-the-shelf (COTS) items, cameras—both still and video—are widely used. Now, affordable digital single-reflex (SLR) cameras and camcorders are readily available. In the visible range (between 400 and 700 nm), oil has a higher surface reflectance than water, but it exhibits fewer general absorption tendencies [6, 22].

The oil that is "optically thick" absorbs solar energy and releases it again as thermal energy, primarily in the 8–12 μm spectral range [18–20]. Infrared images show that thick oil is hot, intermediate thicknesses are cool, and thin oil or sheen cannot be seen. In the evening, the opposite is seen. Although the precise thicknesses at which these transitions take place are unknown, scientific evidence indicates that the minimum detectable layer occurs between 10 and 70 μm and that the transition between the hot and cool layers happens between 50 and 150 μm. Due to the difference in emissivity between oil (0.94–0.97) and water, when the oil and water are at the same actual temperature, the oil will appear to be cooler (0.98). The infrared temperature difference between oil and water can be used to detect oil spills, and the magnitude of the difference is correlated with the thickness of the layer [1, 17, 18, 22].

Therefore, infrared sensors in the 8–12 μm range are now far more reliable and accurate than traditional infrared scanners. In this view, the "thermal infrared region," with wavelengths between 8 and 12 μm, is where infrared remote sensing has most frequently been used. Mid-band IR system tests (3–5 μm) have shown that these sensors might be useful. No spectral structure is present in this region, according to specific studies in the thermal infrared (812 μm) [17, 18, 22].

However, oil detection using infrared technology is not foolproof due to potential interferences and false positives, so the use of both IR and UV together can offer a more conclusive sign of the presence of oil than either method by itself. UV sensors are not used in operational response modes and would not play a significant role unless they are used in conjunction with IR technologies [1, 6, 17, 18, 22]. The Moderate-Resolution Imaging Spectroradiometer (MODIS) instrument may be used to keep track of oil spills. MODIS has a broad spectral range and two bands with a moderate resolution of 250 m and 500 m. On the other hand, using multiple wavelengths can give you more information to tell the difference between oil spills and slicks caused by algal blooms. However, in a tropical region like Malacca Straits, where there is a lot of cloud cover, the MODIS data has a lot of problems because of heavy cloud cover [17, 18, 20, 21]. The use of hyperspectral sensors for oil spill monitoring has the potential to offer precise material identification and a more accurate assessment of their abundance. A hyperspectral sensor's more than 200 wavelengths allow for the exploitation of the spectral signature of oil and the differentiation of various oil types. This can reduce the frequency of false alarms caused by ocean features resembling oil in appearance and color [1, 22].

In this regard, a signature matching method based on airborne hyperspectral imaging is more precise than conventional techniques, where analysis is based on a visual interpretation of the oil's color and its appearance in the satellite image. There is not a commercial hyperspectral sensor in orbit right now. One example of a space-borne technology demonstrator that was launched in 2000 is the NASA EO-1 Hyperion hyperspectral sensor. However, its narrow swath width of only 7.5–100 km is its main disadvantage [20, 22].

The oil absorbs solar energy and releases some of it as thermal energy back into the atmosphere. This oil cannot be detected by IR sensors, which perceive thick oil slicks as hot and intermediate thicknesses of oil as cool. A thick spill can appear cooler than the surrounding water at night because it dissipates heat more quickly. Oil can quickly absorb and release thermal energy, whereas water has a slower rate of heat absorption and release. Oil slicks can cool off more quickly than the surrounding water as a result, and IR sensors can detect this temperature difference. To identify the presence of oil slicks in water bodies, IR sensors are crucial tools [22].

The NOAA Advanced Very High-Resolution Radiometer (AVHRR) has visible and infrared sensors with early detection and monitoring capabilities for oil spills. The 1991 Persian Gulf War's oil spills were investigated. The oil spills might not have a temperature signature that is noticeably different from the surrounding water at night, but the IR channel was able to detect thick and thin oil layers as well as the boundary between water and oil. Only in very favorable lighting and sea conditions were oil spills visible in the images [1, 22].

Another passive sensor is an MWR. The instrument is weather-insensitive because it only detects microwave radiation from the ocean in the cm to mm range. Oil slicks appear as bright objects on a darker sea because they emit microwave radiation that is stronger than the water. Oil slicks can have strong surface-emissivity signatures, but since determining the thickness of oil slicks requires a spatial resolution of tens to hundreds of meters, aircraft sensors are the most appropriate choice for this type of sensor for oil spill thickness monitoring [1, 6, 22].

Several studies for the monitoring and detection of oil spills compare SAR and optical sensors. For instance, the SAR data have the lowest backscatter levels in regions with algal blooms, whereas the SeaWiFS measures high levels of chlorophyll in these regions. Needless to say, different data sets could be used to distinguish between oil spills and look-alike phenomena like algal blooms [9, 22–24].

5. Potential of radar and microwave techniques for detecting oil spills

Oil on the sea surface dampens some of the small capillary waves that occur naturally in clean seas. Capillary waves reflect radar energy, producing a "bright" area in radar imagery. The presence of an oil slick can be detected as a "dark" area or one that has an absence of sea clutter. In this regard, Synthetic Aperture Radars (SARs) and Side-Looking Airborne Radars (SLARs) are the two primary types of radars used for environmental remote sensing and oil spill response. SLARs, despite being an older technology, are less expensive to purchase and use long antennas to improve along-track resolution. SARs achieve along-track resolution by using the forward motion of the sensor (an aircraft or spacecraft) to generate a very long antenna (which is range independent). A SAR signal requires sophisticated electronic processing to extract images. SARs are more expensive than SLARs but have a wider field of view and higher resolution. Comparative tests reveal that SAR is significantly better. Because they are made to identify complex targets, search, and rescue radar systems have little to no use for locating oil spills [16–22].

Radar detection of oil slicks is limited by sea state, low sea states will not produce sufficient clutter in the surrounding sea to contrast with the oil, and very high seas will scatter radar sufficiently to block detection inside the troughs. Indications are that wind speeds of at least 1.5 m/s are required as a minimum to allow detectability. Beyond this, wind speeds higher than 6 m/s will again remove the effect of an oil slick being distinguishable from the surrounding sea [9, 22–24].

Microwave radiation is emitted by the ocean. Because oil emits more microwave radiation than water, it appears as a "bright" area on a darker sea because oil is a stronger microwave emitter than water. Oil has a higher emissivity than water, which has a 0.4 emissivity factor. This difference in emissivity can be picked up by a passive device, which could act as a method of oil detection. The device could theoretically be used to measure the thickness of a slick because there is also a change in signal with thickness. This method has been very effective [20, 22, 24].

The methodology is dependent on prior knowledge of a range of environmental and oil-specific parameters, and the signal return is periodically influenced by oil thickness. Any one of two or three film thicknesses can be inferred from a given signal strength for a specified slick. When the effective thickness is an odd multiple of a quarter wavelength of the observed energy, microwave emission is at its highest. Additionally, the signal-to-noise ratio is low and biogenic materials interfere. Achieving high spatial resolution is challenging [1, 22, 24].

6. Look-alikes keystone issue in SAR data

The term frequently refers to an oil spill in the ocean. Oil spills can have devastating effects on the marine environment, including killing wildlife and polluting the water [6, 20, 23, 25]. In particular, an oil spill is a type of pollution that occurs when a liquid petroleum hydrocarbon is released into the environment as a result of human activity. Crude oil, refined petroleum products (like gasoline or diesel fuel) or byproducts, ship bunkers, oily waste, or waste mixed with oil are some of the different components that make up the oil. Pollution from the oil spill is challenging to remove. Natural oil seeps are another source of oil entering the marine environment. Although the majority of oil pollution caused by humans occurs on land, seagoing oil tankers have received the majority of public attention and regulatory attention. Unrelated to the oil spill, there are dark patches [9, 21, 22].

SAR satellite data is typically regarded as the most effective and superior satellite sensor for finding oil spills. Nevertheless, oil spill thickness estimation and oil type identification cannot be done with SAR data. The ability to distinguish between oil spills and look-alikes is the main issue with SAR data for oil spill detection. In actuality, both show up in SAR data as dark patches. Natural dark patches are referred to as "oil slick look-alikes" in this context. Natural films and slicks, ice, threshold wind speed regions (wind speeds of 3 m/s), wind protection from the land, rain cells, shear zones, internal waves, and other phenomena are examples of look-alikes (**Figure 6**). In a strict sense, an oil spill only refers to man-made slicks connected to crude petroleum and the products it produces, such as heavy and light fuel [9, 22, 24].

Currently, the SAR sensor is unable to differentiate between the various pollutants. However, for the large Sea Empress oil spill, there is a good correlation between the largest reduction in backscatter and the thickest oil as determined by visual

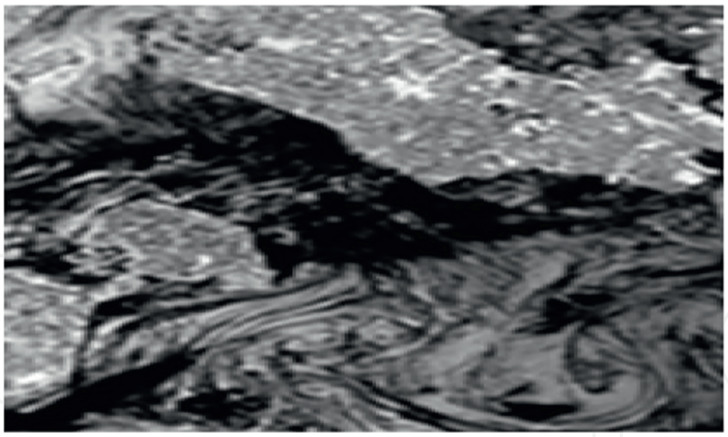

Figure 6.
Look-alike in SAR data.

observations for a constrained range of wind speeds (5–6 m/s). This suggests that a single SAR frequency may not be sufficient to estimate the thickness of the oil spill. When selecting features to distinguish between oil spills and lookalikes, these experiences must be taken into consideration. To distinguish between oil spills and look-alikes, physical, geometrical, and geographical parameters must be used, as well as significant characteristics like wind speed [9, 16–24].

7. Conclusion

Beyond oil spills, this chapter has demonstrated a variety of other concepts. It has looked into the effects of oil exploration and extraction on the environment, the economy, and politics, as well as the effects of spill-related harm on a region. As a result, the chapter also offers some fundamental knowledge about tracking oil spills from space. This is shown with the help of optical and microwave remote sensing technology.

The primary issue with using radar and microwave data to monitor an oil spill is the possibility of false alarms from look-alikes. As a consequence, there are a variety of issues that must be resolved regarding the detection of oil spills from space. Combining these technologies with other strategies, such as *in-situ* measurements and ground-based observations, is essential.

Author details

Maged Marghany
Global Geoinformation Sdn.Bhd., Kuala Lumpur, Malaysia

*Address all correspondence to: magedupm@hotmail.com

References

[1] Wang Z, Fingas M, Page DS. Oil spill identification. Journal of Chromatography A. 1999;**843**(1-2):369-411

[2] Takeshita R, Bursian SJ, Colegrove KM, Collier TK, Deak K, Dean KM, et al. A review of the toxicology of oil in vertebrates: What we have learned following the Deepwater horizon oil spill. Journal of Toxicology and Environmental Health, Part B. 2021;**24**(8):355-394

[3] Little DI, Sheppard SR, Hulme D. A perspective on oil spills: What we should have learned about global warming. Ocean & Coastal Management. 2021;**202**:105509

[4] Lourenço RA, Combi T, da Rosa AM, Sasaki ST, Zanardi-Lamardo E, Yogui GT. Mysterious oil spill along Brazil's northeast and southeast seaboard (2019-2020): Trying to find answers and filling data gaps. Marine Pollution Bulletin. 2020;**156**:111219

[5] Cheng H, Hu Y. Lead (Pb) isotopic fingerprinting and its applications in lead pollution studies in China: A review. Environmental Pollution. 2010;**158**(5):1134-1146

[6] Fingas M. The Basics of Oil Spill Cleanup. CRC Press; 2002

[7] Zhang W, Li C, Chen J, Wan Z, Shu Y, Song L, et al. Governance of global vessel-source marine oil spills: Characteristics and refreshed strategies. Ocean & Coastal Management. 2021;**213**:105874

[8] Doerffer JW. Oil Spill Response in the Marine Environment. Elsevier; 2013

[9] Otremba Z. The impact on the reflectance in VIS of a type of crude oil film floating on the water surface. Optics Express. 2000;**7**(3):129-134

[10] Marghany M. Genetic algorithm for oil spill automatic detection from ENVISAT satellite data. In: Computational Science and Its Applications–ICCSA 2013: 13th International Conference, Ho Chi Minh City, Vietnam, June 24-27, 2013, Proceedings, Part II 13. Berlin Heidelberg: Springer; 2013. pp. 587-598

[11] Etkin DS. Analysis of oil spill trends in the United States and worldwide. In International Oil Spill Conference 2001. 2001, 2, pp. 1291-1300). American Petroleum Institute

[12] Wang J, Zhou Y, Zhuang L, Shi L, Zhang S. Study on the critical factors and hot spots of crude oil tanker accidents. Ocean & Coastal Management. 2022;**217**:106010

[13] Stogiannidis E, Laane R. Source characterization of polycyclic aromatic hydrocarbons by using their molecular indices: An overview of possibilities. Reviews of Environmental Contamination and Toxicology. 2015;**234**:49-133

[14] Hoang AT, Pham VV, Nguyen DN. A report of oil spill recovery technologies. International Journal of Applied Engineering Research. 2018;**13**(7):4915-4928

[15] Reed M, Johansen Ø, Brandvik PJ, Daling P, Lewis A, Fiocco R, et al. Oil spill modeling towards the close of the 20th century: Overview of the state of the art. Spill Science & Technology Bulletin. 1999;**5**(1):3-16

[16] Fingas M, editor. Oil Spill Science and Technology. Gulf Professional Publishing; 2010

[17] Marghany M. RADARSAT for oil spill trajectory model. Environmental Modelling & Software. 2004;**19**(5):473-483

[18] Marghany M. Synthetic Aperture Radar Imaging Mechanism for Oil Spills. Gulf Professional Publishing; 2019

[19] Venkatesh S. The oil spill behaviour model of the Canadian atmospheric environment service part I: Theory and model evaluation. Atmosphere-Ocean. 1988;**26**(1):93-108

[20] Marghany M. Automatic Detection Algorithms of Oil Spill in Radar Images. CRC Press; 2019

[21] Marghany M. Radarsat Lagrangian flow effects on oil spill spreading. In: IEEE International Geoscience and Remote Sensing Symposium. Vol. 4. IEEE; 2002. pp. 2023-2025

[22] Brown CE, Fingas MF, Goodman RH. Oil-spill remote sensors: New tools that provide solutions to old problems. In: Arctic and Marine Oilspill Program Technical Seminar. Vol. 2. Canada: Ministry of Supply and Services; 1998. pp. 783-794

[23] Bello J, Eriksen P, Pocwiardowski P. Oil leak detections with a combined telescopic fluorescence sensor and a wide band multibeam sonar. In: International Oil Spill Conference Proceedings. Vol. 1. International Oil Spill Conference; 2017. pp. 1559-1573

[24] Marghany M. Finite element model of residual currents and oil spills transport. InIGARSS 2000. In: IEEE 2000 International Geoscience and Remote Sensing Symposium. Taking the Pulse of the Planet: The Role of Remote Sensing in Managing the Environment. Proceedings (cat. No. 00CH37120). Vol. 7. IEEE; 2000. pp. 2966-2968

[25] Topouzelis KN. Oil spill detection by SAR images: Dark formation detection, feature extraction and classification algorithms. Sensors. 2008;**8**(10):6642-6659