Oil Spill Detection Using Remote Sensing and GIS in Eastern Coast of United Arab Emirates

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Abstract: One of the most dangerous oceanic pollutions nowadays is marine oil spills, which occur when crude oil is released into the oceanic water and must be contained quickly since they can extend to large areas and result in serious ecological, economic, and health consequences. Places like the Gulf of Oman are highly vulnerable to oil spill accidents due to the high marine activity there. Remote sensing and geographic information systems (GIS) have proven their capabilities in countless fields, and detecting oil spills is one of them. This study explores the potential of combining remote sensing and Geographic Information Systems (GIS) for oil spill detection on the Eastern Coast of the United Arab Emirates. Leveraging Sentinel-1 SAR and Sentinel-2 optical data, we develop and evaluate a methodology to identify oil spills. While specific accuracy assessments await further testing, initial visual analysis indicates promising results. The study contributes to advancements in oil spill detection by demonstrating the potential of using these remote sensing techniques in this region. Additionally, it highlights the value of GIS integration for data analysis and visualization. This research holds promise for improved oil spill monitoring and environmental protection efforts on the Eastern Coast of the United Arab Emirates.

1 INTRODUCTION

Marine oil spills are a hot topic that concerns many governments due to their comprehensive impacts. This kind of pollution can not only disrupt wildlife habitats, but it can also harm people's health and affect the fishing and tourism industries as well. The oil spill is harmful to ocean and shoreline environments, especially in places like the Arabian Gulf and Gulf of Oman that are exposed to such threats due to the marine activities that take place there. Desalination plants, fish farms, and tourism suffer from economic drawbacks whenever an oil spill incident occurs. To reduce the consequences of this issue, quick and strategic solutions must be obtained. Remote sensing and GIS are some of the most reliable tools that are used in such circumstances. Remote sensing is a very powerful tool that can be employed in protecting the marine environment and monitoring the oil spills that change the physical and chemical qualities of the sea surface due to its ability to cover large areas in a short amount of time as well as functioning day and night during different weather conditions (synthetic aperture radars). Oil slicks form fewer rough surfaces than the surrounding water; therefore, it is less likely for a radar pulse to bounce back to the sensor, creating dark spots in the images that represent the oil spill. But these dark spots can also be caused by natural events in the ocean, like areas with low wind speeds, weed beds, or algae blooms. It is common to call these dark areas "look-alikes."

Using satellite imagery to detect and monitor the oil spill is not a new topic. Countless studies have proven the role of remote sensing in this field. For instance, Dhavalikar and Choudhari (2022) have applied remote sensing techniques by using synthetic aperture radar (SAR) images to capture, quantify, and classify oil spills and lookalikes. They have found that oil spills caused by moving platforms (ships or rigs) over the Eastern Arabian Sea are greater than the oil spill detected near the Bombay High Oil Platforms. Evaluating the quality of the images enables the locating of slicks and categorizing them according to wind speed, known oil infrastructure, and natural occurrences. Through this, Issa (2005) was able to map marine oil pollution in the Arabian Gulf and Gulf of Oman, create an oil spill atlas

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offshore the United Arab Emirates, and identify over six hundred potential spills between 1992 and 2003 using SAR and optical data. Chaturvedi et al. (2019) demonstrated that Sentinel-1 VV polarization serves as the most effective tool for oil spill detection. Furthermore, Gafoor and Al Shehhi (2022) used Sentinel-1 SAR and Sentinel-2 optical data, which were pre-processed and analyzed using SNAP and ArcGIS Pro software. The results of the study showed that remote sensing and GIS are effective tools for detecting and monitoring oil spills. The combination of SAR and optical data was particularly effective, and the use of band ratios from Sentinel-2 data was useful in distinguishing oil spills from other lookalikes. Also, Grimaldi et al. (2010) evaluated AVHRR TIR channels 4 and 5 data and were able to detect thin and old oil films with high sensitivity and dependability. Kolokoussis & Karathanassi (2018) use it in both known natural outflows and light oil spill events. Researchers developed and evaluated two object-based image analysis (OBIA) methods for detecting oil spills from Sentinel-2 imagery: spectral matching and texture analysis. Both methods were able to detect oil spills in the Sentinel-2 imagery, with the spectral matching method being more effective at detecting thicker and more concentrated oil spills, and the texture analysis method being more effective at detecting thinner and more dispersed oil spills. Fahim Abdul Gafoor and Maryam R. Al Shehhi (2022) processed and analyzed Sentinel-1 SAR and Sentinel-2 optical data using SNAP and ArcGIS Pro software. The results of the study showed that remote sensing and GIS are effective tools for detecting and monitoring oil spills. The combination of SAR and optical data was particularly effective, and the use of band ratios from Sentinel-2 data was useful in distinguishing oil spills from other lookalikes. Also, Grimaldi and others (2010) evaluated AVHRR TIR channels 4 and 5 data and were able to detect thin and old oil films with high sensitivity and dependability.

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The eastern coast of the United Arab Emirates is an active marine shipping area that overlooks the Gulf of Oman, which has recorded several oil spills over the past years; some of them were reported and others were not. These frequent accidents must be taken into consideration to reduce or avoid any drawbacks from the situation. In this paper, we utilized some remote sensing and GIS technologies that can significantly contribute if such accidents occur. The main objectives of this study are summarized in the following points:

- Detection and identification of the oil spill using Sentinel-1 SAR images.
- The oil spills were detected using Sentinel-2 band ratios.
- Indicating the size of the oil slicks.

2 STUDY AREA AND MATERIALS

The study area covers the eastern coast of the UAE, which has an extent of approximately 1747.6 km2, with centroid coordinates of 56.4831371 Eo and 25.28068759 No (Figure 1). This area is known for the marine transportation traffic that occurs there, and this is due to the Fujairah and Khor Fakkan ports that are located along the eastern coast. Fujairah Port is considered the largest port in the Gulf of Oman and the second largest bunkering hub globally (Port of Fujairah, n.d.). In addition, Khor Fakkan Port, which lies beyond the Strait of Hormuz on the UAE's Indian Ocean shore, is a world leader in container transshipment. Its advantageous location gives it the perfect center for transhipping goods to locations in East Africa, the Red Sea, and the upper Gulf (Ports & Terminals, Sharjah Ports Authority, 2023). Due to these conditions, this region is exposed to continuous oil spill incidents that might occur from ship accidents or intentional or unintentional oil leakage. For instance, a large oil spill was reported on March 30, 1994, which resulted from a collision between tanker Baynunah and tanker Seki and resulted in 16,000 metric tons spilling into the Gulf of Oman. Then oil washed ashore about thirty kilometers of shoreline north of the UAE port of Khor Fakkan due to the wind and currents. The impact affected several economically and ecologically delicate regions. Moreover, in 2005, Fujairah Port was prohibited, and in 2007, the UAE issued violations for pollution caused by ships.

Eastern Cost of United Arab Emirates

Figure 1: Study area.

3 DATA AND METHODOLOGY

3.1 Data Used

In this study, two different data sets were considered to detect the oil spills, which are synthetic aperture radar (SAR) and optical images from Sentinel-1 and Sentinel-2. The data from the sites was acquired from the Copernicus Open Access Hub and the Alaska Satellite Facility (ASF) for different dates when the oil spill incidents occurred. The SAR Level 1 Ground Range data of the sites was acquired from Copernicus Open Access Hub and Alaska Satellite Facility (ASF) for different dates when the oil spill incidents occurred. Detected products were used in this study with medium resolution in IW (interferometric width) mode, 10x10 m pixel resolution, 5.5 cm wavelength, and 251.8 Km ground range coverage. The data was provided in VV and VH polarization. Furthermore, the Sentinel-2 data used was level-2A, which is atmospherically corrected and provided in thirteen spectral bands and different spatial resolutions (10m, 20m, and 60m), with 60m resolution bands used to perform the analysis.

The images were collected on different dates, depending on the date of the incident and their availability. Table 1 shows the date when the oil incident took place, according to the local news, and the dates at which the available data was captured. These incidents were caused by distinct reasons, such as pipe leakage, ship collisions, and terrorist attacks.

Table 1: Data availability, dates, and types.

Reported	Captured	Type
2019-05-12	2019-05-14	Sentinel-2A
2019-10-28	2019-10-31	Sentinel-2A
		Sentinel-1
2022-05-12	2022-05-13	Sentinel-2A
2022-08-22	2022-08-12	Sentinel-1
	2022-08-16	Sentinel-1

Furthermore, digital elevation models of the study area were collected from the USGS Earth Explorer, which were used to apply the terrain corrections for the SAR data. The DEM images are Shuttle Radar Topography Mission Void. Filled data has a resolution of 90 m. The images were enhanced to complete missing data, thus providing a more comprehensive dataset of the digital elevation model.

3.2 Sentinel-1 SAR Data Processing

The collected SAR images were pre-processed using the Synthetic Aperture Radar toolset in ArcGIS Pro software, which provides correction and processing tools for the SAR data. The pre-processing stage started with downloading the orbit file and applying the orbit correction, which uses an orbit state vector (OSV) file that is more precise for modifying the orbital data in the SAR dataset. Then the thermal noise will be removed to eliminate distortions caused by noise in SAR imagery, creating a smoother and more visually appealing image. Radiometric calibration will be applied, where SAR reflectivity will be transformed into calibrated normalized backscatter values using a reference plane for normalization. Radiometric terrain flattening will be implemented to adjust SAR data to compensate for radiometric variations caused by terrain variations. Then speckle filtering will be applied using the Despeckle tool to reduce speckle noise in SAR imagery by eliminating the grainy or salt-and-pepper appearance caused by coherent illumination. Next, geometric terrain correction will be used that transforms the distorted geometry of SAR imagery into a map-projected coordinate system using a range-Doppler backgeocoding algorithm. Finally, the SAR data will be converted from linear to decibels (db). The dB scale is the ideal choice for displaying SAR images because of its logarithmic structure, which allows it to manage big numerical values and wide dynamic ranges with efficiency. Since SAR data reduces the range of amplitude or intensity values, converting it to dB units makes image interpretation easier and improves the image's visual representation. After the preprocessing stage is done, the data is ready to be analysed. A threshold was implemented on the VV band, in which the decibel values that represent the oil slicks will be selected, which are lower than -22 db. The pixels with these values will be represented by a class, which will be converted into a polygon, and further analysis will be executed, such as measuring the surface area and the relative variation in the backscatter intensity across the oil slicks.

3.3 Sentinel-2A Data Processing

Next, Sentinel-2A band ratios help detect oil spills in remote sensing imagery. We may divide two spectral bands to show their respective intensities. This may assist in identifying image features. First, create a model builder to run two ratios. The first one is R: B3/B2, G: (B11+B12)/B8, B: (B3+B4)/B2, and the second one is R: b3/b2; G: (b3 + b4)/b2; B: (b6 + b7)/b5. Separately, for each ratio, we will composite three bands to get the false color or ratio band. And for unsupervised classification, group pixels in a picture by spectral or spatial similarity. It may extract oil pixels from a picture by finding pixels with comparable spectral properties to previous oil spills. After that, convert the raster to a polygon to estimate the size of the oil spill. The flowchart shows the fundamental procedures used to identify oil spills using satellite imagery.

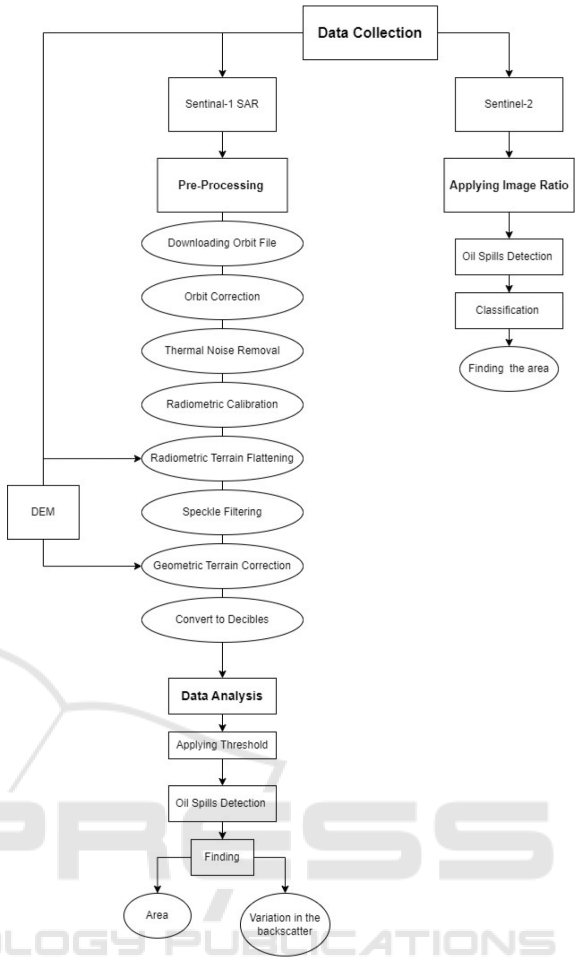

Figure 2: Methodology Framework.

4 RESULTS AND DISCUSSION

The oil spill incidents that were reported in the local news were captured by the satellites either after a number of days since the incidents occurred or before they occurred. Some of the incidents were captured by Sentinel 1, and others by Sentinel 2. Most of the Sentinel-2 images contained clouds, which degraded the quality of the image and affected the analysis.

4.1 SAR Products

The resulting SAR images were able to detect the oil slicks very clearly in the image due to the low backscattering intensity of the oil compared with the features surrounding it, such as the water. Oil slicks appear as dark patches in radar imagery due to the suppression of capillary waves, resulting in a flatter ocean surface and reduced radar reflection (Figures 3–5) (Moreira et al., 2013). Figure 3 shows the oil spill that resulted from the collision of two ships in the Gulf of Oman on August 28, 2022. This accident resulted in intensive pollution of the seawater in the region. The resulting image shows how the oil slick extends widely along the coast. Figure 4 shows the oil leakage that occurred in Khor Fakkan Port; however, there is another oil spill caused by a ship in the middle right side of the image. Figure 5 shows the same location as the previous image, but after four days. It is noticeable how the extent of the oil spill increased significantly, which creates doubts that this oil spill was not caused by a simple leakage only, but there is a probability that there are multiple agents in this situation.

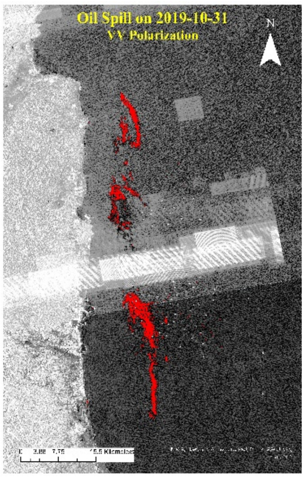

Figure 3: Oil spill detection and extraction on 2019-10-31.

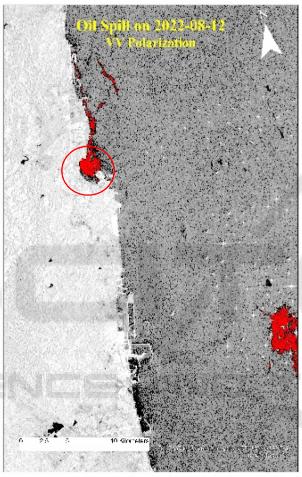

Figure 4: Oil Spill detection and extraction on 2022-08-12. The circle marks Khor Fakkan port location.

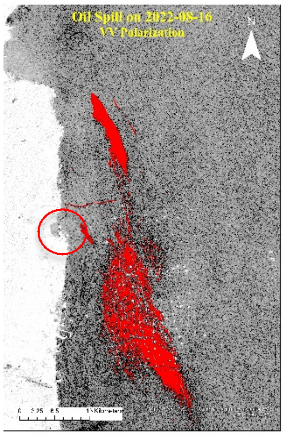

Figure 5: Oil Spill detection and extraction on 2022-08-16. The circle marks Khor Fakkan port location.

After detecting the oil spill in the images, we applied a binary threshold classification to extract the oil spill features. This allowed us to estimate the overall area of each oil slick, in which the largest extent of oil spill was recorded on August 16, 2022, with approximately 165 km2 of oil that extends in front of the eastern coast of the UAE (Table 2). Determining the extent of the oil spill can aid the responsible authorities in creating strategies to clean up the spills. Furthermore, the overall images show that the oil slicks have unique shapes and textures, in which they exhibit smooth, uniform, and continuous texture with regular shapes (Al-Ruzouq et al., 2020).

Table 2: Overall area of each oil slick.

Incidents	Area (Km^2)
2019-10-31	54.8
2022-08-12	13.1
2022-08-16	164.9

Moreover, if the oil slick feature were extracted solely in VV polarization, variation in the backscatter values would be illustrated within the oil spills themselves (Figure 6). This can pinpoint a very crucial fact: many factors can affect the backscattering of the oil, such as the type of oil, thickness, and weathering degree (Garcia-Pineda et al., 2020).

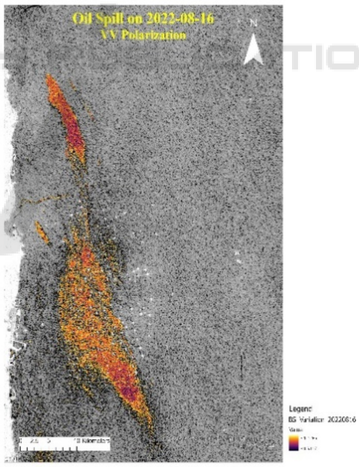

Figure 6: The image shows the backscatter intensity variation within the oil slicks.

4.2 Optical Products

According to Figure 7, the band ratio of the oil spill on Fujairah's eastern coast shows that an oil spill was there on October 31, 2019, May 14, 2019, and May 13, 2022. The ratio of B3/B2, (B11+B12)/B8, and (B3+B4)/B2 shows the oil spill more clearly and darker. These band ratios are more sensitive to oil spills than others. It is good at reflecting near-infrared light. Since water does not reflect much in the NIR range, it is easy to tell the difference between oil and water. Algae has a high reflection in the blue, green, and red spectra, while oil has a low reflectivity in those ranges. Also, it reflects more SWIR light in the B11 and B12 bands than in the visible wavelengths, and SWIR bands are less scattering-prone, making them more vulnerable to oil spills (Diaz, 2023).

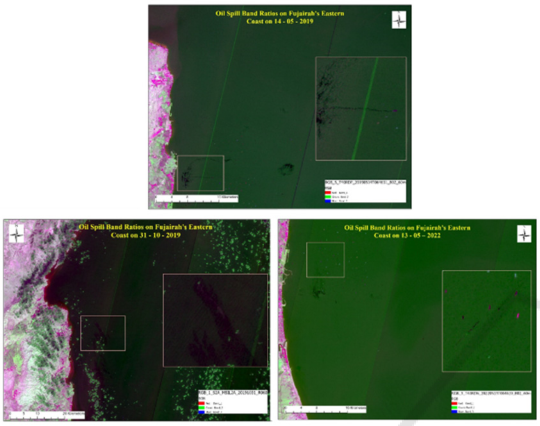

Figure 7: False Color Subset of Sentinel-2 Imagery.

While the band ratio in b3/b2; (b3 + b4)/b2; (b6 + b7)/b5 was pale and less vulnerable to oil spills since they are based on visible light reflectance at the same dates, Cloud cover obstructed the determination of the oil spill presence in the image captured on May 13, 2022. Water and suspended particles scatter visible light, making oil spills more difficult to see. The spectral response of the oil spill over the picture is enhanced by using the ratio (b3 + b4)/b2, while the ratio (b6 + b7)/b5 is used to display vegetation-related information. Furthermore, an oil spill may be mapped using a false-color composite of sentinel-2 (MSI), as shown in Figure 8 (F. A. Gafoor et al., 2022).

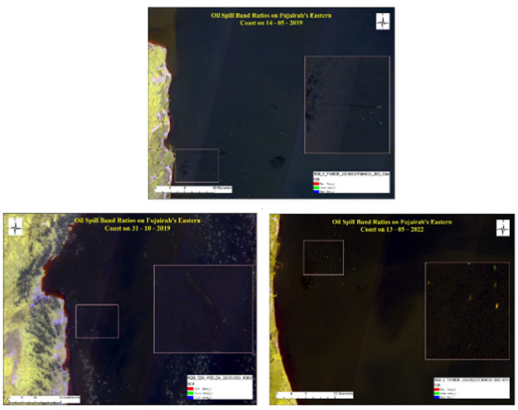

Figure 8: False Color Subset of Sentinel-2 Imagery.

Then classify the oil spill by using the unsupervised classification technique to identify and extract the composite of oil pixels, which can then be utilized to estimate the extent of surface area that has been contaminated by the oil. The use of object-based classifications and segmentation algorithms has the potential to enhance the accuracy of oil slick detection by mitigating the occurrence of false negatives. The estimated extent of the oil leak spans around 1.215676 square kilometres as of May 14, 2019, as presented in Figure 9.

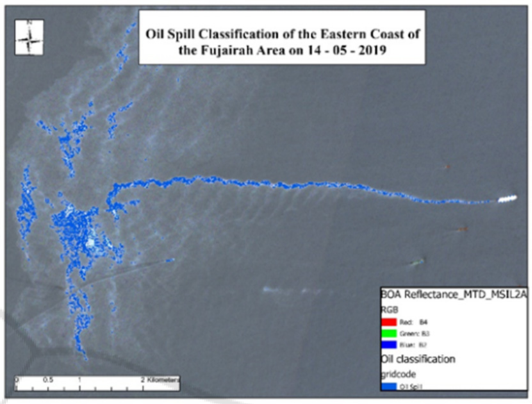

Figure 9: Unsupervised classification technique.

5 CONCLUSIONS

Detecting oil spills on the Eastern Coast of the UAE is a challenging task due to the intricate water conditions, limited depth, and frequent occurrence of cloudy weather. The careful processing and segmentation of satellite photos are imperative to enhance the detection of oil spills in each area. The utilization of both synthetic aperture radar (SAR) and optical data has proven to be effective in identifying oil spills, with the application of band ratios derived from Sentinel-2 data being particularly valuable in distinguishing oil spills from similar phenomena. According to the research findings, Sentinel-1 VV polarization and Sentinel-2 band ratios, namely B3/B2, (B11+B12)/B8, and (B3+B4)/B2, proved to be very efficient in detecting oil spills. The use of remote sensing and Geographic Information Systems (GIS) in the realm of oil spill identification and monitoring is gaining significance, given the escalating occurrence of oil spills. The use of remote sensing and Geographic Information Systems (GIS) may provide significant insights to decision-makers tasked with addressing oil spills and minimizing their ecological ramifications. As a future plan, we believe that the use of artificial intelligence and machine learning techniques can significantly enhance the results, generating more precise and accurate outcomes. Furthermore, this technology can be used to distinguish the oil spill from other lookalikes.

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