Oil spill detection by satellite remote sensing in Zakynthos Island, Ionian Sea, E. Mediterranean

Assessing the water quality is one of the most essential issues in order to ensure environmental protection and public health. Remote sensing is an effective tool for monitoring of pollutants in open and coastal waters derived from human-induced activities and accidents or natural events. In this study high-resolution satellite data from different sensors (i.e. Sentinel-2, Landsat-8) were used in order to monitor and identify the origin, structure and spatial extent of naturally occurring sea surface oil slicks in the coastal zone of Zakynthos Island (Ionian Sea, E. Mediterranean). We also examined the potential effect of earthquake activity on the oil slick behavior during 2018-2019, a period including a strong earthquake measuring magnitude $M_w$ 6.8 occurred in the Ionian Sea. Experimental results showed that the oil spill is a permanent feature, however the largest oil slicks were recorded after seismic events of various magnitudes. Successive satellite images during late July 2019 indicated that oil spill spreading is affected by ocean parameters (i.e. winds and currents). More in situ observations need to be collected for further validation and natural oil outflow study.

Keywords: oil spill, remote sensing, earthquake, Zakynthos Island

Introduction

Over the last decades, several remote sensing techniques have been developed for the detection and observation of different forms of marine pollution as oil and waste discharges, algal blooms and plastic debris (Maianti et al., 2014, Kikaki et al., 2018). A review of oil spill remote sensing (Fingas & Brown, 2018) indicated that improved IR cameras and fluorosensors can be used for oil spill detection, and passive microwave as indicator of oil slick thickness. Oil spill mapping is currently carried out using radar due to its independence of weather conditions (i.e. rain/clouds), whereas many algorithms have been proposed for oil spill detection and monitoring. However, discriminating oil spills from biogenic slicks and look-alikes is still a challenge as algorithms sometimes lead to unsatisfactory results. Due to this fact, additional information about oceanographic parameters (i.e. chlorophyll-a, winds, sea surface currents, fronts) and ship traffic, oil platforms or oil seeps should be considered (Alpers et al., 2017).

Regarding automatic approaches, unmixing algorithms have been successfully applied in multispectral and hyperspectral data, however the detection accuracy depends on data spectral and spatial resolution (Sykas et al., 2011). Level set segmentation has been proved as a robust tool for oil spill real-time detection in SAR data (Karantzalos & Argialas, 2008). Chen et al. (2018) integrated deblurring and segmentation methods into one framework with exchanging information between the two procedures, and Krestenitis et al. (2019) applied semantic segmentation along with deep convolutional neural networks. Machine learning
techniques based on supervised and unsupervised/ semiautomatic classification have been also efficiently applied in AVIRIS (Liu et al., 2019) and multispectral data (Liu et al., 2017). Regarding the study area, Kolokoussis & Karathanassi (2013) developed an object-based method for oil spill detection using high-resolution multispectral images (i.e. WorldView2, QuickBird). The specific methodology was also efficiently performed in Sentinel-2 data in Zakynthos area and in Salamina Island after ‘Agia Zoni II’ ship wreck (Kolokoussis & Karathanassi, 2018). Karathanassi (2014), based on laboratory measurements, indicated that thicker oil spill leads to higher reflectance, and using hyperspectral data in Zakynthos Island proposed that oil spill detection can be achieved in the near infrared electromagnetic spectrum region. In this study multitemporal high-resolution satellite data were used to detect and describe the evolution of sea surface oil slicks in Zakynthos Island. All available Sentinel-2 images between 2018 and 2019 were collected, a period including several seismic events (Table 1). Landsat-8 data were also obtained. Based on successive satellite observations along with ocean conditions description, we explored oil spill spreading. A detailed analysis of oil spill evolution using various sensors, is presented before and after the strong earthquake that occurred on 26 October 2018 in the area.

Study Area

The island of Zakynthos is one of the most seismically active regions in the Mediterranean Sea as it is located very close to Cephalonia fault and to the convergent boundary between the Eurasian and African plates (Fig. 1) (Papazachos and Papazachou, 1997). The study site is located in the gulf of Laganas in Zakynthos Island (Fig. 2). It includes two natural oil springs: a) the “Herodotus springs” of Keri Lake, located in the southern part of island (Fig. 2b) expanding over an area of 3 km² at 1 m elevation (Avramidis et al., 2017); and b) offshore sea surface oil slicks, commonly visible in the study area (Fig. 2c). In the latter area, continuous natural seepage of oil has been recorded at depths of ~150 m. Earlier studies on marine sediments conducted by HCMR, highlighted the presence of petroleum hydrocarbons with peculiar molecular profiles, not characteristic of other marine sediments in the Hellenic region. Previous studies of HCMR (2008) by side scan sonar revealed the presence of several depressions on the seafloor covering an overall area of 100x30 m, where natural hydrocarbon seepage occurs (Fig. 2d).

![Fig.1 Main tectonic elements in Greece (Lekkas and Mavroulis, 2018).](image-url)
Fig. 2 (a) The island of Zakynthos (after proc. in Qgis), (b) Herodotus springs of Keri Lake (Sentinel-2 image), (c) Observed sea surface oil slick (http://patrastimes.gr/), (d) Side scan sonar profile illustrating seafloor depressions associated with oil seepage (by G. Rousakis).

Methodology

Sentinel-2 multispectral data (resolution=10 m) from April 2018 to September 2019 were downloaded from Copernicus official website. Satellite data with a cloud presence of over 25% were rejected and not further processed. The rest of the data were atmospherically corrected and surface reflectance values were extracted based on the ACOLITE atmospheric processor (Vanhellemont and Ruddick, 2016). After atmospheric correction proposed indices (i.e. B2/B11 and StdDev(B2)*B2/B11 by Kolokoussis & Karathanassi, 2018) were applied in all Sentinel-2 (S2) data for oil spill detection. For earthquake events description, Landsat-8 (L8) data (resolution=30 m) were additionally obtained. In total, two Landsat-8 path rows, i.e. 184/34 and 185/34, and one Sentinel-2 tile, i.e. 34SDG, were used for this study. Planet satellite images (resolution=3 m) were also used for validation. CMEMS (http://marine.copernicus.eu) data were used for the study of surface currents velocity and wind data from National Observatory of Athens for wind conditions description. Image processing was achieved using Python programming language and maps were created using Qgis.

Regarding the earthquake activity period, multispectral (Sentinel-2 and Landsat-8) and radar data (Sentinel-1) before and after the specific seismic events were obtained from Copernicus and USGS official websites. Chlorophyll-a maps were also created using Sentinel-2 data and the MedOC3 algorithm (Santoleri et al., 2008). During July 2019, successive satellite images were used in order to estimate oil spill velocity and describe its evolution along with ocean conditions.
Results-Discussion

Collected multispectral satellite data during October 2018-September 2019, indicated that oil spill is a permanent feature of study area, due to the natural oil seep located underwater. It has to be emphasized that largest oil slicks were tracked after seismic events. In almost all cases one oil slick of mean 6 km length and width was ranged from 100 m to 2 km. Landsat-8 image acquired on 2 July 2019 demonstrates indicative oil spill position at sea surface (Fig. 3). Earthquake events recorded in Zakynthos area during the period late October 2018-Early September 2019, are given in Table 1. The greatest earthquake occurred on 26 October 2018 (Mw 6.8), which led to the largest oil spill in study area for the corresponding period. On 26 October 2018 four oil spill features were tracked in a satellite image captured by Sentinel-2, 9 hours after the earthquake. Figure 4 presents the oil spill areas in RGB composite. The length of these areas was 2-9 km, as the width was 25 m-2 km. Bands ratio B2/B4 was also applied in the specific image in order to outline the oil spill features (Fig. 5). During late October prevailing winds direction was southwestern as currents direction was E-W.

<table>
<thead>
<tr>
<th>Earthquake activity</th>
<th>Earthquake magnitude Mw</th>
<th>Landsat-8</th>
<th>Sentinel-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>26 October 2018</td>
<td>6.8</td>
<td></td>
<td>26/10</td>
</tr>
<tr>
<td>11 January 2019</td>
<td>3.7</td>
<td>16/1</td>
<td></td>
</tr>
<tr>
<td>27 February 2019</td>
<td>3.8</td>
<td></td>
<td>28/2</td>
</tr>
<tr>
<td>17 March 2019</td>
<td>4.5</td>
<td>21/3</td>
<td>25/3</td>
</tr>
<tr>
<td>23 April 2019</td>
<td>3.8</td>
<td>29/4</td>
<td>29/4</td>
</tr>
<tr>
<td>20 May 2019</td>
<td>3.9</td>
<td>24/5</td>
<td></td>
</tr>
<tr>
<td>20 June 2019</td>
<td>3.8</td>
<td>25/6, 2/7</td>
<td>23/6</td>
</tr>
<tr>
<td>28, 30 July 2019</td>
<td>3.9, 4.2</td>
<td>27/7, 3/8</td>
<td>28/7</td>
</tr>
<tr>
<td>14 August 2019</td>
<td>3.5</td>
<td>19/8</td>
<td>17/8</td>
</tr>
<tr>
<td>6 September 2019</td>
<td>3.7</td>
<td>13/9</td>
<td>6/9</td>
</tr>
</tbody>
</table>

Fig.3 Atmospherically corrected RGB composite of Landsat-8 acquired on 2 July 2019.
Regarding the specific event, we examined if oil slick was detectable before the earthquake. Both Planet and Sentinel-2 images demonstrated that an oil spill of 8 km total length was also observed on 11 October 2018. Processing of Sentinel-1 image (13 October 2018) using ESA SNAP “Oil spill detection” tool led to oil spill classification over the study area (Fig. 6). However, detection of oil slicks in the northeastern part of gulf highlights that there is need for validation with in-situ observations.

For ocean color study, Chlorophyll-a (Chl-a) maps were created before and after earthquake using Sentinel-2 images (Fig. 7). The mean value of Chl-a was 0.05 mg/m³ on 11 October 2018 and 0.08 mg/m³ on 26 October 2018. Our results are in accordance with in-situ chla
measurements that were collected in the framework of environmental impact study about hydrocarbon exploration in Ionian Sea (HCMR, 2014). Highest Chl-a values were observed in the coastal zone, as satellite tends to overestimate Chl-a concentrations in these areas (reference). Additionally, high Chl-a values were observed in oil spill areas, indicating that there is also a significant overestimation over oil spill regions. Our study confirms former studies (Alpers et al., 2017, Zhao et al., 2014) which indicate that oil spill from biogenic slicks discrimination is still challenging. Blue and Green bands that are used by MedOC3 algorithm cannot discriminate oil from biogenic slicks and different bands have to be used in a future study for oil spill from algal slicks differentiation (e.g FAI Index).

Fig. 6 (a) Sentinel-1 image captured on 13 October 2018 (Amplitude VV). (b) Classification using SNAP “Oil spill detection” Tool.

Fig. 7 Chlorophyll-a concentrations maps using Sentinel-2 data. (a) Image acquired on 11 October 2018. (b) Image acquired on 26 October 2018.

In late July 2019 two successive Landsat-8 and Sentinel-2 images were used to study oil slick spreading, i.e. 27 July (Landsat-8) – 28 July (Sentinel-2). The observed oil slick covered a distance of 4.5 km in 24 hours. It moved in a SE-NW direction and its recorded speed was 0.52 m/s (Fig. 8). Surface currents model outputs (CMEMS) indicated that mean currents velocity was 0.32 m/s with a NE-SW direction (Fig. 7). Southern winds prevailed and the average winds speed was 2.6 m/s.

The specific event confirms that ocean conditions (i.e winds and currents) contribute to oil spill spreading (Zodiatis et al., 2017, De Dominics et al., 2016). However, greater velocities (i.e
1.6 m/s) were recorded in case of Saronikos Gulf, where GNOME oil spill forecasting model was used (Tsiatsiou et al., 2019). Information from forecasting models about oil spill weathering and three-dimensional evolution need additionally to be regarded in a future study.

![Ocean currents velocity and direction for 27 July 2019 (CMEMS after proc.).](image)

**Fig. 8** Ocean currents velocity and direction for 27 July 2019 (CMEMS after proc.).

![Atmospherically corrected RGB composites. (a) Image acquired on 27 July 2019 (Landsat-8). (b) Image acquired on 28 July 2019 (Sentinel-2).](image)

**Fig. 9** Atmospherically corrected RGB composites. (a) Image acquired on 27 July 2019 (Landsat-8). (b) Image acquired on 28 July 2019 (Sentinel-2).

**Conclusions**

In this study we collected high-resolution satellite data from various sensors in order to examine oil spill mapping and spreading in Zakynthos Island. Experimental results showed that between 2018-2019 large oil slicks were recorded after seismic events as the largest was
outlined after strong earthquake measuring magnitude $M_w$ 6.8 in October 2018. Successive satellite images during late July 2019 confirmed that oil spill spreading is affected by ocean parameters (i.e. winds and currents). A detailed comparison between remote sensing and in situ measurements as well as results from oil spill forecasting models need to be included in a future study.

References


