

## Article

# An Open Source Approach for Near-Real Time Mapping of Oil Spills along the Mediterranean Coast of Egypt

Islam Abou El-Magd <sup>1,\*</sup>, Mohamed Zakzouk <sup>1</sup>, Elham M. Ali <sup>2</sup> and Abdulaziz M. Abdulaziz <sup>3</sup>

<sup>1</sup> Environment Division, National Authority for Remote Sensing and Space Sciences, Cairo P.O. Box 1564, Egypt; m.zakzouk@narss.sci.eg

<sup>2</sup> Aquatic Environment Department, Faculty of Fish Resources, Suez University, Suez P.O. Box 35001, Egypt; elham.ali@frc.suezuni.edu.eg

<sup>3</sup> Mining, Petroleum, and Metallurgical Engineering Department, Faculty of Engineering, Cairo University, Giza P.O. Box 12613, Egypt; amabdul@miners.utep.edu

\* Correspondence: imagd@narss.sci.eg; Tel.: +2-02-26251286

**Abstract:** Oil pollution is one of the major critical risks to the Egypt's marine environment due to the heavy traffic caused by shipping in the Suez Canal and the exploration and production of crude oil. Indeed, such frequent oil pollution cases harm to the marine ecosystem and creates pressure on the socio-economic activities within the coastal economic zone of Egypt. Limited data availability creates obstacles to the precise monitoring of oil pollution and the ability to alert the environment agency to take any necessary actions. This research explored the potentiality of developing an open-source model with the use of open-access Sentinel 1 Synthetic Aperture Radar (SAR) data from the European Space Agency to operationally monitor oil pollution at near-real time. As such, early detection and quantification of the volume of pollution creates an early warning system that supports decision makers in clean-up operations and the prosecution of the polluter. The developed model uses an open-source GIS system and Sentinel-1 SAR data to robustly detect and map oil spills and create an a report to alert the appropriate agency of the spill. The model examined a large amount of data, nearly 2000 scenes from the Sentinel 1 SAR sensor, that cover the area of study from 2014 to 2020. The model detected approximately 218 oil pollution cases within this time frame, with about 35% occurring in 2017 alone. The statistical analysis and frequency of oil pollution is mapped near the entrance of Suez Canal and the city of Port Said. This area is known as the anchoring area for the maritime ships that travel via the Suez Canal, and there are also oil and gas production nearby. It was found that the drift direction of the oil spills near Port Said move southwards, which creates a hazard for local fishing activities, Port Said touristic beaches, and marine ports. This model is the scientific and practical solution for the city council and the environmental agency to continuously monitor and receive alerts regarding any oil pollution cases in order to protect the coastal and marine socio-economic ecosystem and maintain sustainability.

**Keywords:** synthetic aperture radar; open source; oil spills; Suez Canal; Mediterranean Sea



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## 1. Introduction

### 1.1. Background

Oil pollution is the discharge of liquid petroleum hydrocarbons into the marine environment by means of man-made activities [1]. It represents a serious threat to the marine ecosystem and coastal infrastructure. In many oil pollution cases, waste oil, oily ballast water, and other refined petroleum products such as gasoline and their by-products are released from shipping vessels. Many research studies correlated the frequency of oil spills with main shipping routes, where they found that frequent spills happen along these routes [2]. The only accepted oil discharges are below 15 ppm to prevent spills but that is not enough to prevent the impact of pollution [3]. Light, volatile oil molecules evaporate quickly and oxidize, the product of which is highly toxic. Heavy oils are less

toxic but remain in the eco-system for a long time, especially if they become mixed with the pebbles and sand along the beaches. Oil spills may severely reduce the populations of phytoplankton and aquatic organisms.

Remote sensing technologies provide an effective tool to map oil spills in the marine environment at a low cost [4]. Space-borne optical and Synthetic Aperture Radar (SAR) data can be used to scan large water mass areas for possible oil spills, and aircrafts can then verify the spill and polluter source [4]. While space-borne optical sensors are limited to daylight and clear weather conditions, SAR data can be used during both day and night and is unaffected by clouds [5]. Unfortunately, it is difficult to detect oil spills through fog and dark conditions, however, SAR resolves this problem since it emits and receives microwave radiation, which is not affected by weather conditions [2].

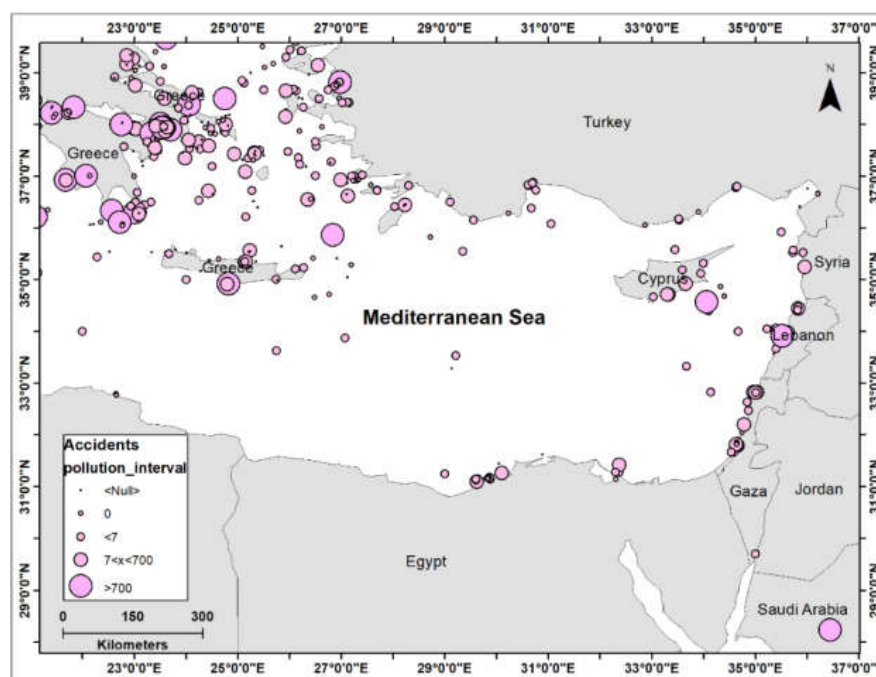
Egypt has a long coastal marine environment that extends for more than 3300 km that is at risk of oil pollution. While there is a challenge to meet the growth in shipping activities in the Mediterranean Sea, the monitoring tools developed by environmental policy makers and practitioners keep an eye on the possible risks from oil pollution and help them take necessary actions. The key limitation is the oil spills are dynamic and quick to disappear, so it is very difficult to confirm through field visits. Therefore, space-borne satellite images are an efficient solution that help safeguard the environment through fast detection, mapping, and reporting of the spills for quick action. The precise detection of oil spills is important in clean-up operations to reduce the negative impact on the environment and to prosecute the polluter. Employing satellite-based technologies and open-source software is a new approach that could efficiently support this challenge in developing countries. The study adopted this approach to use open-source and time-series Synthetic Aperture Radar data to map all possible oil spills that happened from 2014–2020 and on a daily basis within in the last 4 years along the Mediterranean coast. The development of an open- source toolkit able to map and monitor oil spills that could support local authorities and environmental agencies in Egypt is anticipated. This research introduces a scientific and practical solution for city council and the environment agency to robustly and operationally monitor and receive alerts of any oil pollution to protect the coastal and marine socio-economic ecosystem and to maintain sustainability.

### 1.2. Literature Review

Historically, oil spill emergency cases are managed by the Egyptian Environmental Affairs Agency (EEAA) in Egypt's coastal environment at least four times a year [6]. For example, in 2004 at the Sidi Kerir Port Terminal, the Good Hope ship lost nearly 1000 tons of light crude oil while loading. In the same year, 9000 tons of Kuwait medium crude oil was lost in the Samidoon incident at the Suez Canal. The Suez Canal Authority took over the situation to recover the oil using booms and skimmers. During the period of 2004–2014, Petrosafe, an oil spill responder company, responded to more than 50 oil spill cases in Egypt. Despite the laws, conventions, and the national oil spill contingency plan, there is still no proper tool to monitor drilling activities and tanker transit pollution.

Previous research studies estimate that the total volume of oil discharge in the Mediterranean Sea ranges from 1600 to 1,000,000 tons per year [7]. In 2011, the Regional Marine Pollution Emergency Response Center for the Mediterranean Sea (REMPEC) reported that the oil released in the Mediterranean Sea for the period 1977–2010 was greater than 100 tons and was geographically distributed as follows: Greece (30%), Italy (18%), and Spain (14%) as the main countries followed by Egypt (8%), Algeria (6%), Lebanon (6%), and others (12%) [8]. When correlated with maritime traffic, it is consistently correlated. Most of the reported accidents are grounding (21%), collisions (17%), explosions (14%), cargo transfer failure (11%), and sinking (9%). CleanSeaNet is an oil spill and vessel detection service provided by the European Maritime Safety Agency (EMSA) that analyzes available Synthetic Aperture Radar (SAR) images and the information retrieved, including spill location, area, length, possible source of pollution, and the confidence level of detection, particularly for European countries [9].

Figure 1 shows a map of pollution that occurred in the Mediterranean Sea, which was developed based on the database of the Mediterranean Integrated Geographical Information System on Marine Pollution Risk Assessment and Response (MEDGIS-MAR) [8]. Oil pollution is classified into three categories: less than 7 tons, from 7 to 700 tons, and more than 700 tons. The analysis of this database shows that many cases of oil pollution of the 7–700-ton size were near the Nile Delta during the period of 1990–2013, while only 5 cases were recorded between 60–350 tons and were related to tankers. Table 1 lists 24 incidents recorded for Egyptian waters extracted from the MEDGIS-MAR database.



**Figure 1.** Oil accidents in the eastern Mediterranean Sea during the period of 1990–2013 classified into 3 classes: less than 7 tons, from 7 to 700, and more than 700 tons [8].

**Table 1.** 24 large oil spills in the Mediterranean waters of Egypt [8].

Date	Location	Accident Type	Pollution Size	Ship Name, Type
1 September 1982	Alexandria	Grounding	0	NORTRANS ENTERPRISE, Bulk carrier
31 May 1987	Sidi Kerir term.	Cargo transfer failure	60	VERGO, Oil tanker
8 August 1987	Suez Canal	Grounding	<7	PEACEVENTURE L., Oil tanker
30 March 1989	Sidi Kerir	Cargo transfer failure	300	ESSO PICARDIE, Oil tanker
14 April 1992	Sidi Kerir	Cargo transfer failure	200	OLYMPIC STAR, Oil tanker
27 October 1992	Port Said	Collision	350	SOHEIR, Oil tanker
9 November 1992	Sidi Kerir	Other	<7	ROSARIO DEL MAR, Oil tanker
21 February 1993	Off Sidi Kerir	Engine breakdown	<7	CARLOVA, Oil tanker
2 July 1994	Alexandria	Grounding	<7	SEAOATH, Oil tanker
30 October 1995	Alexandria	Grounding	<7	CAPO ARGENTO, LPG carrier
18 October 1997	Off Port Said	Other	<7	IRVING GALLOWAY, Oil tanker
6 May 2000	Abo-Qir bay, 6 km from Alexandria	Sinking	322	DALIA S., General cargo
17 June 2000	Alexandria port	Other	<7	CAPTAIN FOUAD, General cargo
21 June 2013	Port Said	Contact	0	MSC PERLE, Container carrier
10 May 2013	Port said	Other	0	CMA CGM ONYX, Container carrier
13 September 2013	Alexandria	Other	1	AHMAD-M, General cargo
26 April 2017	Alexandria, Egypt	Fire or explosion		RINELLA M, Oil tanker
10 October 2014	2.4 nautical miles from El Dakheila	Grounding	0	LONG BRIGHT
21 May 2017	Idku, Egypt	Grounding		SCHILLPLATE, General cargo
19 May 2016	140.389 off Alexandria	Other	1	Oil/bulk/ore Tug boat
6 March 2015	11.5 miles south-west of the island of Kythira	Engine or machinery breakdown	0	FT ODIN, Any other type
12 June 2015	Alexandria Port	Other	1	ALEX
12 March 2014	Alexandria (EGY) inner anchor	Engine or machinery breakdown	0	GENCO RELIANCE
16 March 2014	Alexandria	Hull structural failure	0	CEYLAN

Another comprehensive research study conducted by the Joint Research Center (JRC) [10], added more results to the REMPEC tool, as it included the small spills from ships, as shown in Figures 2 and 3. From this JRC research study, nearly 19,000 SAR images were processed, and more than 9000 possible oil spills could be mapped in the waters of the Mediterranean Sea between 1999 and 2004. The results are consistent with the main ship navigation pathways in the Mediterranean Sea.

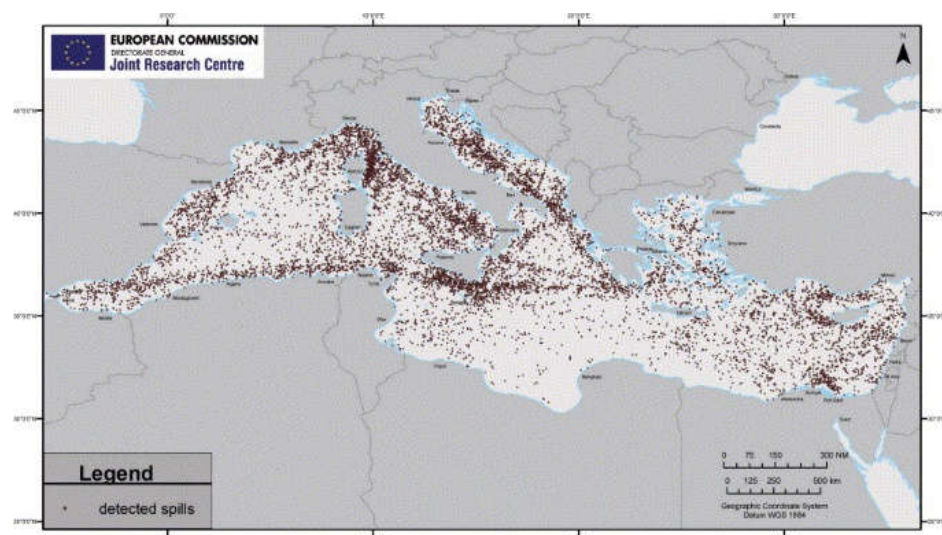


Figure 2. Possible oil spills in the Mediterranean Sea detected between 1999 and 2004—[10].

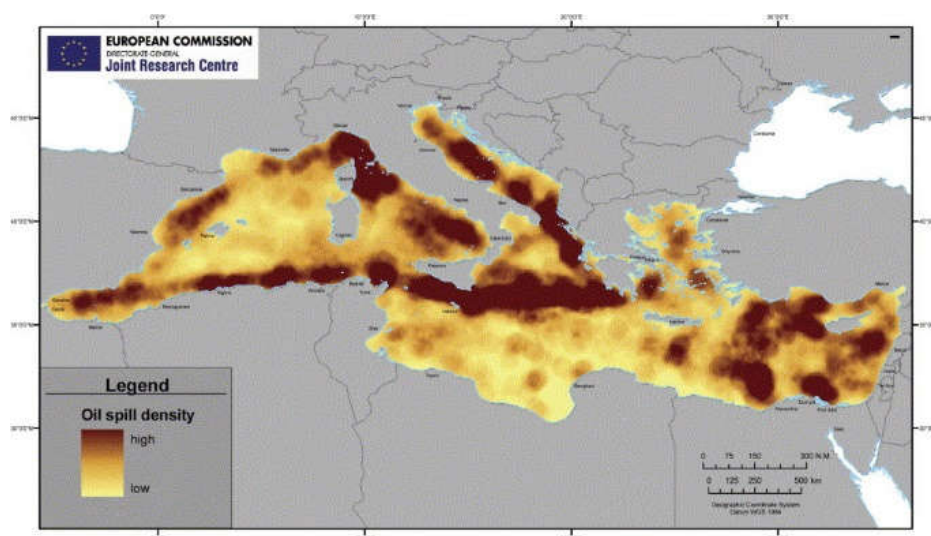


Figure 3. Oil spill density in the Mediterranean Sea [10].

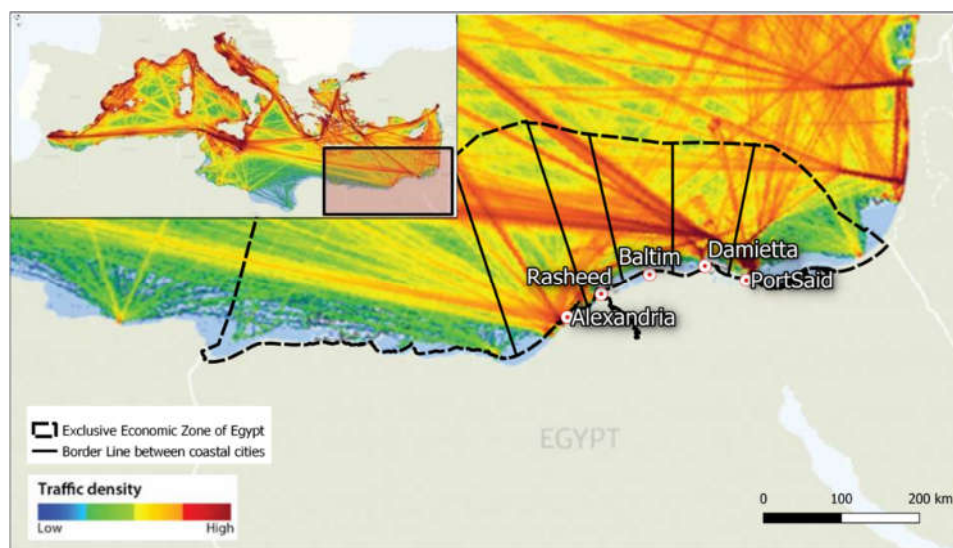
Moreover, a research study carried out by the Cyprus Oceanography Center to map oil spills around Cyprus in the period of 2007–2011 detected more than 1000 oil slicks that were related to ship navigation pathways (Figure 4) [11]. It is expected that Egyptian coastal waters might have had the same hazards during that period. Unfortunately, limited research studies are available on the oil spills in the coastal zone of Egypt along the Mediterranean Sea despite the high probability of pollution related to dense traffic and oil exploration and production. Therefore, this research was carried out to explore the potentiality of developing tool using SAR data and open-source software to support the environmental agency in monitoring oil pollution.



## 2. Materials and Methods

### 2.1. Study Area

The area of study is the Mediterranean Sea coastal waters of Egypt from Port Said and the Suez Canal to Marsa Matruh. This area is occupied by the five major cities of Alexandria, Rasheed, Baltim, Damietta, and Port Said together with the major sea ports at Damietta and Alexandria. This area is exposed to extensive marine shipping and both oil and gas exploration and production activities. The Mediterranean Sea is considered to be the busiest among the world seas in maritime traffic (Figure 4) [12].



**Figure 4.** Density of maritime traffic in the Mediterranean Sea in 2017 [12].

### 2.2. Methodology

Radar sensor is the effective tool for oil detection, as it senses oil during both the day and night and under any weather condition. In fact, oil spills on the sea surface dampen the capillary waves making lower backscatter than the surrounding clean seawater surface [13]. This enables the oil to be detected as a dark spot surrounded by a bright background. The challenge is that there are many other sources that can also produce similar dark spots in the image, including calm water areas with no capillary waves, rain cells, seaweed that calms the water above it, freshwater slicks, and whale and fish sperm [14].

This research used the radar data captured in the C band at incidence angles around  $20^\circ$ , which is suitable for sea imaging. The magnitude of backscatter increases with the wind, as it is directly affects the number of capillary waves [15].

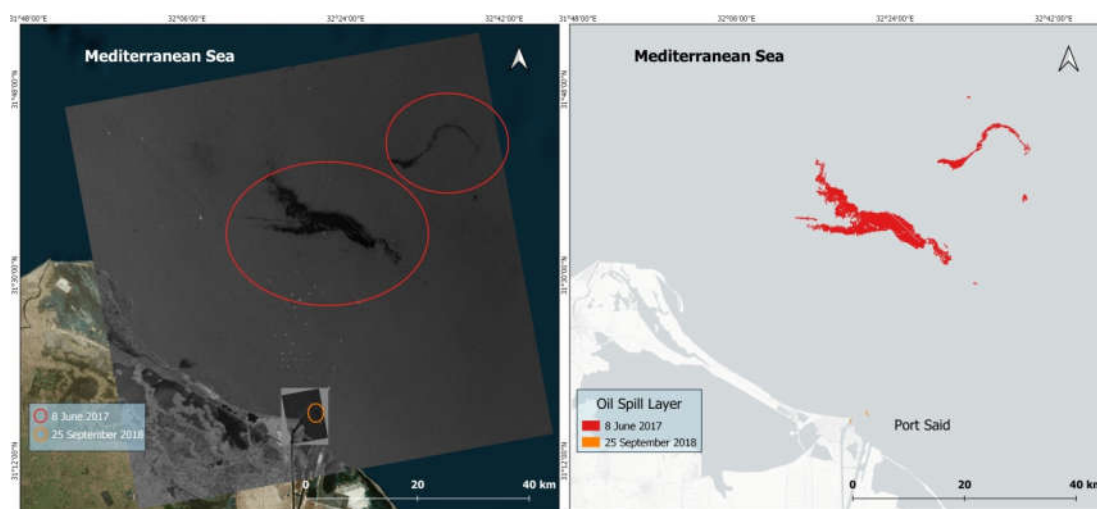
This research is building on the model developed by El-Magd et al. [1] and is improved to be integrated with open-source software and robustly uses the Sentinel Application Platform (SNAP) toolbox to initially process Sentinel-1 SAR data to detect and map oil spills as a raster image, as shown in Figure 5 (left), which is consequently masked to a separate raster celled area, Figure 5 (middle). Q-GIS is then used to convert the raster image into a vector layer for further spatial analysis, as shown in Figure 5 (right). This research developed the model to operate sequentially and robustly to implement these operations for the near real-time or real-time detection of oil spills and to create early warning alerts.



**Figure 5.** Left—is the preprocessed raw data: result after speckle filtering and geometric correction. Middle—is the masked oil spill area after processing and clustering the SAR image based on a predefined threshold of 2 decibel. Right—is the vector conversion of the raster oil spill mask to be enable area and other geographical calculations.

### 3. Results

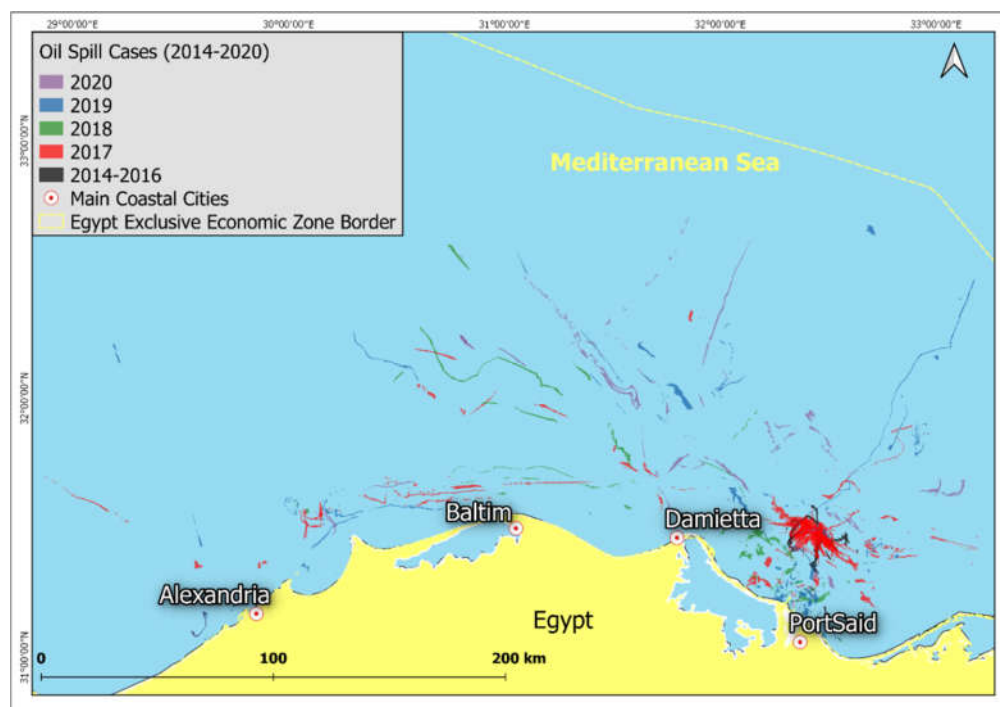
Since 2014, initial online exploration of nearly 2000 Sentinel-1 images covering the area of study was completed using the Sentinel hub EO browser and Google Earth Engine to visually check any dark spots. This step filtered the exploration to a set of 116 scenes that are suspected of probable oil spills. The model was then applied onto these 116 scenes to detect the actual oil spills. The model detected about 218 cases of dark spots that represent oil spills. The total area of these oil spill cases is 1964 km<sup>2</sup>, which is distributed near the coastal cities and marine ports. The model is capable of detecting any size of oil spill, from large oil spill cases, such as the spill on 8 June 2017 that covered nearly 94 km<sup>2</sup>, to the smallest oil spill case, such as the one on 25 September 2018 covering only 0.3 km<sup>2</sup> (Figure 6). The largest oil spill case is near the anchoring area of the ships that travel through the Suez Canal, however it is also near four oil platforms for oil and gas production, and it might be any of them that are the source of pollution. However, the smallest oil spill is at the entrance of the Canal, and its detection is very important.



**Figure 6.** The capability of the model to detect the largest oil spill event near the entrance of the Suez Canal at Port Said city, which happened on 8 June 2017, with an actual mask of the oil layer with an area equals 94 km<sup>2</sup> and the smallest oil spill event detected, which happened on 25 September 2018, at the Canal entrance with an area of 0.3 km<sup>2</sup>.

The model enabled the development a spatial geodatabase of the recorded frequency of oil pollution cases. Figure 7 shows the location of the total cumulative 218 pollution cases within the time frame of 2014–2020. Nearly 187 out of the 218 cases occurred between 2017 and 2019. Table A1 lists all of the information about the 218 oil spill cases including their dates, the nearest city, their frequencies, and source of data. It can be clearly observed that the majority of these oil spill cases are near the city of Port Said and the entrance of

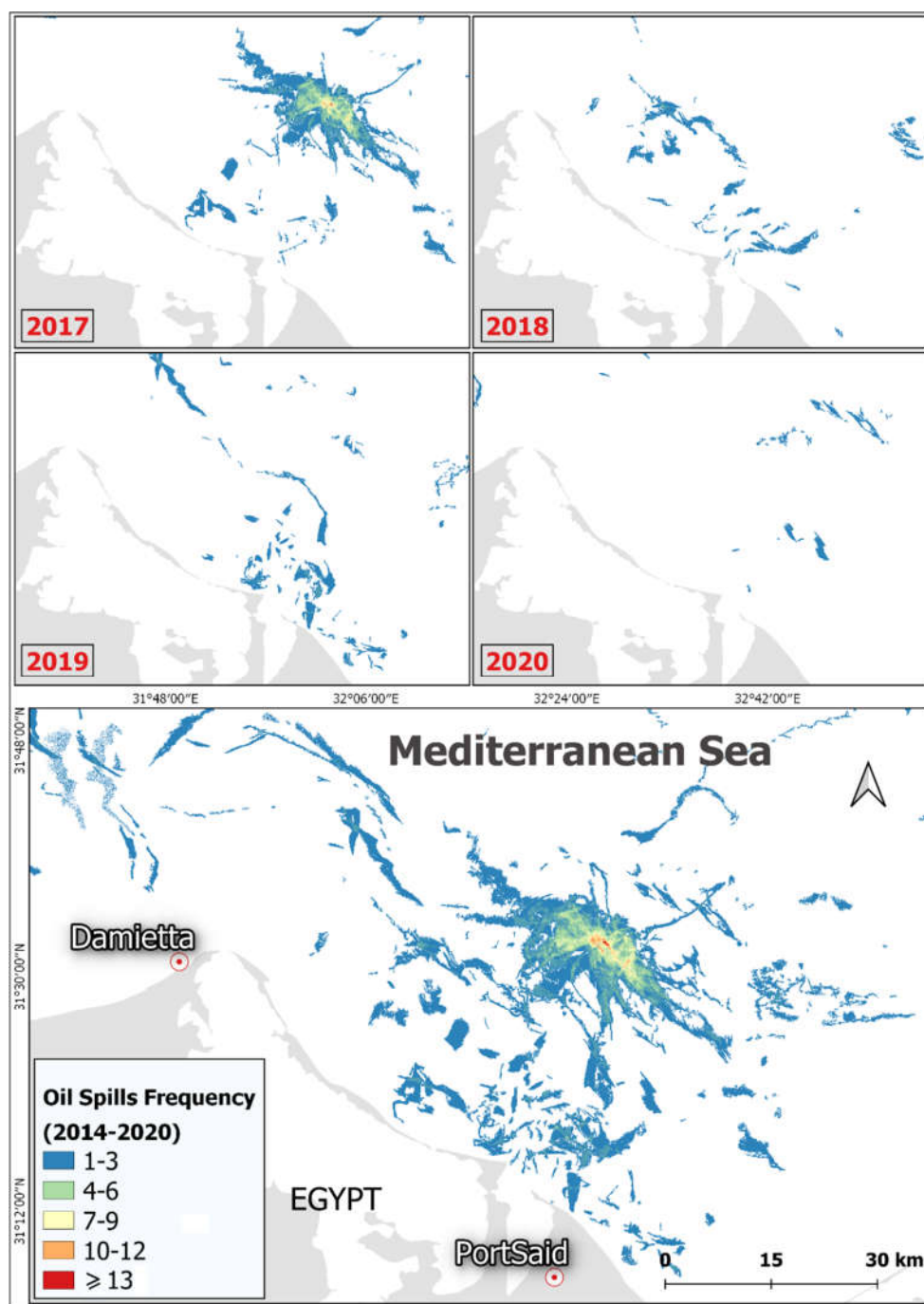
Suez Canal. The location of these oil spill cases reflects that maritime shipping and the pathway to Suez Canal play key role in such oil pollution cases. Through geometrical analysis of these cases, it was found that most of the detected incidents have a longitudinal shape, whether horizontal, vertical, or in between, which indicates that the discharges occurred while the vessels were moving. That result confirms the literature, which indicates that discharge from ships represents the largest ratio of all pollution sources [2]. Horizontal spills that have an east-west orientation may refer to local ships moving near the coast, and vertical spills with a north-south orientation might indicate discharges from international ships.



**Figure 7.** Spatial distribution of the cumulative frequency of 218 oil spill cases detected along the Egypt Mediterranean coast in the period from 2014 to 2020.

In the analysis of spill coverage areas, there are many oil pollution cases (about 84) in the range of 0.3–10 km<sup>2</sup>, which are small and might give an indication that no attention should be paid to it. However, it is important that these small sized cases be monitored since they cover large areas, in total reaching 253 km<sup>2</sup>, and they appear frequently.

The model enabled the statistical analysis of the frequency of oil pollution cases in this period in total and on a yearly basis (Figure 8). It is obvious that 2017 has the highest frequency of repeated oil pollution cases in comparison to 2018, 2019, and 2020. The majority of high frequency cases are also near Port Said City, which is to ship anchoring area and the oil and gas platforms. This means that this area is at high risk of regular oil pollution and that it needs further attention and action plans to minimize the frequency.

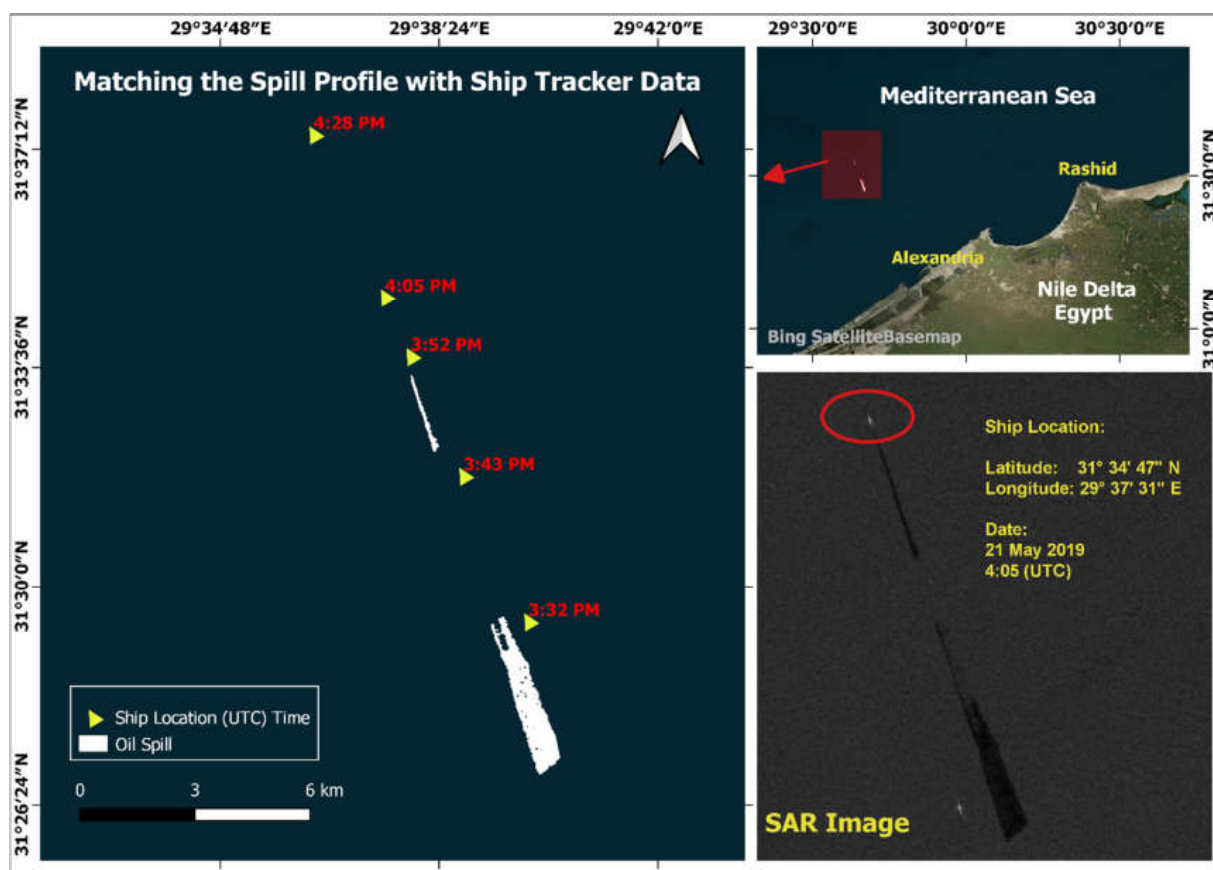


**Figure 8.** Frequency of oil spills cases on locational dimension near Port Said on a yearly basis that shows the majority of oil spill cases are near Port Said between 2017 and 2019.

#### 4. Validation

On 21 May 2019, a small spill was detected near the Alexandria Port with a bright spot at the tip of the longitudinal dark patch, as shown in Figure 9. The longitudinal pollution pattern and the bright spot are strong evidence that the pollution source is a mobile ship. When this dark spot was validated against the maritime shipping traffic database, it was confirmed with the pathway of an oil tanker that was in the area at the same time and along the same route as the dark spot. This database enabled the viewing of the movement location of the ship and the longitudinal shape of the dark spot. Therefore, the integration between the maritime shipping traffic database with oil spill model monitoring is important to identify manner whether the source of pollution is a ship or not in a timely.





**Figure 9.** Inter-correlation between longitudinal oil spill case detected by the model near Alexandria City on 21 May 2019 @ 4:05 UTC and the location and direction of the movement of a maritime ship. This enabled the identification of the source of the pollution as the ship.

## 5. Discussion

Limited research has been conducted on the oil spill monitoring of Egyptian waters using remote sensing despite being part of the most crowded seas in the world. For example, El-Magd et al., used hyperspectral imaging to define the spectral profile of oil spills in the Nile River [16]. Recently, Kostianoy et al., and Kostianaia et al., mapped part of the spills in the Mediterranean and Red Sea using SAR for the period of 2017 to 2019 [17,18]. This motivated us to develop a model on a scientific basis that was capable of detecting and mapping oil spill cases and analyzing them. Oil spills in the Mediterranean Sea of Egypt frequently occur and vary in size, from small to large oil coverage. Most of them are likely due to illegal ship discharges or/and oil and gas exploration and production. The frequency, shape, and pattern is more likely indicative of the source. To monitor such a large marine environment for oil pollution, there is a need of a regular source of information and an efficient tool to keep an eye on and record all oil spill cases. The developed model in this research provided an efficient tool to monitor the oil spills in the Mediterranean marine environment of the coastal zone of Egypt on a daily basis. Statistical distribution of the recorded 218 cases to explore the proximity to the coastal cities, and activities show that the majority of oil spills are near the marine ports. Port Said City and the entrance of the Suez Canal have the highest frequency of oil spills, with nearly 136 cases that are correlated with the anchoring area of the maritime traffic ships and at the proximity to for oil and gas platforms. Table 2 summarizes the number of oil pollution cases with proximity to the main coastal cities, which area mainly occupied by marine harbors. The number of oil pollution cases increase from west to east, with the minimum recorded cases being near Matrouh (this is not a traffic heavy harbor), the medium frequency cases near Alexandria,

Baltim, and Damietta, with an exponential increase toward Port Said City and the entrance of Suez Canal. However, there is an obvious increase at the entrance of Suez Canal after the launch of the new canal in 2015, but this kind of correlation requires further long term study to understand if the launch of the new canal plays a role or not.

**Table 2.** Number of oil spill accidents for Egypt's main coastal cities.

City	Number of Processed Scenes	Total Pollution Area (km <sup>2</sup> )	Number of Pollution Cases
Port Said	71	1107	136
Damietta	13	386	27
Baltim	15	229	23
Rasheed	10	158	20
Alexandria	6	71	11
Marsa Matruh	1	13	1
Total	116	1964	218

The highest frequency of oil cases recorded are close to the maritime shipping route to the Suez Canal and is in agreement with the historical study done by JRC [10]. The shape and geometry of the oil spills are clearly indicative of shipping as a major source of oil pollution. This is also in agreement with the high shipping traffic in the Mediterranean Sea and the number of vessels that pass into the Suez Canal. Moreover, oil exploration and production plays another role in oil pollution, and the largest oil spill recorded in 2014 was close to four platforms of oil production. Therefore, the circular or the irregular shape of oil pollution is also an indication of the source of oil production.

## 6. Conclusions

In conclusion, historically and contemporarily, oil pollution in the Mediterranean Sea is very high, with multiple sources, including maritime shipping or oil and gas exploration and production. Monitoring such oil pollution cases is necessary to take action against the polluter and to respond quickly to remediate the environment. Egyptian coastal water is under a high risk of high pollution, however there is no regular near-real time or real-time monitoring system for oil pollution. The limited research in this area is the motivation of this research, which explored the development of an open-source model using Sentinel 1 SAR data to create an visual of the marine environment and is capable in detecting and mapping oil spill cases. The model detected about 218 oil pollution cases with nearly 2000 km<sup>2</sup> of oil pollution areas within the area of study in the last few years. Geographically, the model mapped the frequency of oil pollution within the dimensions of time and space, which showed that the area near the north exit of the Suez Canal at Port Said City has the highest frequency of oil spills due to the proximity to the anchoring area for ships and platforms for oil and gas production. Due to the absence of aerial surveillance in most of developing countries, there is an inability to regularly monitor oil pollution and spot the polluter. The availability of Sentinel 1 SAR data due to free data access by the European Space Agency is an effective source of information that enables the model to continue looking at the marine environment on a daily basis. More efficiently, the integration with the maritime shipping traffic database could enable to correlate the source oil pollution with the source ships using the ship tracker database. This was validated with one oil pollution case detected on 21 May 2019. With the increasing load of petroleum activities in the Mediterranean waters of Egypt, an increase of the risk of serious incidents will occur, so environmental capabilities to monitor oil pollution in the economic water zone should be developed. The presence of a near real-time monitoring system will decrease the rate of pollution cases itself, as the polluter will be careful in order to avoid penalization in response to the Egyptian Environmental Act, which is the novelty of this research. Finally, the use of SAR and open-source data is an effective approach to detect oil spill incidents and approximate the covered area and to create a report for contingency plans and hazard

mapping. This model could be adopted by the Environmental Agency for a warning system and alarm for oil spill cases as a near-real-time service, which can help to find the responsible ship or/and platform. The developed model might need a further validation mechanism at an acceptable level of confidence.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

**Table A1.** Detailed database generated from the model with all detected oil spills in the area of study from Sentinel-1 SAR data between 2014 and 2020.

ID	Date	Nearest City	Area (km <sup>2</sup> )	Frequency	Data Source
1	4 October 2014	Port Said	26.41	1	Sentinel-1
2	2 April 2015	Port Said	4.01	1	Sentinel-1
3	19 April 2015	Port Said	24.15	1	Sentinel-1
4	26 April 2015	Port Said	11.33	1	Sentinel-1
5	19 July 2015	Port Said	6.22	1	Sentinel-1
6	6 August 2016	Port Said	17.6	1	Sentinel-1
7	3 January 2017	Port Said	7.83	1	Sentinel-1
8	16 January 2017	Baltim	8.22	3	Sentinel-1
9	20 January 2017	Baltim	25.02	2	Sentinel-1
10	21 January 2017	Port Said	4.24	1	Sentinel-1
11	2 February 2017	Port Said	13.01	1	Sentinel-1
12	6 February 2017	Alexandria	6.95	1	Sentinel-1
13	7 February 2017	Port Said	1.11	1	Sentinel-1
14	8 February 2017	Port Said	2.51	1	Sentinel-1

Table A1. Cont.

ID	Date	Nearest City	Area (km <sup>2</sup> )	Frequency	Data Source
15	9 February 2017	Port Said	5.14	1	Sentinel-1
16	19 February 2017	Rasheed	58.69	3	Sentinel-1
17	20 February 2017	Port Said	2.67	1	Sentinel-1
18	26 February 2017	Port Said	2.29	1	Sentinel-1
19	4 March 2017	Port Said	12.35	3	Sentinel-1
20	10 March 2017	Port Said	5.91	2	Sentinel-1
21	29 March 2017	Port Said	10.89	1	Sentinel-1
22	3 April 2017	Port Said	16.73	3	Sentinel-1
23	8 April 2017	Port Said	26.19	2	Sentinel-1
24	9 April 2017	Port Said	12.42	2	Sentinel-1
25	15 April 2017	Baltim	10.05	1	Sentinel-1
26	21 April 2017	Port Said	30.28	1	Sentinel-1
27	22 April 2017	Port Said	17.12	3	Sentinel-1
28	27 April 2017	Port Said	12.09	2	Sentinel-1
29	2 May 2017	Rasheed	12.04	2	Sentinel-1
30	3 May 2017	Port Said	19.88	1	Sentinel-1
31	9 May 2017	Port Said	79.32	1	Sentinel-1
32	16 May 2017	Port Said	64.65	3	Sentinel-1
33	21 May 2017	Port Said	39.75	1	Sentinel-1
34	26 May 2017	Port Said	28.22	1	Sentinel-1
35	27 May 2017	Port Said	16.96	2	Sentinel-1
36	1 June 2017	Damietta	22.53	2	Sentinel-1
37	2 June 2017	Port Said	7.83	1	Sentinel-1
38	8 June 2017	Port Said	93.98	2	Sentinel-1
39	8 July 2017	Port Said	18.01	1	Sentinel-1
40	9 July 2017	Port Said	5.11	1	Sentinel-1
41	15 July 2017	Port Said	38.27	2	Sentinel-1
42	20 July 2017	Port Said	21.16	1	Sentinel-1
43	25 July 2017	Baltim	16.86	2	Sentinel-1
44	26 July 2017	Baltim	12.28	1	Sentinel-1
45	13 August 2017	Baltim	15.08	1	Sentinel-1
46	26 August 2017	Damietta	6.56	2	Sentinel-1
47	13 September 2017	Baltim	13.16	1	Sentinel-1
48	29 September 2017	Rasheed	6.5	1	Sentinel-1
49	1 October 2017	Port Said	3.71	3	Sentinel-1
50	15 November 2017	Alexandria	19.53	2	Sentinel-1
51	30 December 2017	Port Said	29.87	2	Sentinel-1
52	9 January 2018	Damietta	45.22	3	Sentinel-1
53	10 January 2018	Port Said	9.08	3	Sentinel-1
54	28 January 2018	Port Said	20.73	3	Sentinel-1
55	15 February 2018	Baltim	49.68	1	Sentinel-1
56	28 February 2018	Baltim	18.06	3	Sentinel-1
57	5 March 2018	Port Said	9.71	1	Sentinel-1
58	17 March 2018	Port Said	3.36	3	Sentinel-1
59	18 March 2018	Port Said	2.36	1	Sentinel-1



Table A1. Cont.

ID	Date	Nearest City	Area (km <sup>2</sup> )	Frequency	Data Source
60	23 March 2018	Rasheed	3.43	1	Sentinel-1
61	28 April 2018	Baltim	16.3	2	Sentinel-1
62	3 May 2018	Port Said	22	5	Sentinel-1
63	21 May 2018	Rasheed	7.05	3	Sentinel-1
64	22 May 2018	Port Said	7.59	3	Sentinel-1
65	3 July 2018	Port Said	8.63	1	Sentinel-1
66	27 August 2018	Damietta	11.25	2	Sentinel-1
67	19 September 2018	Baltim	12.53	2	Sentinel-1
68	20 September 2018	Port Said	1.8	2	Sentinel-1
69	25 September 2018	Port Said	0.3	2	Sentinel-1
70	18 November 2018	Port Said	3.42	3	Sentinel-1
71	19 November 2018	Port Said	18.01	1	Sentinel-1
72	10 January 2019	Port Said	2.46	1	Sentinel-1
73	6 February 2019	Alexandria	20.46	3	Sentinel-1
74	23 February 2019	Port Said	27.42	4	Sentinel-1
75	18 March 2019	Port Said	4.61	1	Sentinel-1
76	4 April 2019	Rasheed	21.02	1	Sentinel-1
77	5 April 2019	Port Said	4.68	1	Sentinel-1
78	6 April 2019	Port Said	4.42	2	Sentinel-1
79	11 April 2019	Port Said	2.16	1	Sentinel-1
80	18 May 2019	Port Said	2.05	1	Sentinel-1
81	21 May 2019	Alexandria	4.64	1	Sentinel-1
82	22 May 2019	Port Said	1.31	3	Sentinel-1
83	23 May 2019	Port Said	19.86	2	Sentinel-1
84	16 June 2019	Rasheed	6.08	2	Sentinel-1
85	4 July 2019	Port Said	1.06	2	Sentinel-1
86	11 July 2019	Port Said	12.12	3	Sentinel-1
87	23 July 2019	Port Said	7.06	4	Sentinel-1
88	4 August 2019	Port Said	19.28	2	Sentinel-1
89	10 August 2019	Port Said	9.24	2	Sentinel-1
90	21 August 2019	Port Said	24.92	4	Sentinel-1
91	22 August 2019	Damietta	31.35	5	Sentinel-1
92	27 August 2019	Port Said	1.83	2	Sentinel-1
93	27 August 2019	Alexandria	7.79	2	Sentinel-1
94	28 August 2019	Damietta	51.64	2	Sentinel-1
95	21 September 2019	Port Said	41.33	1	Sentinel-1
96	1 October 2019	Rasheed	15.88	4	Sentinel-1
97	2 October 2019	Port Said	12.02	5	Sentinel-1
98	8 October 2019	Damietta	17.73	2	Sentinel-1
99	20 October 2019	Port Said	1.79	3	Sentinel-1
100	1 November 2019	Rasheed	16.93	2	Sentinel-1
101	7 November 2019	Port Said	0.69	1	Sentinel-1
102	24 March 2020	Damietta	29.55	1	Sentinel-1
103	30 March 2020	Baltim	8.11	1	Sentinel-1
104	22 April 2020	Alexandria	12.16	2	Sentinel-1

Table A1. Cont.

ID	Date	Nearest City	Area (km <sup>2</sup> )	Frequency	Data Source
105	24 April 2020	Damietta	7.11	4	Sentinel-1
106	29 May 2020	Baltim	8.05	1	Sentinel-1
107	12 June 2020	Baltim	8.05	1	Sentinel-1
108	17 June 2020	Damietta	9.1	1	Sentinel-1
109	5 July 2020	Baltim	7.62	1	Sentinel-1
110	28 July 2020	Damietta	19.05	1	Sentinel-1
111	20 August 2020	Marsa Matruh	12.68	1	Sentinel-1
112	26 August 2020	Rasheed	10.24	1	Sentinel-1
113	27 September 2020	Damietta	69.42	1	Sentinel-1
114	21 October 2020	Damietta	65.33	1	Sentinel-1
115	26 October 2020	Port said	21.16	3	Sentinel-1
116	27 October 2020	Port Said	39.59	5	Sentinel-1
Sum	116 Dates		1964 km <sup>2</sup>	218 Spill	

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