USING REMOTE SENSING FOR PLASTIC DEBRIS MONITORING IN THE EGYPTIAN NORTHERN COAST

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ABSTRACT

Accumulation of plastic debris in water bodies has recently become a global concern, where the hotspots are being affected by a flow of toxic plastics from different sources. This study applied a science-based methodology for monitoring and assessment of macro plastic debris in the shoreline and sea surface of a pilot Egyptian Mediterranean site. Optical spectral of **Sentinel-2 and Planet scope images** were examined using a combination of different spectral bands with several indices and verified by the pixel-value classification method of **Sentinel-2 images**. Further, microwave remote sensing (Sentinel-2, SAR sensor) was analyzed to add more information to the optical study. Quantitative field measurements of marine debris were applied using UNEP/MAP metadata to support satellite results. This study found that 82% of beach accumulated materials were artificial polymers and that classification image was the most precise technique that reflects the real variety of different features. The overall accuracy of plastics detection and identification using remote sensing techniques reached about 70-80%.

INTRODUCTION

Marine debris is a complex, multisectoral cultural problem that impacts ecological, economic, and social sectors around the globe **(Shevealy, *et al.* 2012).** Artificial polymers (i.e., plastics) are considered one of the main materials concerning marine debris **(Pawar, *et al*., 2016)** and a universal problem polluting the world's waterways **(Norden and Karlsson, 2018).**

The debris consists of different low degradable items **(Allsopp, *et al.*, 2006)** that have been purposely discarded into the sea, or on beaches; brought indirectly to the sea by rivers, sewage, stormwater, or winds; or accidentally lost, including material lost at sea in bad weather (**Galgani, *et al.*, 2015**). The durability and resilience characteristic of plastics in water bodies mainly resulted from their long degradation time which can reach thousands of years **(Sheavly and Register, 2007)**. However, some plastic items over time are broken up into micro-plastics and smaller fragments **(Eriksson and Burton, 2003).**

Plastic debris poses serious threats to marine wildlife through different forms such as entanglement and ingestion, as well as habitat alteration, degradation, or destruction **(Shevealy, *et al.*, 2012).** Physical hazards associated with plastics in aquatic environments and chemical contaminants present immediate and chronic threats to both aquatic and terrestrial food webs **(Melanie, *et al*., 2015).** Many of these pollutants are known endocrine disruptors and developmental toxicants **(Koelmans, *et al.*, 2014).**

Tracking of plastic hotspots in marine environment recently become a necessary part for assessing the extent and possible impact of their accumulation **(Moya, *et al.*, 2018)** and reaching quantifiable targets for reducing marine debris based on scientific assessment of their impacts **(Shevealy, *et al*., 2012).** Satellite images can support measuring trends about anomalous events **(Martínez-Vicente, *et al.*, 2019)** that could have a significant impact on the economy (**Geyer, *et al*., 2015**) and provide uniform observation coverage of large areas of the ocean and shorelines (**Maximenko, *et al.*, 2016).**

Plastic polymers have strong signatures on many wavelengths that contrast them to seawater and other natural objects **(Maximenko, *et al.*, 2016).** Several studies have proved that Sentinel-2 satellite images were effective in identifying plastic clusters in the sea (**Themistocleous, *et al.*, 2020**). Floating macro-plastics can be identified within mixed aggregations in the marine environment using a spectral signature **(Biermann, *et al.*, 2020).**

This study examined an application for monitoring macro-plastic debris using space-based information as a large-scale ground coverage method in parallel within situ fieldwork surveys in El-Shatby beach, Alexandria governorate (one of the Egyptian Mediterranean coastal areas).

MATERIALS AND METHODS

Based on recent scientific research, remote sensing capabilities were applied to support the results of the field measurements concerning monitoring of macro plastic debris accumulation for further analysis. Optical sensors of Sentinel-2 and Planet imagery with spectral detection in the electromagnetic spectrum (functionally invisible bands (Red, Green, and Blue), Near-InfraRed band (NIR)) were studied, as in Table 1.

Table 1 Wavelength range of Sentinel-2 and Planet satellites (blue, green, red, and NIR) spectral bands

Bands Color	Sentinel-2 (nm)	Planetscope (nm)
Blue	448–546	455 – 515
Green	537–583	500 – 590
Red	545–583	590 – 670
NIR	763–909	780 – 860

Microwave remote sensing (Synthetic Aperture Radar (SAR) Sensor) was also examined for the same specified area of interest (AOI). Synchronous field surveys dates for data collection in the (AOI) with space-based data captured by satellites were implemented in this study. The challenge was choosing a suitable space-based sensor that contains information about plastic debris using the electromagnetic spectrum bands to fulfil the differentiation between plastics and other suspected objects (sea surface, shoreline, sands, rocks, and vegetation).

A set of procedures were applied to extract all possible information from satellite images captured for AOI in a color pixel representation to classify and trace ground items, in order to verify the results of collected field samples of macro- plastics in beach and sea surface (i.e. plastic bags, fishing nets, plastic bottles, etc.), in addition to vegetation that was identified as another carrier or media that accommodate different discarded plastic items.

1- STUDY AREA

The AOI includes El-Shatby sandy beach located in Alexandria governorate between 31°12'26"N 29°54'54"E and suffers from the probability of accumulation of plastic items from multiple sources (i.e., surrounded anthropogenic activities, waste mismanagement, natural conditions, etc.). A standard sampling unit was monitored (100-meter stretches) **(Vlachogianni, 2017)**, taking 30 meters to shift from the beach end to the left as a safety buffer, as in Fig. 1.

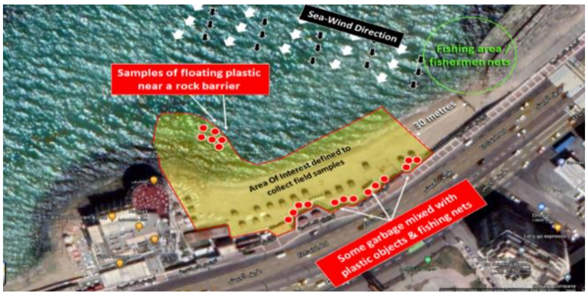

Fig. 1 AOI of El-Shatby Beach

The AOI (highlighted by yellow color) suffers from waste disposal mainly from touristic restaurants and cafeterias on the left side, fishing, and domestic tourism activities on the right side, and public walking in El-Corniche from the backside, in addition to the surrounded urban development.

2- FIELDWORK DATA ANALYSIS

Beach samples in the AOI were collected as number of items per square meter according to UNEP/MAP metadata **(Vlachogianni, 2017)**, from 2017 to 2021 through different seasons, as in Fig. 2, 3. Quantities, materials and sources of the beach macro-plastics were identified, classified and compared with other marine debris and the top five debris items were defined. Surveys were not conducted during the year 2020 due to beaches closure as one of the Covid-19 national procedures.

Fig. 2 locations of plastic debris accumulation in El-Shatby site

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Fig. 3 Number of marine debris found in El-Shatby beach

Fig. 4 showed that the maximum percentage of debris materials in El-Shatby beach were artificial polymers (72%) while worked wood (2%) and glass/ceramics (0%) were the minimum. The main source of discarded debris was tourism (79%) while shipping, illegal dumping and fishing activities were considered secondary sources.

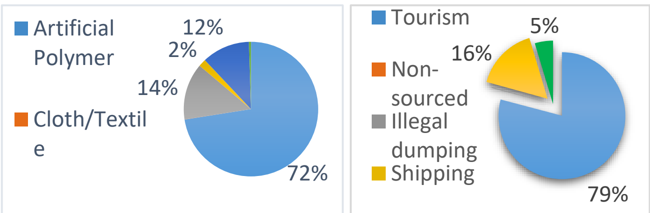

Fig. 4 Identification of beach debris a) materials, b) sources

The most accumulated areas with marine debris were the rocks located on the left side of the AOI and the vegetation strip found along the coastline. In addition to the area at the backside close to El-Corniche. The majority of the floating items at the sea surface were plastic bags and bottles, which were mainly disposed of directly by wind forces from the beach to the sea as a land-based source due to their lightweight.

The top five items found in the AOI were (cigarette butts and filters, shopping bags, plastic cans, and drink bottles), their weight varied from meso to macro debris, as shown in Fig. 5.

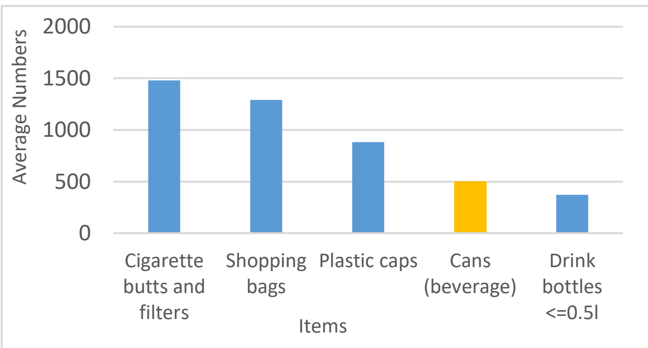

Fig. 5 Top five items of marine debris (blue refers to artificial polymers / yellow refers to metal)

Comparing the average number of plastic items (artificial polymers) in each year by other materials through surveys, average plastic items count 72% of the total discarded items. The fourth year showed increase in the plastic items mainly resulted from domestic tourism and athletic activities as locals recently prefer outdoors rather than indoor places due to Covid-19 safety measures, as shown in Fig. 6.

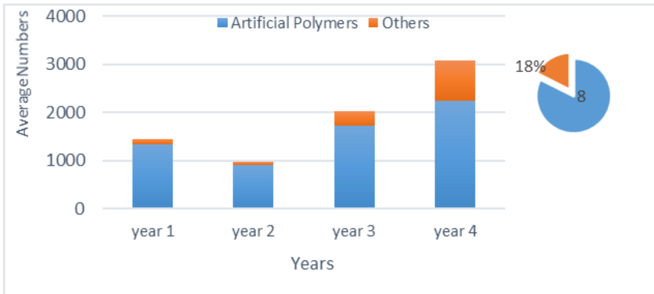

Fig. 6 Artificial Polymers compared with other materials

3- Sentinel-2 Satellite Images

Sentinel-2 optical remote sensing satellite was examined, the European satellite launched in 2014 for earth observation missions. Sentinel-2 is equipped with multi-spectral sensor capability to detect ground objects in 10 m real dimensions (Spatial Resolution), in addition to 12 Bands (Spectral Resolution) varies from visible band, Near InfraRed (NIR) and ending by Short Wave InfraRed (SWIR). The Sentinel-2 image was selected on 11 June 2021, just one day before the last field survey that starts on 12 June 2021, to identify macro-plastic debris using space information with all relevant natural conditions before any possible anthropogenic intervention, as in Fig. 7.

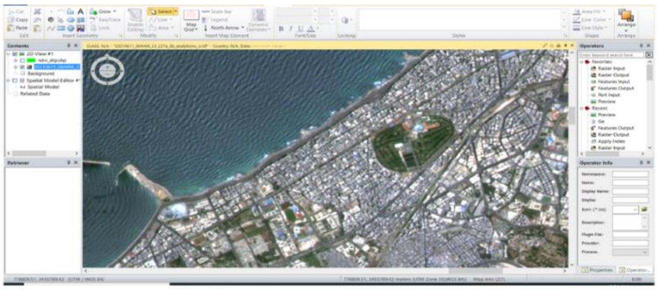

Fig. 7 Sentinel-2 image of El-Shatby site on 11 June 2021

A common image processing software (ERDAS Imagine) was used to interpret and process Sentinel-2 images and to apply some spectral band's combination to analyse materials-based objects observed at the AOI. The analysis was done using built-in reference spectral library developed by (US Geology Survey Authority (USGS)) and (NASA research Jet Propulsion Lab (JPL)) representing analytic charting between ground objects and their behaviour within each spectral band (Red-1, Green-2, Blue-3 and NIR-4), as in Fig. 8.

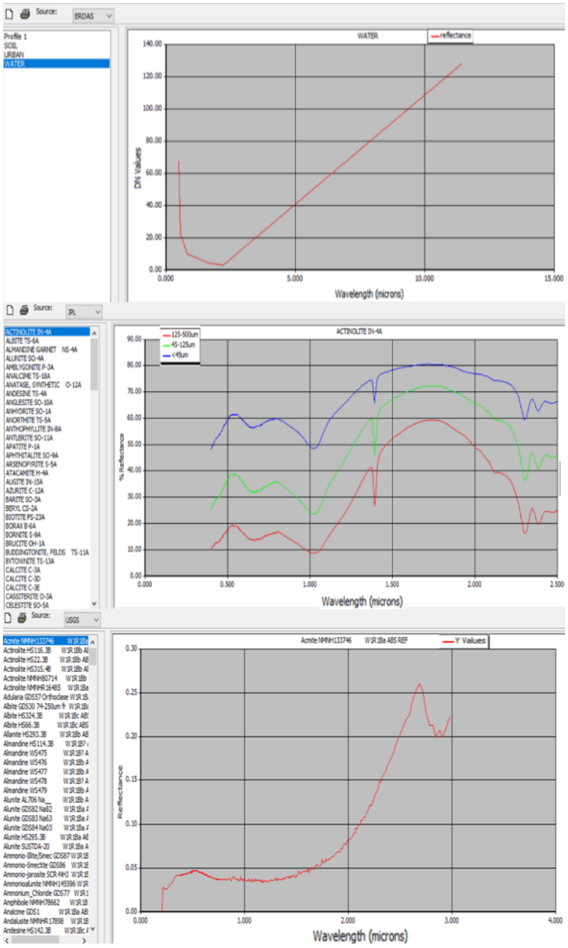

Fig. 8 Analytic charting between ground objects

These spectral libraries were used to identify and classify nature objects at the AOI, in order to reach an optimum method for object separation, based on some computational equations known as band combinations, presented in a scientific keyword to extract industry information.

Five spectral indices (Water Ratio (WRI)), Automated Water Extraction (AWEI), Modified Normalized Difference Vegetation (MNDVI), Plastic Index (PI), and Reversed Normalized Difference Vegetation (RNDVI)) examined. Using Sentinel-2 satellite for extracting different relevant features (ratios that separate objects from their neighbours using spectral bands stored in the satellite image library, according to a recent study **(Rokni, *et al.*, 2014).** Table 2. represents the arithmetic expressions of the applied indices.

Table 2 Spectral indices using Sentinel-2 satellite

Index	Equations
WRI	(Green + Red)/(NIR+MIR)
AWEI	4 x (Green – MIR) – (0.25 x NIR + 2.75 x MIR)
MNDVI	(Green – MIR)/(Green+MIR)
PI	B08/ (B08 + B04)
RNDVI	(B04 − B08)/ (B04 + B08)

4- Planetscope Dove Satellite

A visual inspection was initiated using the Planetscope Dove satellite as a check-up to verify the common ground, and sea features to confirm the accuracy of the results obtained from Sentinel-2 compared with fieldwork data and to validate their capability to identify plastics. A zoomed-in image (enlarged view) for the AOI with the same four spectral bands (Red-1, Green-2, Blue-3, and NIR-4) were examined using a Planetscope satellite sample on 11 June 2021 captured with higher details (~3-meter spatial resolution), to interpret different objects in the beach and sea surface and their spectral signatures (behaviour with four bands), as in Fig. 9.

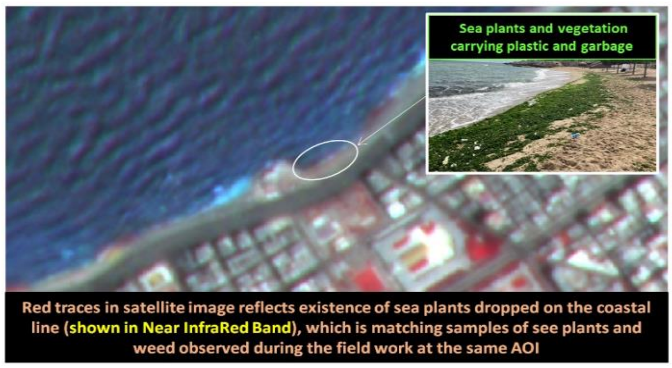

Fig. 9 Spectral Profile of AOI using Planetscope satellite on 11 June 2021

Spectral signatures were studied for different ground features (water body, plastics, rock barrier and vegetation) to support the final results, as in Fig. 10.

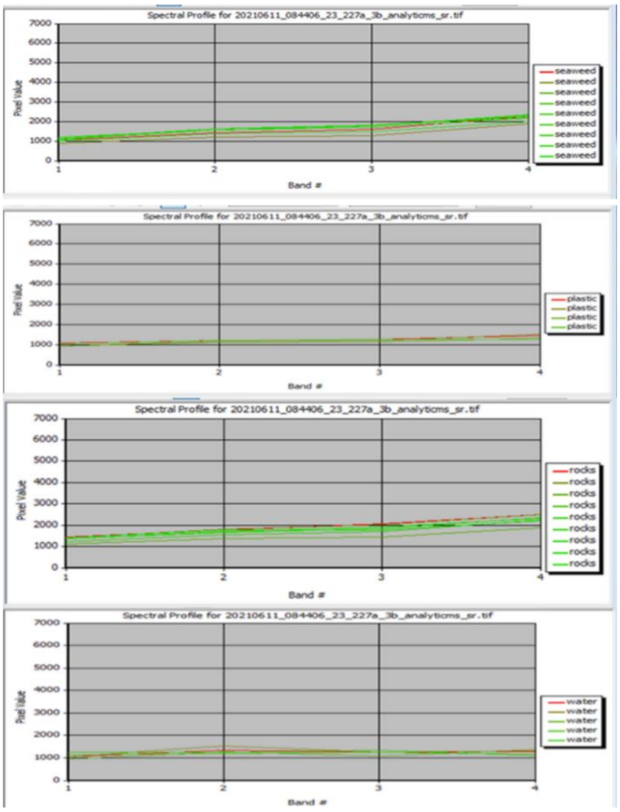

Fig. 10 Verification image using Planetscope satellite in the same AOI

Four indices were examined to identify plastics existence in different features (Normalize Difference Moisture (NDMI), Normalize Difference Vegetation (NDVI), Normalize Difference Water (NDWI), Simplified Ratio (SR)), as in Table 3.

Table 3 Spectral indices using Planetscope satellite

Index	Equation	Reference
NDMI	(NIR – SWIR1) / (NIR + SWIR1)	(Wilsona & ASader, 2002)
NDVI	(NIR − RED) (NIR + RED)	(Abdel-Rahman, et al., 2017)
NDWI	(GREEN – NIR)/ (GREEN + NIR)	(Yoon & Choi, 2018)
SR	(NIR/RED)	(Evangelista, et al., 2009)

5- IMAGE CLASSIFICATION METHOD

Another inspection was applied to Sentinel-2 images using computer technique (pixel-value classification) for AOI to benefit from different spectral bands detected and stored in the image in separating ground features, group each type, and represent them into colored-key classes for simple identification of the actual distribution of these ground features in the AOI. Fig. 11 showed the representation of AOI in the visible band (True Color) detected by the Sentinel-2 satellite that is considered close to the natural colors.

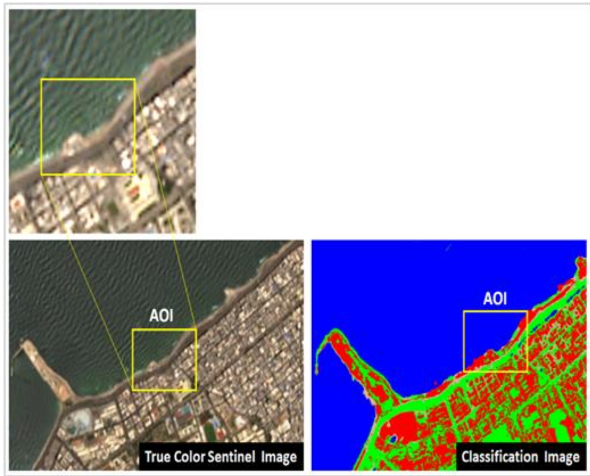

Fig. 11 Visible band (True Color) detected by Sentinel-2 satellite

At the same time, the classification image reflects the real variation of ground features after the computer technique was applied. Sea vegetation was considered as a natural trap for discarded plastic debris and fishing-nets.

6- Sentinel-1 Satellite images (SAR Sensor)

A complementary study was done using different satellite type based on microwave remote sensing (Synthetic Aperture Radar (SAR) Sensor), to add more information to the optical study as SAR can operate during both day and night and during intemperate weather near coastal areas (e.g., clouds or rain).

Based on radar (SAR Satellite) Sentinel-1 image was downloaded from a website for browsing and accessing European satellite's imagery digital catalogue (Sentinel Hub). The image was chosen for the same AOI on 11 June 2021 just one day before fieldwork started, as shown in Fig. 12.

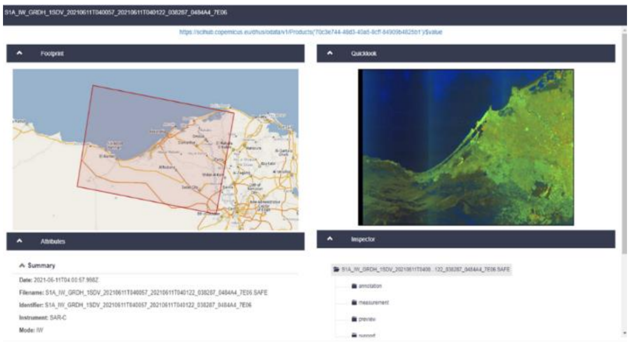

Fig. 12 Sentinel-1 image (SAR Satellite) for the AOI

The SAR sensor is working in C-Band radar remote sensing, which can acquire images for nature objects, store the behaviour of each object when radar waves hit these objects, and return to the sensor (backscattered waves). Besides, SAR sensor is sensitive to metallurgy of each object which refers to the type of material composing these objects (dielectric constant) that supports identifying and separating an object from others.

Image pre-processing was captured to convert sensor values to object-based information values (backscattered values in dB), then some image-filtering algorithms were applied to enhance image details for the next steps. Sea-mask (pixels representing sea only) was extracted from SAR-image, the same technique was applied (sand-mask) to extract detailed information about coastal sand and other objects (plastics, fishing nets, sea vegetation/weeds, garbage) mixed with sand in some locations, as in Fig. 13.

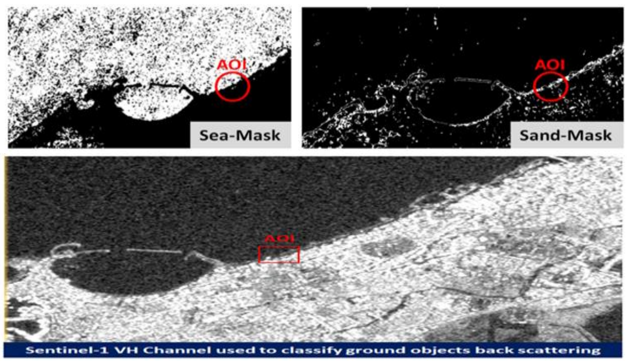

Fig. 13 Sand and sea masks for the AOI

The backscattered waves (dB values) were used to study each object range of values (minimum and maximum) as a threshold representing the existence of these objects in the SAR-image. Table 4 showed that some objects were extracted for analysis presenting the dB values range corresponding to a different object (different composite materials).

Table 4 dB values range corresponding to different objects

Ground objects	Min. Value (dB)	Max. Value (dB)
Waterbody (Sea)	-26	-23
Coastal sands	-21	-19
Rock barrier	-20	-12
Urban	-11	-7

RESULTS and DISCUSSION

The main results of field surveys and remote sensing techniques applied for monitoring of plastic debris in the AOI can be summarized as follows:

- Detection and comparison of ground features behavior in different spectral bands, focusing on the AOI as a zoomed-in (enlarged view) for the classification image studied,

- Calibration, and validation of the spectral zones (bands) specially the (NIR) available in Sentinel-2 image capabilities for ground features where that bands considered as a critical source of information to reflect both vegetation bodies on the coastal areas.

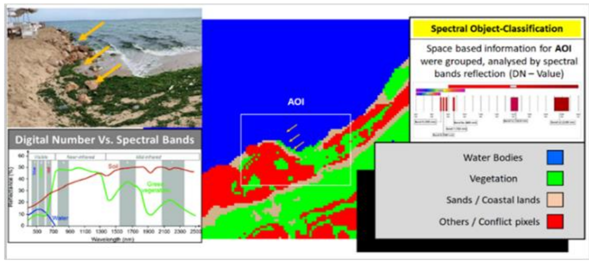

Fig. 14 Spectral zones (bands) to clarify types of ground features

From the analysis of the classification satellite image (Sentinel-2), the vegetation features were extracted and identified by the green color key, as in Fig. 14, proofing that acquired information extracting from simultaneous photos at fieldwork. It observed also the tidal and sea currents affecting where they considered the main factors causing plastic debris accumulation.

The sentinel-1 (SAR sensor) analysed and the backscattered waves (dB values) used to differentiation between mixed features at coastal site. By studying each object range of values (minimum and maximum) as a threshold representing the existence of interested objects. The dB threshold values support in differentiation between pure sand and other debris such as plastics, fishing nets and others. Fig. 15. Shows the dB results using ERDAS imagine software.

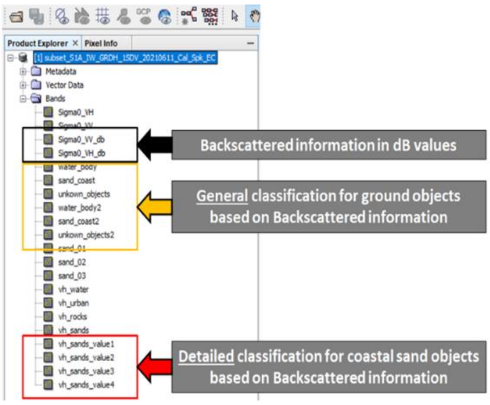

Fig. 15 Backscattering information in dB values

The detailed classification of coastal sand in AOI supported in modelling the distribution of existing objects as plastic debris, fishing-nets, sea-weeds and others within the sandy land areas. In order to simple visualization the inspection of these objects by human eyes in the SAR-image, a composite SAR false colour image (RGB image) generated, so each colour represents different type of object, as in Fig. 16.

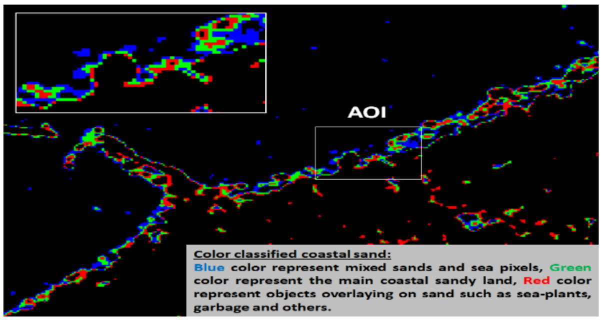

Fig. 16 Sentinel-1 VH channel, coastal sand detailed classification

Validation of Sentinel-1 extracted information compared and analysed with field samples and photographic photo to illustrate how much information this RGB image could describe to differentiate objects under consideration of this study. Fig. 17, represents two photographic photos for two sample locations 1 and 2 and Sentinel-1 RGB output.

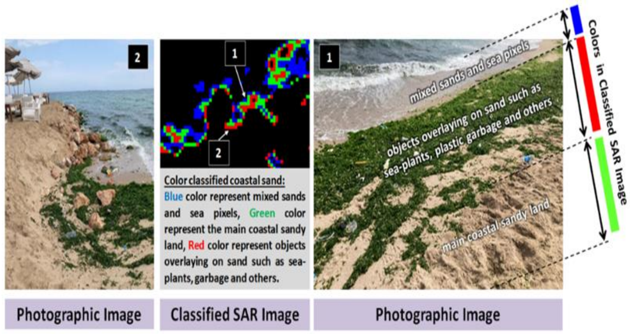

Fig. 17 Comparison between photographic and SAR images

Studying the factors of tidal effects on two points (A, B) at the AOI defined to collect field samples, showed that sea wind

direction and strength have a clear contribution in moving plastic debris from the coastal areas into the sea, and vice versa. Using this digital-catalogue a series of temporal images were taken and studied for the same AOI. Time intervals from June 2020 to June 2021 were studied to monitor the land length-distance to the coastline of the two points (A, B) showing the dynamic extending and shrinking length within this time interval, as in Fig. 18.

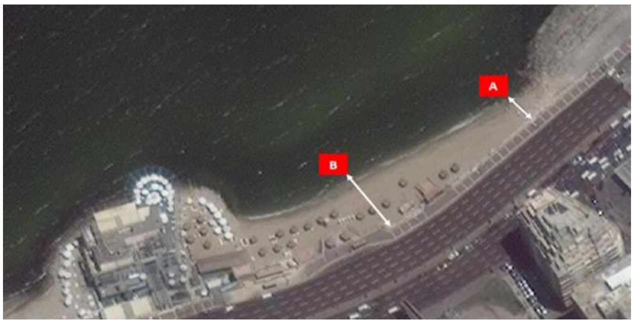

Fig. 18 Points (A, B) for tidal effect analysis*As a result, it was clear from comparing length for the two points (A, B) that land-length of the coast varies from point (A) from 11 meters in November 2020 to 25 meters in April 2021. While for point (B) at the same AOI had a land-length of the coast varies from 25 meters in July 2020 to 35 meters in April 2021. That is reflected in the impact of the non-homogenous tidal effect on the distribution by wind directions. Also, caused plastics collection points (A and B) at the rock barriers floated at the sea surface as shown in Fig. 19.*

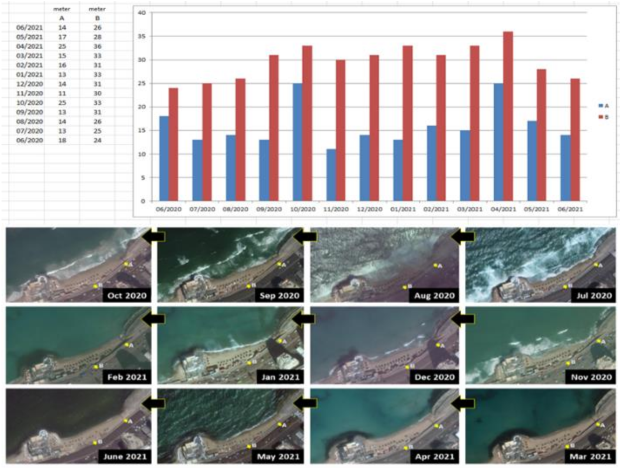

Fig.19 Series of temporal images covering time intervals from (June 2020) to (June 2021)

This study indicated that the coastal vegetation areas considered as the main carrier accommodate light-weighted items such as plastic bottles, plastic fragmented parts, fishing nets, garbage, others and at the same time assist in distinguishing the materials of the ground features.

CONCLUSION

Accumulation of plastic debris increases the level of coastal and marine pollution due to the disposed loads from surrounding anthropogenic activities (land-based and sea-based sources) that negatively impact ecosystems, biodiversity, health and the economy. Reviewed literatures examined the capability of using remote sensing techniques to obtain useful information about the existence of plastic pollution in different water bodies.

This study examined the application of remote sensing techniques in parallel with field surveys to determine the density of macro-plastic debris in different categories: a) beach plastic debris, b) sea surface floating plastics, c) hybrid plastic items mixed with vegetation. Two types of optical satellites (Sentinel-

2 and Planetscope) with different combination of spectral bands and several indices was studied where the results showed that spatial resolutions affect the accuracy level of detecting plastics. Microwave satellite sensors (SAR) was also examined to avoid any possible noise from weather conduction. Pixel-value classification of **Sentinel-2 image** could be used as a verifying method that can illuminate several classes depending on the pixel intensity and reflect the real variation of accuracy**.**

Field surveys showed that plastic (artificial polymers) was the most polluting material at the beach and that identifying vegetation areas using specific indices could indicate indirectly the existence of plastics due to their capability of trapping discarded debris. The overall accuracy of plastic identification reached about 70-80% which proves the potential of using this methodology for the detection of discriminated plastic debris in the Egyptian Mediterranean coast under specific climatic conditions. However, the accuracy of the obtained data depends mainly on several factors (i.e., type of examined satellites, specific combination bands, spectral and spatial resolution, area and density of the accumulated plastics, etc.).

This methodology could be further applied by other Mediterranean countries as a harmonized regional monitoring system to enhance the identification of macro-plastic debris hotspots, reduce efforts and time as well as provide a wide monitoring coverage, thus support the current environmental protection policies in minimizing the negative impacts of toxic plastic debris pollution.

Higher spatial resolution of the examined optical satellites could be used for increasing the accuracy of the spectral bands applied indices. Other technologies could be used in the future to sharply detect plastic debris based on extra-ordinary focused cameras mounted on drones, which provide more centimetre details as sensitivity of object real dimension, at the same time rely on hyperspectral detectors that can work in tens or hundreds of narrow spectral bands capable of classifying and discriminating the different adjacent objects in the same locations in a perfect separation results.

Drones are controlled by ground professionals, with pre-defined flight passes to cover, capture and store images for specific AOIs, supporting analysts to interpret and study unreachable remote areas. Results from drones are fused with the results from satellites to merge multi-layer information required to support governments and decision-makers.

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