ESA Discovery and Preparation – OSIP

Campaign on Remote Sensing of Plastic Marine Litter

Plastic waste and the Black Sea, monitoring litter at sea and on the land from Sentinel-2 data

Executive Summary

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Acronyms

BS	Black Sea
CNN	Convolutional Neural Network
DFT	Discrete Fourier Transform
EO	Earth Observation
ESA	European Space Agency
ESRIN	European Space Research Institute
FPR	False Positive Rate
MD	Marine Debris
MSDT	Multidimensional Signal Detection Theory
RF	Random Forest
ROC	Receiver Operating Characteristic
TPR	True Positive Rate

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1 Introduction and summary

The Project "*Plastic waste and the Black Sea (BS), monitoring litter at Sea and on the land from Sentinel-2 data*" was funded by the European Space Agency (ESA), the aim being

- to facilitate systematic Marine Debris (MD) detection by Earth Observation (EO) for tracking them before they beach, if ever, by improving a detection algorithm already sketched and tested, and develop a true detector from it,

and

- to test various methodologies for the detection & identification of terrestrial illegal dumping sites
  nota: the location of detected terrestrial sites would then be used to provide information on the sources of litter moving from the land to sea using Earth Observation products;
  this challenge was supported by the deployment of the Litter-TEP drift model in the Black Sea study area, an oceanographic model able to predict the movement and abundance of floating and beached MD in the BS (Figure 1).

Figure 1. Position of litter 14/02/2021.

➢ The core topics were

i. to improve the capacity of previously developed marine litter detectors (tested for South-East Asia's dramatic pollution situation, and in the Mediterranean Sea) to 'sense' small amounts of litter,

ii. to provide an estimation of the uncertainty depending on the observation conditions.

The design of the detector and the improvements performed, which were originally framed by the corpus of knowledge and know-how developed in the last decades in '*Ocean Colour*' for the assessment of dissolved matter's[1] & particles'[2] concentration which is valid for micro-litter pieces whose size is zooplankton's, were redefined within the classic framework of '***Multidimensional Signal Detection***

[1] molecular absorption of light
[2] considered as pigments: molecular absorption of light on the surfaces, and scattering by the whole particles

Theory' (MSDT) which is more appropriate for macro-litter pieces[3] and for an object detection's process[4], i.e. the extraction of information on litter presence at the sea-surface with a final test of presence or absence of litter pieces (making a decision between two hypotheses, H1, absent, and H2, present, in the event of a particular observation).

Introduction of *i.* conditional probabilities (Bayes' theorem), and recourse to *ii.* methods for the trade-off between the detector's sensitivity (rate of true detection, called probability of detection) and its specificity (1 less probability of false alarms) such as the use of Receiver Operating Characteristic (ROC) curves, allowed to optimally fix the detection thresholds.

These improvements proved their usefulness, including reliability, accuracy, and precision of the algorithm in changeable conditions which are prevalent in the Black Sea, which is the study area of the project. Further, the capacity to differentiate plastic from other floating debris (such as vegetation, algae and sediment) was improved, achieving a better level of confidence when compared to the Original EO Processor of MD detection. The development of the marine detector was supported by the a-priori information provided by the deployment of the Litter-TEP drift model in the BS, which supplied information about the litter routes and the areas of accumulation.

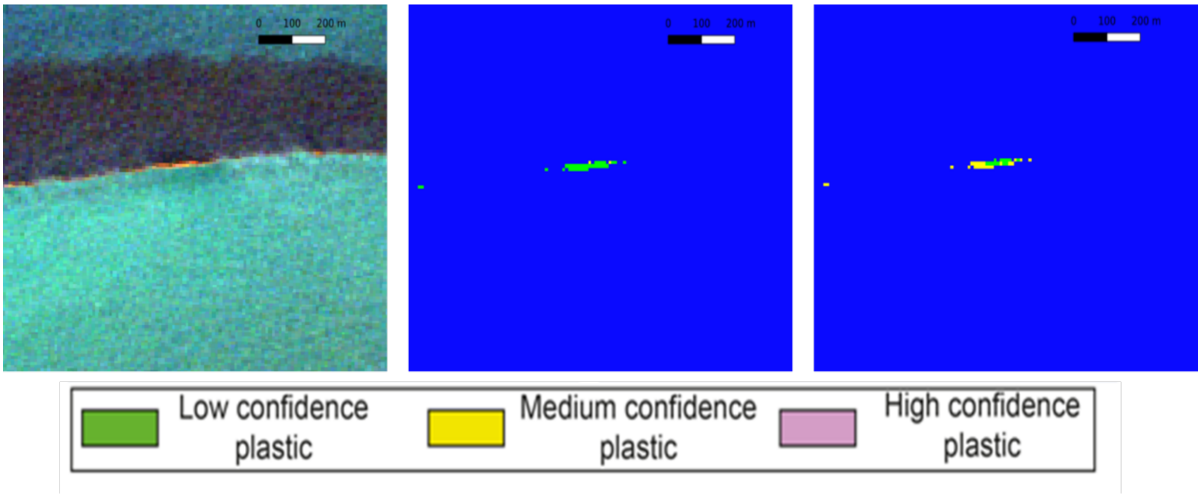

Figure 2. Comparison between the ability to distinguish plastic patch (right image) within the debris of the Original EO Processor (centre image) and the improved MD detector under the framework of MSDT (right image).

- An algorithm to detect terrestrial illegal dumping sites was developed, with the ultimate ambition to frequently update data on potential sources of plastic for the ocean drift model.

This was the key novelty of the Project as only a handful of studies have focused on the ability of EO to detect terrestrial debris.

[3] framework for optimal observation and decision processes (choice between presence and absence of objects, under conditions, and knowing the uncertainties): measurements of the ability to differentiate between information and noise (information = what's looked for, noise = random patterns that distract from the information)⇒=detecting signals of/from against a background of random interference or noise

[4]that should not be confused with a quantification process

Due to the scarcity of projects that focused on this topic and its application mainly to Very High Resolution (VHR) data, four different techniques and algorithms were developed and applied under the framework of this project:

- Two detection change algorithms were developed, based on Discrete Fourier Transform (DFT) and covariogram analysis;

  however, both proved to be unsuccessful for the detection of illegal dumping sites, as they were unable to detect changes <50m for the DFT and <30m for the covariogram;

  furthermore, no band combination or band ratio could be identified that uniquely targeted the plastic sites in question, resulting in changes being detected in a range of undesired locations;

  → as such an alternative approach was required;

- Two methods of classification were then trialled using a Random Forest (RF) and a Convolutional Neural Network (CNN);

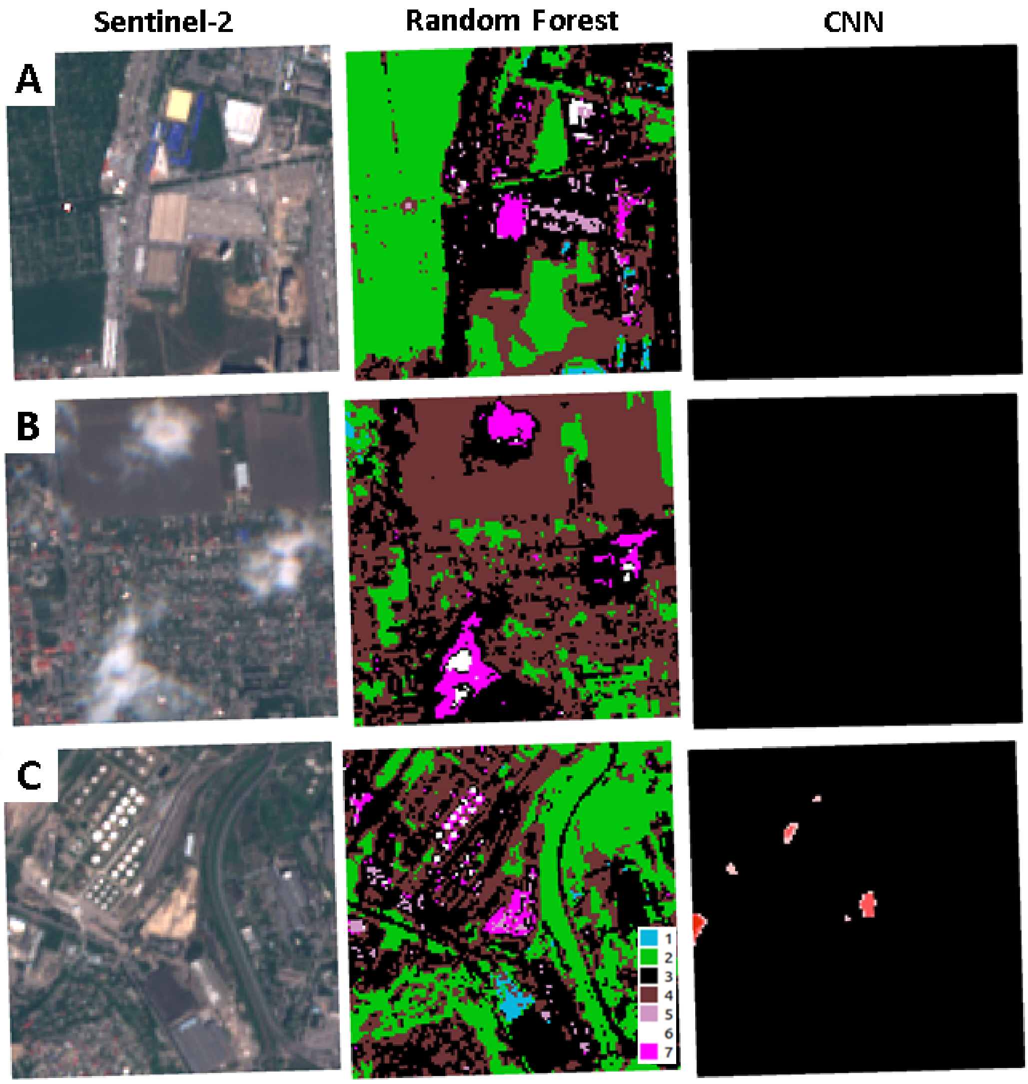

Figure 3. Comparison between the performance of RF and CNN algorithms. RF classes: 1-water, 2-vegetation, 3-urban, 4-bare earth, 5- rock, 6-cloud, 7-plastic.

- Classification using Random Forest was successfully able to detect a range of different plastic dumps, both case study locations and new previously undiscovered locations;

  however, RF suffers from frequent misclassifications and so requires user interpretation to identify the true positives from the large number of false positives;

- Finally, the latest method, CNN provides the best results with the clearest path for progression and improvement.

  → This method considers not only plastics' spectral information but also the spatial context during the classification. The model demonstrated in these figures used transfer learning from a land masking model developed by Isikdogan et al. (2019)[5]. The number

[5] Isikdogan, L. F., Bovik, A. C. & Passalacgua, P., 2019. Seeing Through the Clouds with DeepWaterMap. *IEEE Geoscience and Remote Sensing Letters*

of false positives is reduced when compared to RF (Figure 3), while also retaining the true positive detections (Figure 4).

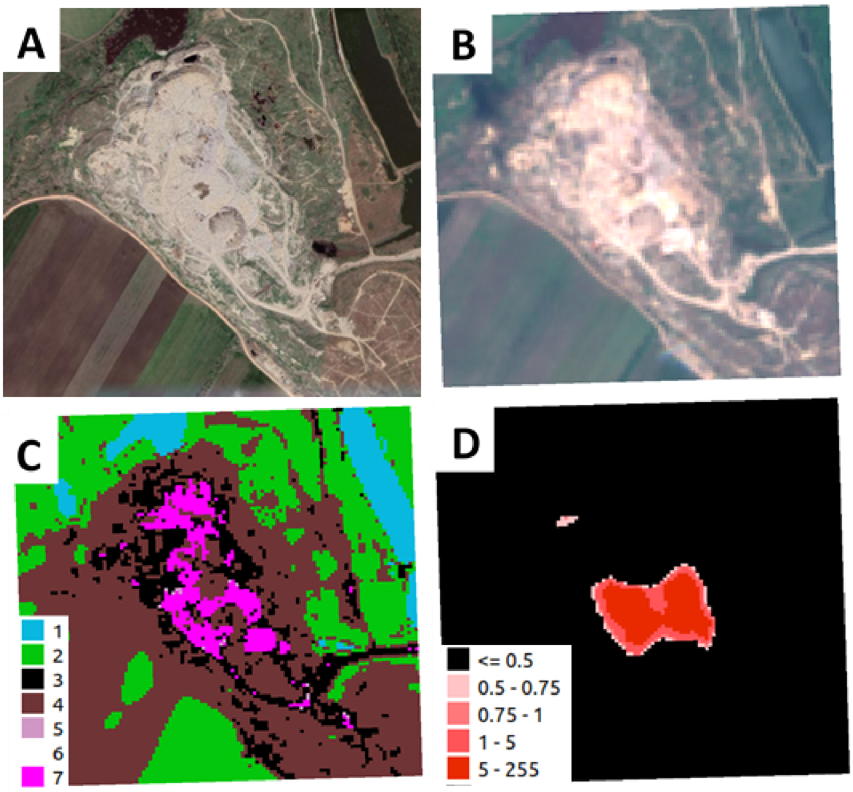

Figure 4. Classification methods over a use case dump site. A-Google Earth, B-Sentinel-2, C-RF, D-CNN. RF classes: 1-water, 2-vegetation, 3-urban, 4-bare earth, 5-rock, 6-cloud, 7-plastic.

Under this project, then, two different algorithms have been developed to detect MD and terrestrial illegal dumping sites. The MD detector is based on the analysis of the spectral reflectance and has been developed under the framework of the MSDT, proving that Sentinel-2 data could be used to spot floating MD. The detector is tuned to the probabilities of detection and false alarms and the thresholds of detection were fixed considering the trade between the True Positives Rate (TPR) and the False Positives Rate (FPR) and the environmental conditions, such as for example, MD presence, which is provided by a marine litter drift model that was deployed in the Black Sea using Copernicus Marine Service information. The terrestrial detector is based on the analysis of the spectral and spatial reflectance of the waste sites using a CNN algorithm, providing information from the plastic source. These two algorithms open a window to provide and improve the information about plastic sources from land to the sea.