Investigating detection of floating plastic litter from Space

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Summary

The littoral zone of Limassol is been polluted by manmade rubbish, especially plastic, something highly noticeable by the locals. Given that we were very aware of the huge damage done to the marine environment, we were determined to find a way to either prevent sea pollution as much as possible or to help the authorities clean the sea in a more effective way. As we know from our Science studies each material reflects or absorbs sunlight radiation differently, enabling the creation of a unique graph for each material, which is called: "Spectral Signature". We decided to experiment using "Remote Sensing". The idea was to create a "plastic target", in order to investigate if plastic floating in the sea can be detected, depending on its Spectral Signature using satellite or drone. Methodology evolved as we were investigating further and exchanging ideas, having hands-on experiences to become more familiar with the science and its instruments, then deciding how to apply our knowledge to make our idea happen. Therefore, we took in situ and laboratory measurements on plastic to create a database with the most representative spectral signatures and discovered its special characteristics which were used as guide to spot it using drone or satellite. After gathering all information needed, we created a floating plastic bottle target, so as to take measurements by both drone and satellite. Then, data was analyzed, and a Prototype Code was created, based on the Spectral Signature of plastic. Finally, by testing the Prototype Code of plastic bottle over and over again, we confirmed that accumulated plastic rubbish can be successfully detected by drone or satellite. Thus, a new, effective way of tracking plastic rubbish is introduced which can contribute in the protection of the marine environment.

Introduction

Water covers 71% of the surface of our planet. It is one of the most important elements in the world without it we cannot survive. Nevertheless, people continue to litter oceans, lakes, rivers etc. without considering the negative impact of their irresponsible actions despite the fact that everyone is directly affected by the implications.

The coaches of Limassol, form no exception. Rubbish can be found either floating on the surface or even deep down the bottom of the sea. In the littoral zone of the sea, where it is more possible to find rubbish in greater amounts and possibly accumulated. Thus, local environmental organizations keep protesting and demand that the government should take action. Willing to contribute to the government's attempts to confront the problem, we decided to create a tool which could take advantage of the reflection or the absorption of sunlight/radiation by each material which happens in a

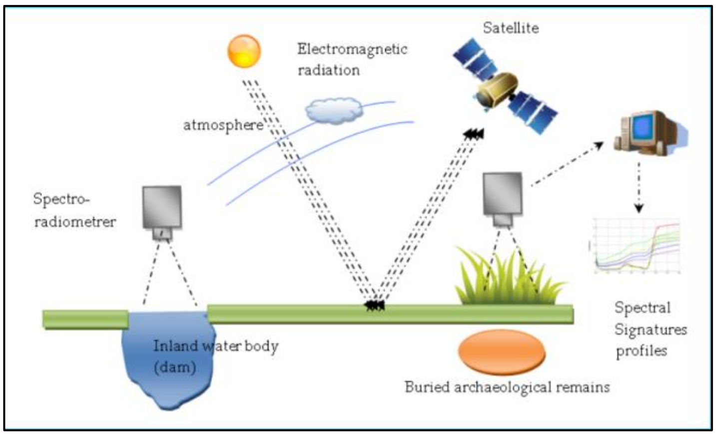


Figure 1: Science of Remote Sensing

unique way. This is accomplished through remote sensing, which makes possible the creation of special graphs, the commonly known “Spectral Signatures”, which convey the reflectance (R%) of each material against specific wavelength values (λ in nm). By analyzing a Spectral Signature, we can figure out the consistency of the object under examination and therefore, identify whether it naturally belongs to the sea or not, i.e. if it is some kind of rubbish.

Given that plastic is the most destructive waste but still widely used, we decided to focus on plastic bottles so as to investigate the hypothesis that: “we can track down the accumulated waste floating on the surface of the sea, including the plastic waste”.

Literature review

Lots of studies present the harmful effect of rubbish in the sea, and more generally against water life. One of the most example is Dr. Wilcox’s research. According to his study, each year 5000-15000 sea turtles get entangled by fishing gear debris and wash ashore Northern Australia. Other researchers studied the number of fish dying due to plastic chunks and the number of birds trapped in floating rubbish mounds (Genelle, 2017) presenting the urgency to take action of any kind either as preventive measures or finding solutions to resolve the problem.

As far as plastic is concerned, it has become an integral part of our daily life. Unfortunately, for every six bottles people use, only one is recycled. This leads to a huge problem given the fact that plastic bottles do not biodegrade, but rather photo degrade, which accentuates the threat of lingering waste plastic for years and for generations to come. It is useful to know that it takes up to 1000 years in order for a single bottle to decompose, leaking all that time pollutants harmful chemicals into soil and water, which may cause health issues. Plenty of reports argue that consumption of plastic by all types of fish, ultimately causes intestinal injury and death to them, spreading the risk towards other bigger fish and marine mammals, considering the food chain.

Moreover, the life of birds and other beings which depend on the oceanic life-forms for their food requirements is also threatened by this dangerous plastic materials, because birds are frequently being tricked by the plastic junk’s brighter colors. In addition, most of the sea birds die due to suffocation while they constantly get caught in the debris. According to many surveys 44% of all seabird species, along with cetaceans and sea turtles have been documented to have plastic debris in or even around their bodies *(“MARINE DEBRIS HURTS HUMAN HEALTH, MARINE LIFE AND SOUTH FLORIDA’S ECONOMY”,(n.d)).*

Another research which was conducted by the University of Bergen was about a whale found suffering across their coastal areas. Scientists at the University of Bergen were horrified by what they discovered inside the Cuvier’s beaked whale. A Scientist Christophe Noever said “it looked more like a garbage bag, just masses and masses of plastic bags twisted into each other and forming one big lump of plastic”. The whale died a few weeks later. *(University Museum Of Bergen,,(n.d)).*

It is worth noting that not only the marine life is threatened by the plastic waste in the sea areas but plastic waste causes harm to people who consume sea food due to infected fish. People who consume sea food could get infected by polluted fish and could suffer from health issues, such as cancer, immune system problems and birth defects.

In addition to the harmful effects of the marine ecosystem, the plastic waste creates negative impact to the economy as it affects economic sectors, including tourism, fisheries and aquaculture, among others. *(“MARINE DEBRIS HURTS HUMAN HEALTH, MARINE LIFE AND SOUTH FLORIDA’S ECONOMY” ,(n.d), “What’s the Problem with Plastic Bottles?”,(n.d)).* As far as Limassol's main source of income from tourism is concerned, the city's economy will be benefited if the government considers our suggestions.

In our study, we will demonstrate whether our spectral library is applicable and can be used to detect, classify and measure sea litter pollution. This “tool” can provide important information to stakeholders, such as municipalities and environmental agencies so as to prioritize the necessary actions which must be undertaken to preserve the coastline and more specifically to keep the bathing areas clean so as to be appropriate for the end-users. Under this perspective, we have conducted a campaign regarding the recycling of plastic bottles in our school. After discussing with our school mates the negative impact of the plastic bottle in the sea life, they all helped to recycle plastic bottles. In this way we had the chance to raise environmental awareness around us. It is vital to recycle and not just throw waste thinking that someone would pick them up *(“What’s the Problem with Plastic Bottles?”,n.d).*

As part of battling plastic pollution, particularly in the ocean, many countries, including Cyprus, have restricted or abolished several forms of plastic products. Cyprus has declined the plastic bag production, while plastic bags are not freely offered in the market. This deed-measure has successfully made a lot of people to reuse their plastic bags which is friendly for the environment and marine species’ life.

Several projects which are close to our project were developed the last years.

In a survey which was conducted by the University of Aegean’s marine remote sensing group they attempted to test the detection and quantification of artificial plastic targets in the sea, in order to prove the usefulness of UAV technology in the marine sector *(University of Aegean, n.d.).* In particular, they created three 10 m x 10 m targets, containing separately 3600 plastic bottles of 1,5 lt, 185 plastic bags and 200 m^2 fishing nets knowing that satellites as sentinel 1-,and sentinel 2- can detect objects with these dimensions. In their project four satellites (Sentinel 1- , Sentinel 2-, TeraSAR-X and Worldiew-3) and 4 drones collected information of the study area for each of the targets created. This information was used to accurately map the position and density of plastic in specific spectral areas (visible, infrared and thermal-since thermal camera was used too). Their main aim was to investigate the potential detection of large plastic concentration, which was detected from the satellites, and they intend to find a way to measure the density of the plastics in a volume of water *(Topouzelis, 2018).*

Studies and attempts of the European Space Agency to get rid of plastic in the seas and oceans show the importance of our investigation. Particularly, they are clearly mentioning the current ability of satellite maps to stimulate accumulation of litter in vast amounts in the Pacific, Atlantic and Indian oceans. What they are trying to reach now in their new project, is the practicability of direct optical measurement of plastic litter in the sea areas from satellites, and to procure a special spectral signature of plastic picked up from orbit, as the processing software can today pick out concentration of phytoplankton, water-borne pollution and suspended sediments.

The ESA's new project anticipates distributing a preliminary set of requirements for a satellite to detect marine plastic litter in the infrared *(European Space Agency, n.d.)*.

Methodology

Determined to focus on plastic, which is the major threat to marine life, we decided to investigate the possibility of being able to track accumulated plastic with the assistance of Remote Sensing Technology using the information provided by available satellites.

Initially, we had to get acquainted with the science of Remote Sensing. Therefore our team participated in lectures, during summertime, throughout which we were able to understand the background and how to apply our knowledge by analyzing graphs of the Spectral Signature of materials. Moreover, we had to familiarize with the Remote Sensing instruments used in field experiments, so we visited the Cyprus University of Technology laboratories where we took experimental measurements under the supervision of specialists, so that we learn how to operate these instruments. These measurements were taken in a special room, called 'dark room' where there is no other light resource so that the target reflects only the light emitted from a lamp at a fixed position.

Our main instrument is the "Spectroradiometer". It is one of the most important instruments that as without it Remote Sensing Science would not be applied. The "Spectroradiometer" tracks and measures the intensity of the electromagnetic radiation it gets from each surface in a certain spectral band of either the visible or the invisible field, a process vital for this science. Another instrument we were introduced to was the "Spectralon White Panel". It is a square piece of white surface that reflects 100% of the electromagnetic radiation it gets exposed to. Measurements must be taken on this panel on a regular basis before moving on to the target, because a reference value is needed to rely our calculations on due to the fact that radiation changes according to the season and hour of the day.

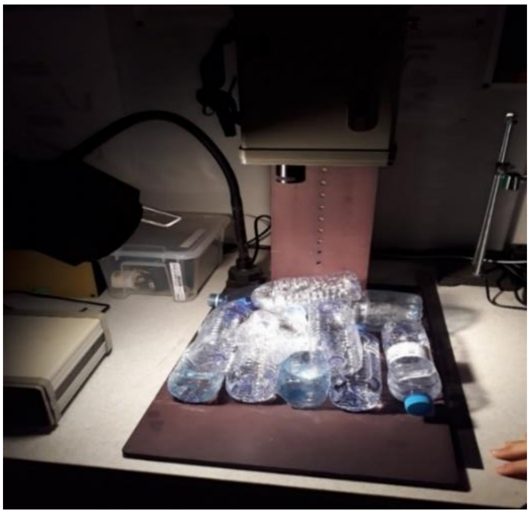


Figure 2: Experimental Measurements in Dark Room

Figure 3: Instrument Specifications

Hands-on experience augments material learned by attending classes. Therefore, on July 17th, 2017, our team accompanied by our teachers, friends and a professor of Cyprus University of Technology conducted a field experiment. We went to the Limassol beach near the old Harbour to collect waste found in the coastal zone and took in-situ measurements from them using the "Spectoradiometer" connected to a special fiber optic probe (a very thin thread made of either plastic or glass that allows digital information to get transmitted in the form of light as quickly as light travels. Each fiber optic probe includes dozens or even hundreds of fibres that have an equal-to-the-hair diameter) so that we would be able to take measurements on materials which either floated on the surface of the water or were underwater. Following the indications of our instructor, we took at least three measurements on each material and in different depth so that we could work out a representative average Spectral Signature for each one afterwards. Moreover we took measurements on the "Spectranol White Panel" multiple times, in case the radiation changed.

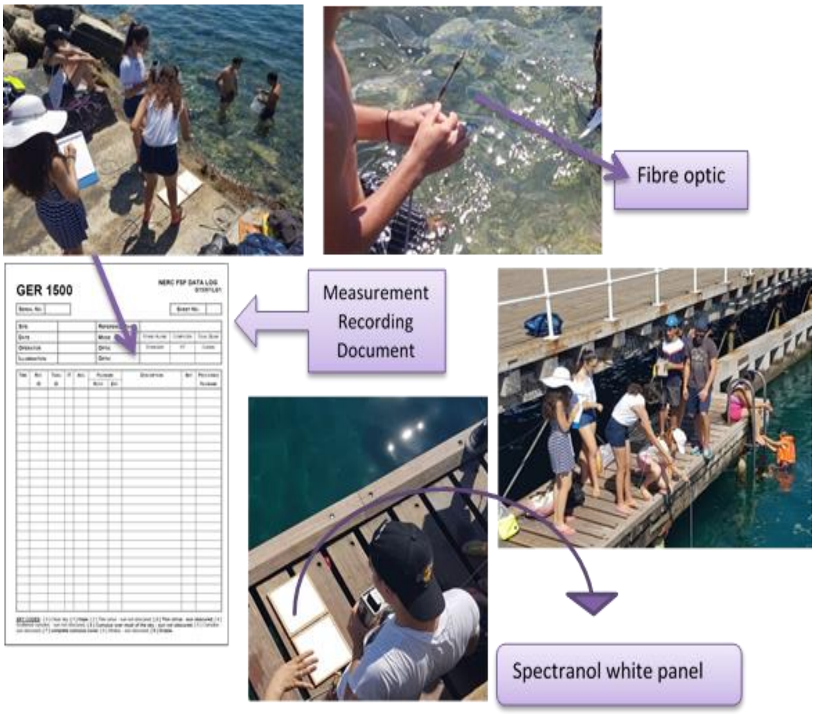


Figure 4: Taking Measurements

What followed up was the analysis of the data we collected which was done using the Excel software program. Initially, we created the "Spectral Signature" of each material (a graph of the reflectance (R%) against the wavelength (λnm), as explained before), grouped the common materials and worked out the average graph (unless there were outliers). We also converted the final graphs into "at satellite" graphs, which we will explain more explicitly in a section below.

The following picture is one of the many excel booklets which we created the spectral signatures.

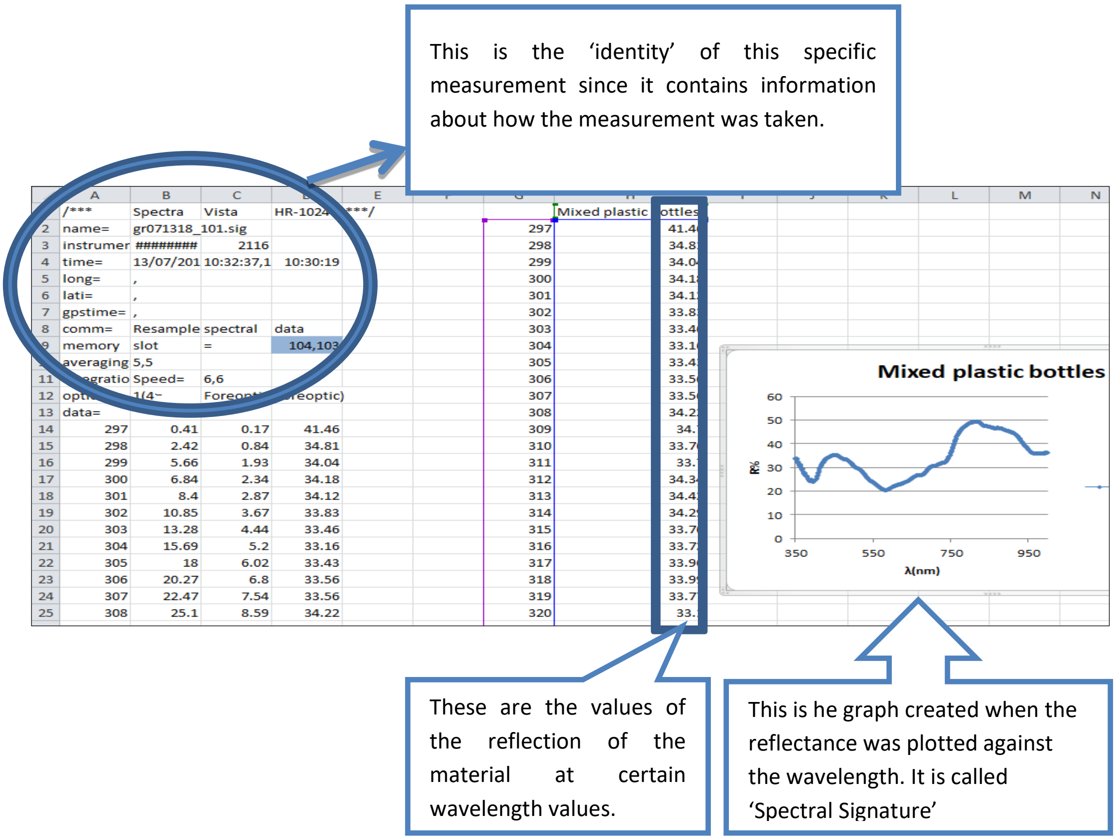


Figure 5: Procedure of working out an average graph out of lots of measurements

Firstly, we compared each graph of common materials, crossing out the non- concordant ones- since they would act as outliers and destroy the reliability of the graph.

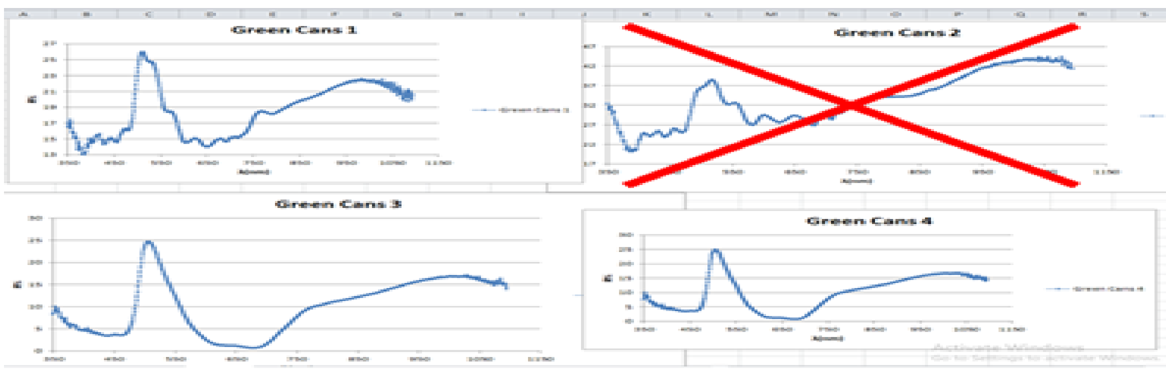


Figure 6: Rejected Measurements

Next up, we studied the average graphs created, trying to figure out similarities between common materials, to find out whether we would be able to recognize the material by its spectral signature. By comparing maximum reflection or absorption at the visible field, we were able to figure out the color of the material, and by comparing peaks at the invisible field, we could decide on the type of material. In general, we concluded that by having a representative graph for a type of material, we can work out whether the new material investigated has similarities with the first one in either the color or type of material.

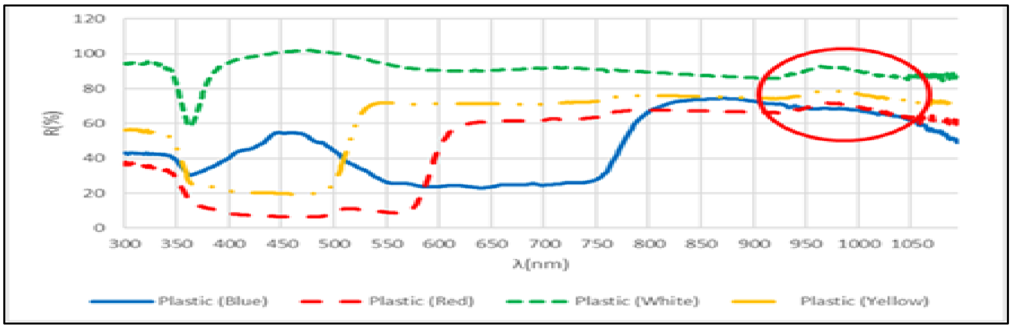


Figure 7: Spectral Signatures of plastic beach Doughnut

All these Spectral Signatures belong to common types of materials. This can be deduced by their common maximum reflectance between 950-1000nm, because common materials have the same value of reflectance at the infrared zone. We also know that they are plastics because all plastic materials studied had this maximum reflectance at that point. Therefore, the maximum reflectance of each material at the infrared zone, indicates its substance.

As for the color, we spot the maximum reflectance of each material and check in which color's field is in according to the Electromagnetic Spectrum table (**Appendix B**).

For example, the blue line in the graph belongs to a blue colored plastic due to its maximum reflectance at 450nm, which according to the scale above falls at the zone of the color blue. i.e. by comparing the maximum reflectance of the plastics in the visible spectrum to the wavelength values where each color is reflected, we can deduce their color.

Even though this started as an experimental field survey, after analyzing the data collected, we realized that the measurements were reliable. Therefore, they could be used in a future survey or even as an extension to ours.

However, all this practice was preparation for our main objective, which was: **The detection of accumulated plastic in the sea using an artificial plastic target.** The main part of our study begins when

Figure 8: Target (plastic Bottles)

our team decided what the plastic target would be made of just only plastic bottles! After collecting more than 4000 plastic bottles, we connected them by passing fishnet through the bottom part to the cap of the bottle making 160 10m lines long. Then, we carefully sealed them so that water wouldn't enter and made them sink. Subsequently, we moved on joining the lines together again with fishnet again and supporting them with 3m pipes to give it more stability. Initially we intended to create a 10x10m target, because these are the minimum dimensions of a target possible to be detected by available public satellites. However, given that previous evidences suggested that it's more likely to find this amount of accumulated plastic, we decided to perform the experiment with a 3x10m target to check whether it can be detected or not. This way we would deduce more accurate result for our country model. In a later section in our essay, we are going to explain how we managed to track our smaller target, even though the minimum dimensions are the ones mentioned above.

Moving on to the application part, we had to decide on which day our experiment was going to take place. This decision was of course predefined by the dates that the satellite we chose to take measurements from, (Sentinel 2), was passing over the Limassol sea area. This satellite is operated by the European Space Agency and provides information to the public for free about forest areas and potential nature disasters. It can also record changes in the plant distribution and the earth morphology. Nevertheless, we focused on its ability to detect marine contamination. Given that Sentinel 2- passes over Cyprus every 5 days we decided to conduct our experiment on the 15th of December 2018 when a team of divers was able to contribute, and a sailor was available as well.

A day before a truck transferred the bottle lines from our school – where we had been collecting them for months- to a room at the old port of Limassol which was kindly provided by the Governmental Department of fisheries and marine research. There, with the help of our teachers, students from our school and a couple of researchers, we managed to join the lines as we mentioned. Moreover, in order to provide extra stability, we came up with the idea of joining bottles with the pipe or together with plastic nylon joins at a regular pattern.

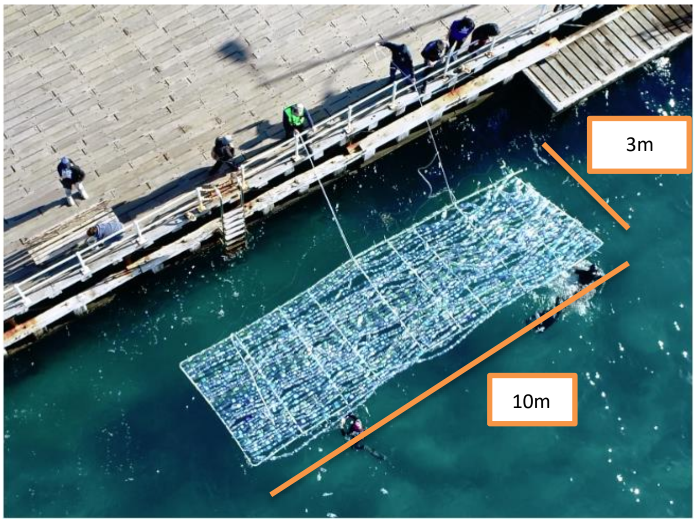


Figure 9: Dimensions of the target

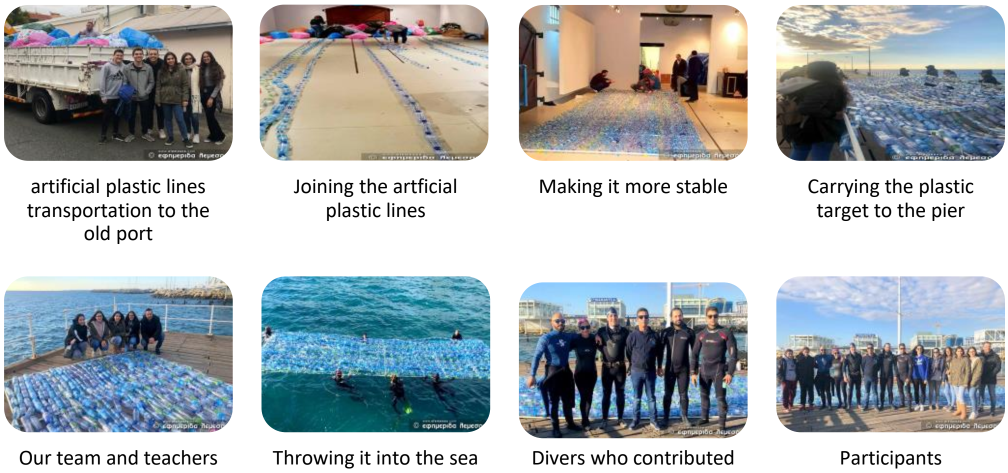


Figure 10: Day of the experiment

The day of the experiment we gathered at 7 am to carry the target to the pier. There we took measurements on it using the radiometer before and after we placed it in the water. Then the divers carried it approximately a further 200m deeper from the pier. They made sure to place it in such a way so that the sun light would reach it directly when the satellite passed. They stabled it to ensure that it wouldn't change its position until 10:30 when Sentinel 2- was scheduled to pass. At the same time measurements were taken by a drone that was equipped by both a red-infrared and a red-green-blue camera. Both satellites and drone measurements were analyzed.

Beginning with the drone, the pictures taken by each camera were different. This happens due to the fact that one of the cameras takes measurements at the blue-green-red spectral bands whilst the other one only at Red and infrared. Therefore, the blue-green-red camera gives pictures where the colors of the objects can be seen. Even though this kind of picture seems useful to track and identify plastic, it is actually useless when it is taken from a much higher altitude since plastic rotates and deforms when left in water for a long period.

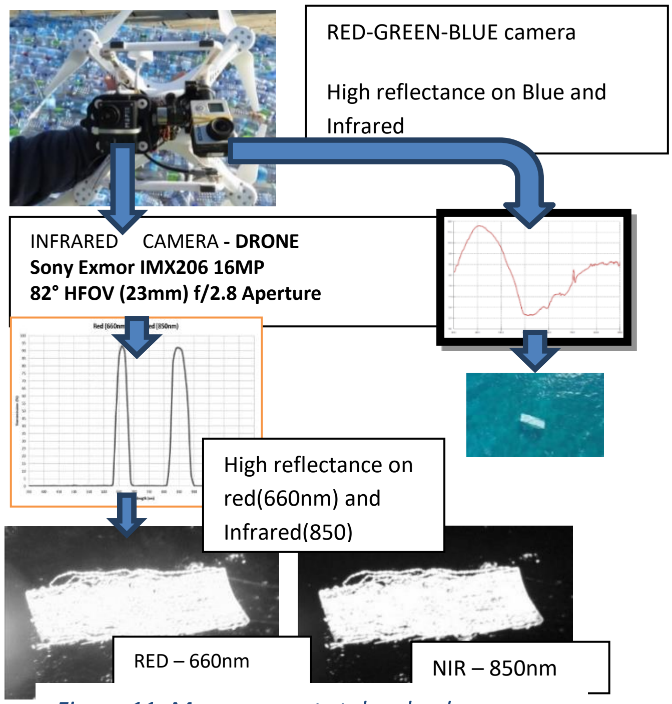


Figure 11: Measurements taken by drone

On the other hand, the red-infrared camera takes measurements on these two specific bands. These measurements are decoded to special reflectance values turning them into monochrome pictures where black represents full absorption and white full reflectance. Given that, the water fully absorbs radiation after 700 nm wavelength, it is always shown black on the infrared band picture, while the plastic target is shown as white because it thoroughly reflects infrared radiation.

The picture created by decoding the measurement in the red band shows that both water and plastic reflect red.

A graph with peaks at red and infrared bands is obtained. The two values plotted are the ones taken by the camera which do not completely match the ones in the special spectral signature of the material, in situ taken, but are relatively similar to them. They are just simplified models created by us depending on the pictures' decoded results. However, according to the wavelength value of the infrared peak, the material can be distinguished. This way, all objects, apart from water, are white colored, because they all reflect infrared radiation up to a point, so after tracking them on the picture, they can be identified once their infrared reflectance values are deduced. Thus, plastic is successfully detected at 850 nm wavelength.

Therefore, by comparing the blue-green-red camera to the red-infrared one, we deduce that plastic can easily be detected using the 2nd one by just being white colored on the picture decoded, whereas, people are needed to identify it on the colorful picture given by the 1st one, which might sometimes be even impossible since it can be transparent or even blue and cannot be spotted in the water.

The pictures by the satellite were uploaded late that night on a website called https://www.sentinel-hub.com/ from where they were downloaded for free. At first, our artificial plastic target was not visible at the optical channel.

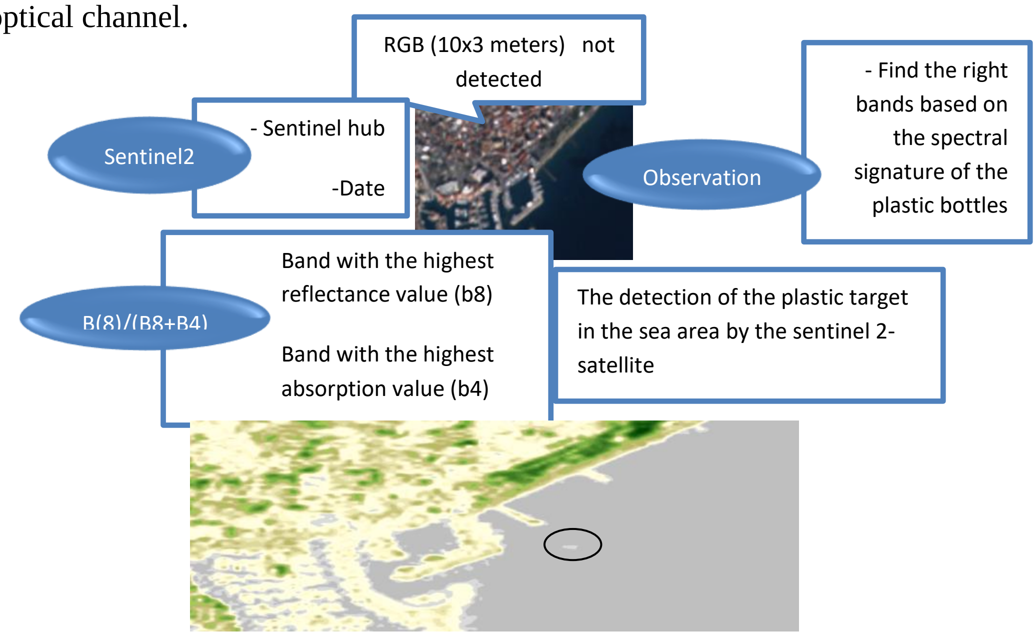


Figure 12: Processing satellite picture

Thus, the satellite picture had to be proceeded and analyzed, by applying special calculations implemented between spectral pixel band values. The bands among which we were able to choose from, were the ones that sentinel 2- can track as shown in the Table 1 (**Appendix A**).

Mathematical operations of addition, subtraction, multiplication and division can be applied to two or more images that have the same reference system and essentially typify the same geographic area. The operations are implemented between the digital pixel values of the spectral channels without involving adjacent pixels.

Mathematical operations can be made in the spectral channels of the same satellite image as well as in spectral image channels coming from different dates. The four basic operations between images (spectral channels) are adding and subtracting images, as well as multiplications and divisions of images. The addition creates a weighted sum between two or more images.

Addition is mostly used to decrease overall noise in the images and increase the signal to noise ratio (SNR) in order to create a better quality images. Subtraction is applied between pairs of images of the same area that belong to the same reference system but have been taken at different times. Subtraction is useful for tracking timeless changes. Subtraction between images can be made provided that images have been radiometrically corrected since high accuracy of the images' geometric correction (about ¼ of the pixel dimension) is reached. Multiplication is usually applied when two or more land coverings are distinguished in one image and a target exists to be observed and isolate a particular one.

A typical example is the masking for separating water surface from the land. For this purpose, the near infrared spectral channel is used, whose spectral characteristics give too little reflection to the water surfaces and high reflection in the vegetation areas. Subsequently, a threshold is selected between the near infrared spectral values to separate the two categories. Then, binary image is created with values 1 and 0. All pixels with values below the threshold value have the value of 1, if not they have the value of 0. Finally, this binary image multiplies with the original image in order to export only areas corresponding to water surfaces.

After all, channel divisions are the most used mathematical operations between remote sensing data. Significant advantages arise from the division application to digital images such as the reduction of shadows and its relief effects in general, as well as limiting the effects of atmospheric conditions. Before the application of the division into the spectral channels is pretty essential to remove the random noise, and to make the atmospheric correction.

So, we had to use the spectral signatures of plastic bottles we created by taking in situ measurements using the radiometer, because, according to the bands that the Sentinel 2- could track, corresponding values to them should be extracted from that spectral signature. Then, we chose the ones most suitable for us to achieve a better resolution. These were the bands 8 and 4 because when applying the formula B8/ (B8+B4), due to the high denominator obtained, the outcome is relatively small and therefore we get better resolution in the picture, as deeply explained before. The formula used can be designed as the researcher wants as long as the outcome is small but not zero.

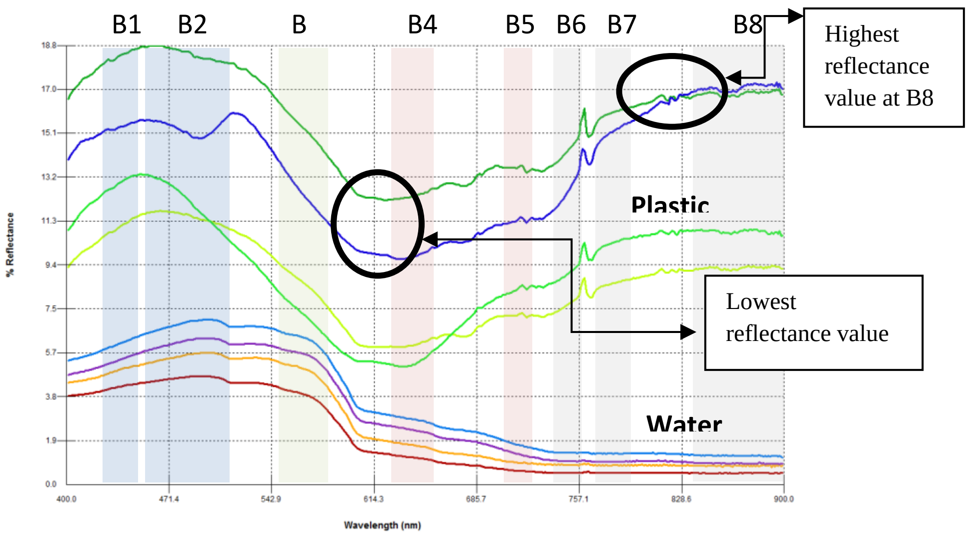


Figure 13: Spectral signature of plastic bottles and water

To make things clearer, let's give an example:

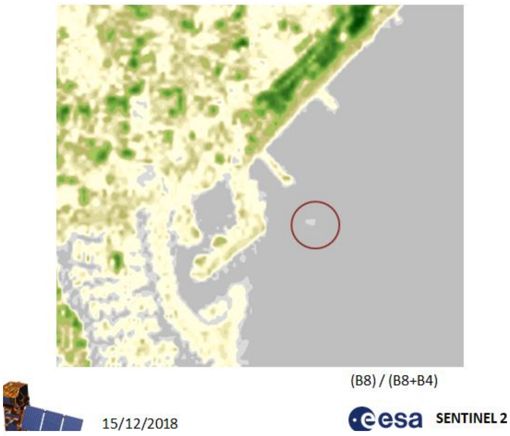


Figure 15: Detected target

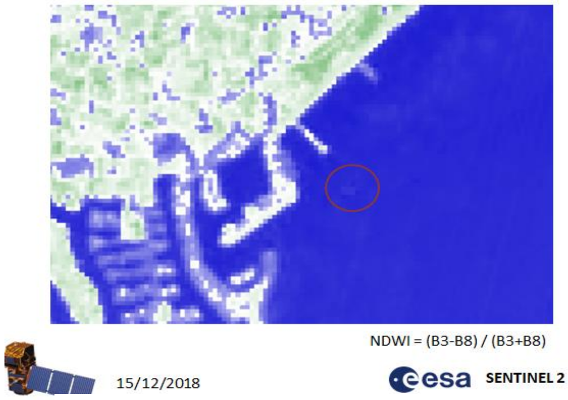


Figure 14: Poor Resolution picture

The picture on the right has a poor resolution because high band values were chosen and a wrong formula was used whilst the outcome was almost zero. It's almost impossible to spot our target. If the outcome was too high, the resolution would be bad as well. However, when the right values and a proper formula are used, high resolution will be obtained. Something equivalent was done and the following image resulted. The target is successfully detected.

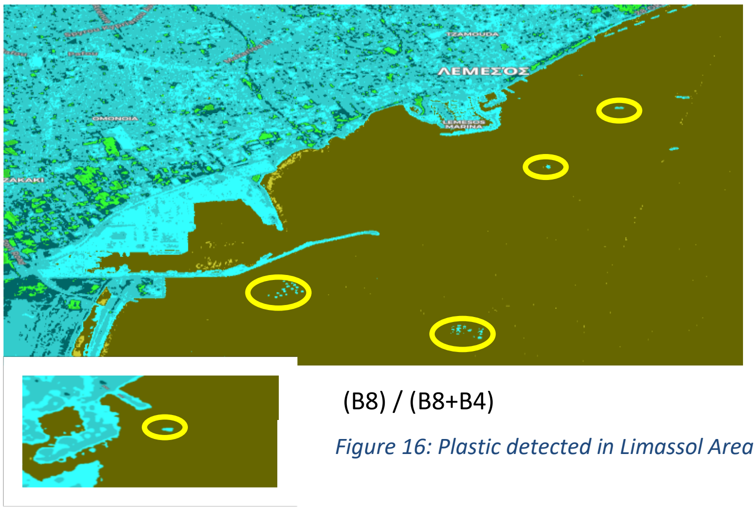
Following the above methodology, we managed to detect a 3x10m target, even though the minimum size of target should be 10x10m.

Afterwards, a code (**Appendix D**) was created using Python's Programming language. Depending on the formula we used to obtain the clearest possible resolution in order to be able to track objects whose band values verify the formula. This, of course, can happen if and only the material is plastic. I.e. when the code is inserted in the website mentioned before, it automatically colors the materials on the satellite picture which verify the formula, plastic.

Taking advantage of the fact that EO Browser is a free web application in which we could browse, compare and analyse various satellite data sources, we managed to insert the 'code' created, by following some steps, into the Sentinel hub website which can be definitely considered as pretty easy to be used, in order to investigate the detection of plastic existence. *https://www.sentinel-hub.com/* Sentinel Hub is a cloud based GIS platform for distribution, management and analysis of satellite data. First of all, by entering this site, we clicked in the explore hub which is the platform we could possibly find and observe the earth from above. Then, we clicked the EO browser where we could Browse and compare full resolution images taken from Sentinel-2, Sentinel-3, Sentinel-1, Sentinel-5P, ESA's archive of Landsat 5, 7 and 8, global coverage of Landsat 8, Envisat Meris, Proba-V and GIBS products in one place. Subsequently, we clicked start exploring and the platform appeared therewithal. Hence, by finding the country-city-area studied we have entered the date desired, in our case the 15th of December in which the plastic target was placed into the sea, and by clicking the search button, the pictures available and taken by the satellite 2- were provided. In our case, two measurements were taken approximately near the study area, but one of them was rejected due to the fact that the plastic target was not exactly in the picture taken (**Appendix C**).

Afterwards, by visualizing the most appropriate picture-the second one- we clicked at the custom button in order to find the platform needed to insert the code created (**Appendix C**).

Surprisingly, by inserting the specific code, more plastic in Limassol's sea area were clearly detected as well as our plastic target.



(B8) / (B8+B4)

Figure 16: Plastic detected in Limassol Area

The following flow diagram shows which steps we followed during the project and in what order:

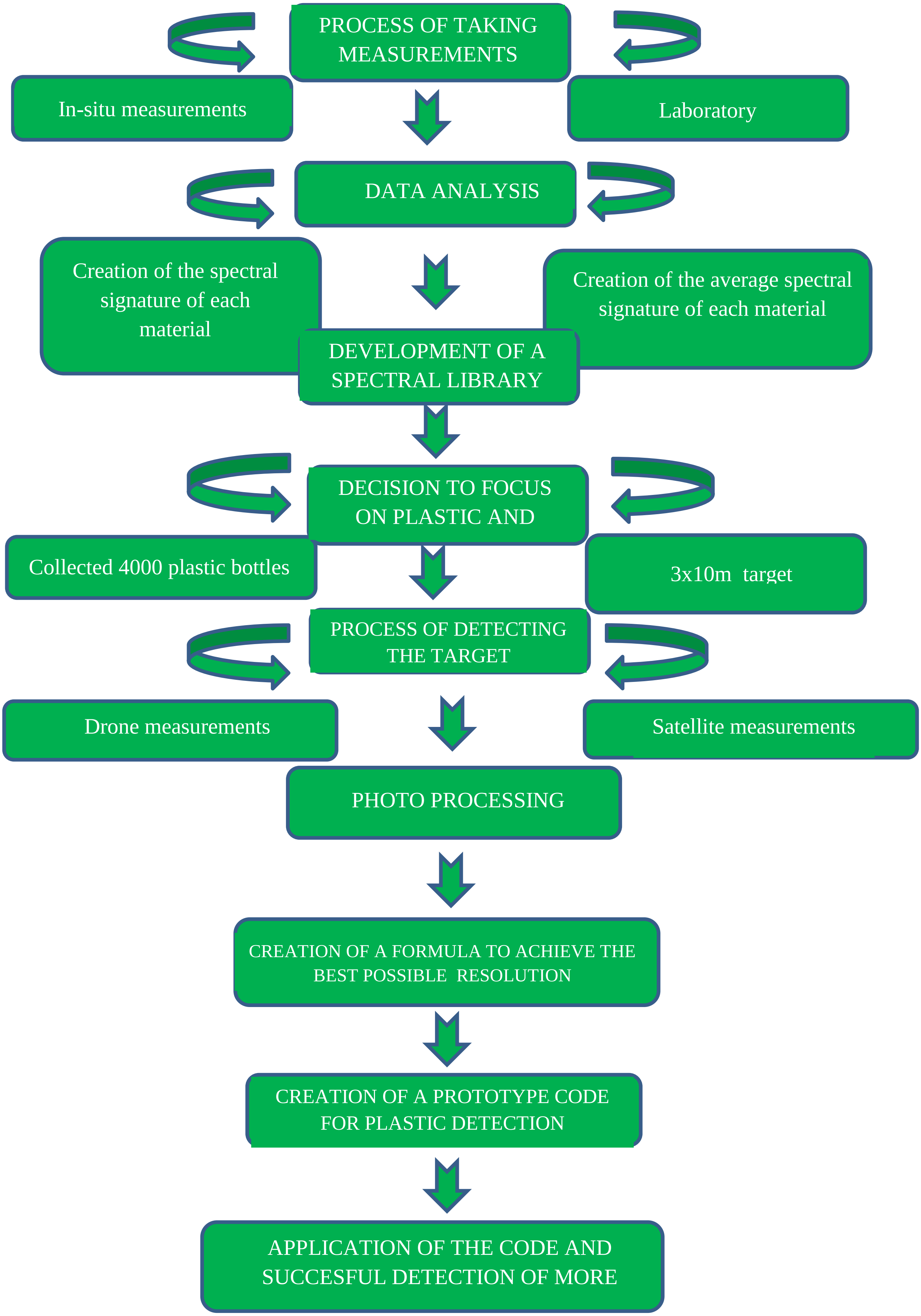


Figure 17: steps we followed during the project and in what order

Future application

By conducting experiments as the one described above, the code of several other waste can be deduced, thus they will be able to be detected as easily as plastic. The spectral library we have created, can totally contribute since it provides data on which researchers can rely on to verify the reliability of their results. So our spectral library should be considered a valuable tool that could be used as a waste indicator to future applications.

Cost analysis

The satellite method we suggest is completely free since information is provided by European satellites available at no charge. This way, accumulated plastic can be detected by just applying the code once the Sentinel 2- satellite passes, which is fairly usual, since it passes every 5 days. On the other hand a drone can be more expensive since it has to be bought, operated by a specialist and permission is needed to fly it. Using this method, even individual plastic units can be detected. This, of course, does not have to be done in regular intervals, but hardly once a month especially during summertime. Service is also another cost factor, since it is essential in order to analyze the data. It can be provided by the Eratosthenes Research Center at the Cyprus University of Technology.

Conclusion

The purpose of our research is to raise the awareness to people and make them more sensitive towards the environment. We intend to create a plastic free world where polluted beaches no longer exist. People who participated in this project became more responsible towards nature, especially marine life, because they have experienced the sea contamination at first hand. Moreover, the students from our school, who were constantly informed about the experiment we were conducting, realized the harmful effects of plastic to the environment and therefore started to recycle and reuse plastic bottles and other materials a lot more than before. The effect is noticeable and the results encouraging. Lastly, given that our project received media attention and was published in the local newspaper, people from all over Limassol have now been well informed about the pollution of the littoral zone and will hopefully adopt a new behavior that doesn't destroy nature.

In conclusion, our survey made people care more about nature. We believe that if the authorities adopt the method we suggest in order to track waste in sea areas and hopefully act accordingly to properly dispose it, an end to sea contamination, might be reached. Such results will be appreciated and more effort will be made by everyone, at least in our area and put more effort to keep the beaches clean. Both local residents and the authorities can be constantly informed about the sea pollution levels by simply checking the website we recommend. Thus, everyone will be able to enjoy clean beaches and safe plastic free environment.

Appendix A

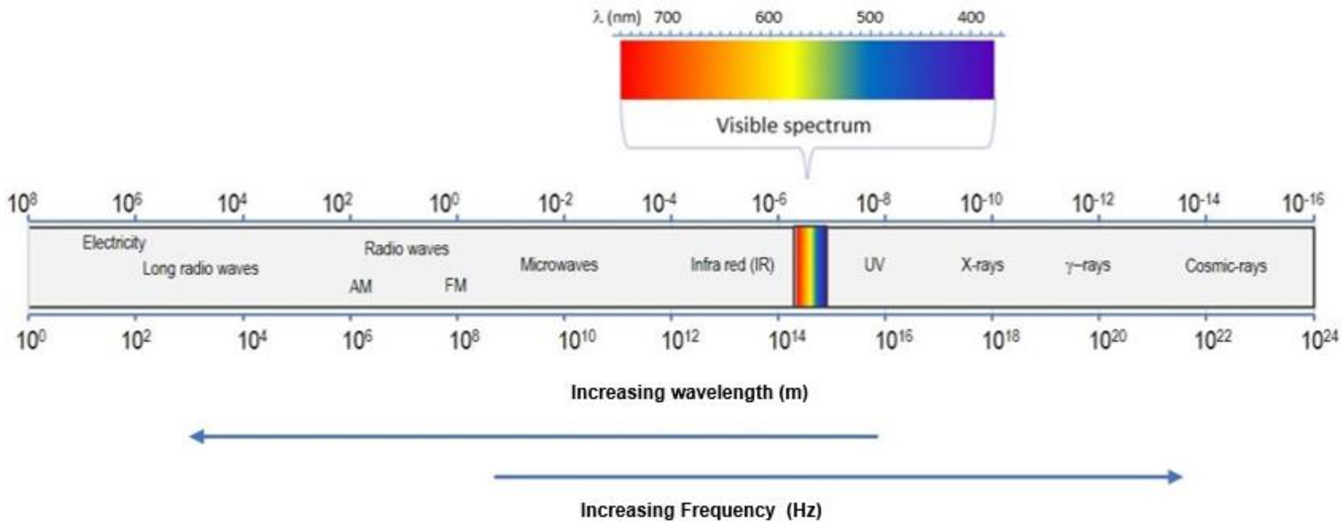
	Sentinel-2A	
	Central wavelength (nm)	Bandwidth (nm)
Band 1 – Coastal aerosol	**442.7**	**21**
Band 2 – Blue	**492.4**	**66**
Band 3 – Green	**559.8**	**36**
Band 4 – Red	**664.6**	**31**
Band 5 – Vegetation red edge	**704.1**	**15**
Band 6 – Vegetation red edge	**740.5**	**15**
Band 7 – Vegetation red edge	**782.8**	**20**
Band 8 – NIR	**832.8**	**106**
Band 8A – Narrow NIR	**864.7**	**21**
Band 9 – Water vapour	**945.1**	**20**
Band 10 – SWIR – Cirrus	**1373.5**	**31**
Band 11 – SWIR	**1613.7**	**91**
Band 12 – SWIR	**2202.4**	**175**

Table 1: Bands of Sentinel-2A

Appendix B

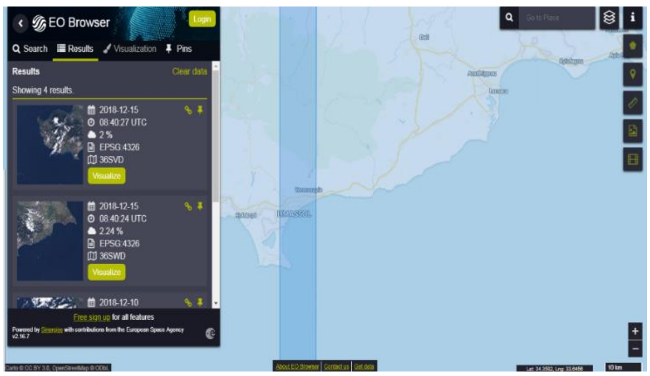
Electromagnetic spectrum, the entire distribution of electromagnetic radiation according to frequency or wavelength. Although all electromagnetic waves travel at the speed of light in a vacuum, they do so at a wide range of frequencies, wavelengths, and photon energies. The electromagnetic spectrum comprises the span of all electromagnetic radiation and consists of many subranges, commonly referred to as portions, such as visible light or ultraviolet radiation. The various portions bear different names based on differences in behaviour in the emission, transmission, and absorption of the corresponding waves and also based on their different practical applications. There are no precise accepted boundaries between any of these contiguous portions, so the ranges tend to overlap.

The entire electromagnetic spectrum, from the lowest to the highest frequency (longest to shortest wavelength), includes all radio waves (e.g., commercial radio and television, microwaves, radar), infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays. Nearly all frequencies and wavelengths of electromagnetic radiation can be used for spectroscopy.

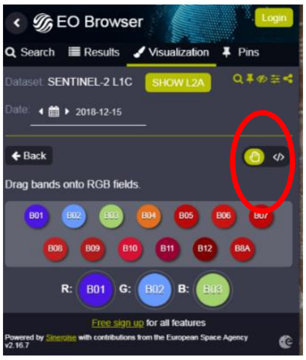


Appendix C

Taking advantage of the fact that EO Browser is a free web application in which we could browse, compare and analyse various satellite data sources, we managed to insert the 'code' created, by following some steps, into the Sentinel hub website which can be definitely considered as pretty easy to be used, in order to investigate the detection of plastic existence. https://www.sentinel-hub.com/ Sentinel Hub is a cloud based GIS platform for distribution, management and analysis of satellite data. First of all, by entering this site, we clicked in the explore hub which is the platform we could possibly find and observe the earth from above. Then, we clicked the EO browser where we could Browse and compare full resolution images taken from Sentinel-2, Sentinel-3, Sentinel-1, Sentinel-5P, ESA's archive of Landsat 5, 7 and 8, global coverage of Landsat 8, Envisat Meris, Proba-V and GIBS products in one place. Subsequently, we clicked start exploring and the platform appeared therewithal. Hence, by finding the country-city-area studied we have entered the date desired, in our case the 15th of December in which the plastic target was placed into the sea, and by clicking the search button, the pictures available and taken by the satellite 2- were provided. In our case, two measurements were taken approximately near the study area, but one of them was rejected due to the fact that the plastic target was not exactly in the picture taken



Afterwards, by visualizing the most appropriate picture-the second one- we clicked at the custom button in order to find the platform needed to insert the code created.



Appendix D

The code in this figure was translated to another programing language so as to be competent to interpret it. According to the formula used to obtain the clearest possible resolution, the most likely outcomes were predicted and matched with colors of our choice which will indicate the target on the picture once the steps of the code lines are followed and the picture is analyzed pixel by pixel.

```
let ndviColorMap = [
[-1.0, 0x000000],
[-0.2, 0xFF0000],
[-0.1, 0x9A0000],
[0.0, 0x660000],
[0.1, 0xFFFF33],
[0.2, 0xCCCC33],
[0.3, 0x666600],
[0.4, 0x33FFFF],
[0.5, 0x33CCCC],
[0.6, 0x006666],
[0.7, 0x33FF33],
[0.8, 0x33CC33],
[0.9, 0x006600]
];
function index(x, y) {
return (x) / (x + y);
}
function toRGB(val) {
return [val >>> 16, val >>> 8, val].map(x => (x & 0xFF) / 0xFF);
}
// We should interpolate between neighboring colors
function findColor(colValPairs, val) {
let n = colValPairs.length;
for (let i = 1; i < n; i++) {
if (val <= colValPairs[i][0])
{return toRGB(colValPairs[i-1][1]);
}
}
return toRGB(colValPairs[n-1][1]);
}
return findColor(ndviColorMap, index(B08, B04));
}
```

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