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Investigating Microplastics in the Mediterranean Coastal Areas – Case Study of Al-Hoceima Bay, Morocco

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ABSTRACT

The issue of microplastics pollution is gaining increasing attention as a global environmental concern. These tiny particles, measuring no more than 5 mm in size and coming in various shapes, can affect all types of marine ecosystems as they are easily consumed by a wide range of marine species. Al-Hoceima Bay, with its semi-enclosed nature and heavily affected anthropized coastline, was chosen as the study area for this research. The main objective was to investigate the presence of various microplastic types in Al-Hoceima Bay by implementing a sampling strategy along the coastline. This comprehensive approach was applied on a local scale within the bay (located in the northwest Mediterranean). Three stations were established in the bay, each located at different levels: the supralittoral, medilittoral and interlittoral. Microplastics were collected from these locations and classified into four categories based on their abundance. Digital microscopy was used to count the plastic particles and they were identified by Fourier transform-attenuated total reflectance infrared spectroscopy (ATR-FTIR). Results showed a higher presence of microplastics in water at 114 particles/L compared to sediment at 70 particles/L. The classification of samples revealed fibers as the most prevalent form, followed by fragments and films being the least commonly found. The abundance of fibers was found to be higher in water 90%, while in sediment it was 31%, however, fragments and leaves were found in higher concentrations in sediment. Polypropylene and polyethylene were identified as the major polymers used in the microplastics analyzed.

Keywords: Al-Hoceima bay, ATR-FTIR, microplastics, plastic, polymer.

INTRODUCTION

The origins of synthetic polymers can be traced back to the 1800s, specifically the 1860s. However, it was not until after World War II that the widespread use of plastics, or the "rise of plastics," began to take shape, leading to the growth and expansion of the plastic industry (Koumba 2018). Currently, the world produces around 362 million tons of plastic annually. Initially, plastics were developed to enhance and simplify human daily life, but as we can see today, the negative environmental effects associated with plastics are becoming more and more prevalent (Koumba 2018). Annually, a substantial amount of this plastic ends up in marine waters, where it gradually breaks down into smaller pieces and accumulates over time (Sutherland et al. 2010). Marine and freshwater contamination by plastics is one of the most pressing global concerns today, and this problem is particularly acute in Morocco. According to this study, immediate action is required from the government to address this issue (Shim and Thomposon 2015, Auta et al. 2017). In light of both the economic significance of tourism in Morocco, as well as the environmental and public health implications. Microplastics are tiny plastic particles measuring less than 5mm in size. These particles are considered pollutants of any ecosystem and are commonly found in oceans and seas. They can accumulate on the ocean floor or be ingested by marine life. Microplastics can be classified into two primary categories: primary and secondary microplastics (Giacovelli 2018).Primary microplastics are small particles that are primarily generated from industrial manufacturing, such as granules, fragments, and microbeads found in cosmetic products (Auta et al. 2017). Secondary microplastics are generated by the breaking down of larger plastic pieces, either through usage or through exposure to the elements in the environment (Lambert and Wagner 2018).

Microplastics can be transported to the shoreline via various means such as runoff, wind, or river systems. Once they reach an estuary, the particles will either sink to the seafloor or float to the surface depending on their physical and chemical properties. Factors like wind, ocean currents, and waves can cause these microplastics to wash up on shores or be redistributed into the marine environment. Over time, physical and chemical changes, or encrustation by living organisms, may cause the particles to settle. However, an increase in environmental hydrodynamics or biological processes can also lead to the resuspension of these microplastics. The interactions between shores and the seafloor with regards to microplastics are not fully understood, and it is believed that traditional shoreline processes such as erosion and accretion also have an impact. Additionally, microplastics on the sea surface can be transported long distances by ocean currents away from their source. This category encompasses fragments that originate from plastic waste in both marine and land environments, as well as films used in agriculture (Galgani et al. 2013) or fibers from textiles that are released into the environment during regular use or cleaning (Braun et al. 2018). Additionally, various forms such as spheres, fibers, leaves, and fragments exist (Thompson 2015). Table 1 illustrates the classification of microplastics based on shape, size, and polymer type. Typically, there are three main types of polymers: thermoplastics, thermosets, and elastomers. Microplastics found in aquatic environments typically take the form of granules, fragments, or fibers, and are composed of various polymers (Galgani et al. 2013, Smith et al. 2018). Particles such as PVC, polyester, polyamide that are largely dense tend to sink gradually and end up in the bottom of the seabed while polymers of light density such as polyethylene, polypropylene and polystyrene tend to float on the surface of the oceans. The main objectives of this paper were to analyze and classify microplastics based on their occurrence and density on four different beaches along the Mediterranean costal area of Morocco.

The improper disposal of microplastics is the primary reason for their presence in marine waters. Additionally, plastic waste can be transported through rivers and other bodies of water, ultimately ending up in the ocean (Yonkos et al. 2014, Lebreton et al. 2017). Furthermore, aquatic wildlife is particularly affected by this kind of debris, which can also pose risks of fouling, entanglement, injury, and ingestion (Colmenero et al. 2017, Franco-Trecu et al. 2017).

The serious threat that microplastics pose to the marine ecosystem affects all levels of the food chain. These plastics have become widespread throughout the oceans, making it a critical issue. Marine garbage, such as plastic, glass, metal, styrofoam, rubber, abandoned fishing equipment, and boats can all contribute to the problem. For example, in the Pacific gyre, microplastics make up between 60% and 80% of all marine debris in the world's oceans, making it the most prevalent form of marine debris (Gregory and Ryan 1997, Pawar et al. 2016).

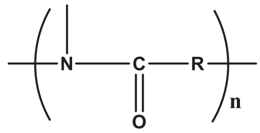
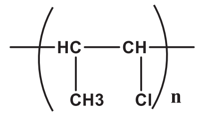
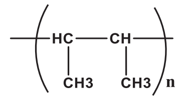
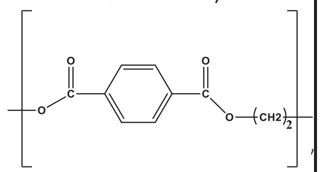
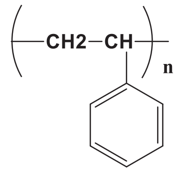
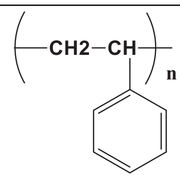
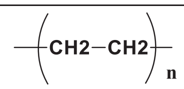
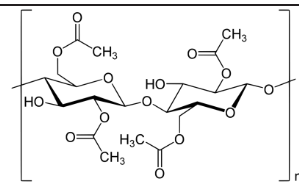
Items that can be classified as marine debris include ropes, nets, fragments, packaging, fishing litter, microplastics, and paper. This research article is the first to present an overview of the microplastic contamination of sediment at the bottom of the bay of Al-Hoceima and opens the way for other works which are more than necessary in terms of the evaluation of the risk of this issue. These reflections could lead, for example, to a reduction in the emission of microplastics within the framework of local contamination.

MATERIALS AND METHODS

Study area

The study area is located at the Al-Hoceima bay, and consists of three different sampled sites (Fig. 1). The city is a famous tourist destination and has a population of about 399654 (Benaissa et al., El Hammoudani and Dimane 2020, El Hammoudani et al. 2021). According to

Table 1. Main polymers found in microplastics [2]

Type of microplastics present (polymer)	Production in million tones	Commercial application	Estimated time for degradation (years)	Monomer
Polyamide (PA)/ Nylon	42	Guitar strings and pics, tennis racket strings, medical implants, electrical connectors, fishing line, tents gears	600	
Polyvinylchloride (PVC)	15	Film, pipe, insulation, roofing materials	>450	
Polypropylene (PP), Poylterephtalate (PET), Polystyrene (PS),	55 32	Rope, bottle caps, gear. Strapping, bottles, boats, textiles	450	  , 
Polystyrene(PS)	17	Cool boxes, floats, cups, utensils, take away packs	50	
Polyethylene PE HPDE LPDE	40 57	Plastic bags, storage, containers for milk	20	
Cellulose acetate(CA)	11	Cigarette butts	10–12	

projections by the Center d'Etude et de Recherches Démographiques (CERED), the provincial population would drop from 399,654 inhabitants in 2014 to approximately 393,704 inhabitants in 2024, an overall decrease of 5,950 people in the space of 10 years.

The Al-Hoceima Bay in northern Morocco is an ecologically and economically important area, particularly due to its fishing and tourism activities. However, Al-Hoceima Bay is also exposed to microplastic pollution, which has become an increasing problem for marine ecosystems worldwide. The city is a popular tourist spot and has an approximate population of 399,654 (du Maroc 2014) As per the estimates by the Center for Demographic Studies and Research (CERED), the population of the province is expected to decline from 399,654 inhabitants in 2014 to around 393,704 inhabitants in 2024, representing a total reduction of 5,950 people over a period of 10 years (du Maroc 2014, El Hammoudani et al. 2019, El Hammoudani and Dimane 2021).

The Mediterranean Sea coast of Al Hoceima bay is situated in the central region of northern Morocco. The bay is enclosed by Quilates (Ras Al Abed) to the east and Maure (Ras Al Abed) to the west. The coastal area under examination stretches for more than 60 kilometers. The Rhis and Nekor rivers, that run through the coastal zone, make up one of the biggest alluvial floodplains in the Moroccan Mediterranean.

This region's coast is one of the well-known tourist sites in Morocco. The research was conducted on five different beaches (Fig. 1). The Al-hoceima urban beaches are primarily used for swimming and sunbathing by local and national tourists from June to September. But, they have a significant recreational use throughout the year as they provide a space for walking, enjoying the scenery, playing sports, and participating in other activities.

The sites selected for the study were chosen based on criteria that may affect the distribution of waste along the coast in order to encompass the entire Al-Hoceima bay. The geographical coordinates, beach typology and activities in the four beaches are shown in Table 2. The coast of Al Hoceima bay is located in the central part of northern Morocco, on the Mediterranean Sea (El Hammoudani et al. 2019, Bourjila et al. 2021). The bay is encompassed between two headlands: Quilates to the East, and Maure (Ras Al Abed) in the West. The total length of the studied coastline is over 60 km, the coastal area is also one of the largest alluvial floodplains of the Moroccan Mediterranean, formed by two important rivers, the Rhis and the Nekor (Taher 2022).

The coast of this region is one of the most traditional tourist destinations of the Moroccan mediterranean. The study was conducted on five beaches (Fig. 1). The urban beaches of al hoceima are fundamentally used for swimming and sunbathing by beach users and national tourists starting from June till September, nontheless, they have an important recreational use throughout the year because they are a place for walk exercises, to enjoy the scenery, play sports as well as attending other activities. The geographical coordinates, beach typology and activities in the four beaches are shown in Table 2.

Sample collection

The sites chosen to be studied were made on the basis of certain criteria that may influence the distribution of waste on the coast in order to cover the entire bay of Al-Hoceima (Fig. 1).

The sites chosen for the study were selected based on criteria that may influence the distribution of waste along the coast in order to encompass the entire Al-Hoceima bay. The samples were collected on days with calm sea conditions between June and august 2022. The techniques employed to measure microplastics (μPs) varied based on the size range being studied. In general, plastic fragmentation results in small particles outnumbering larger ones. The sampling was performed

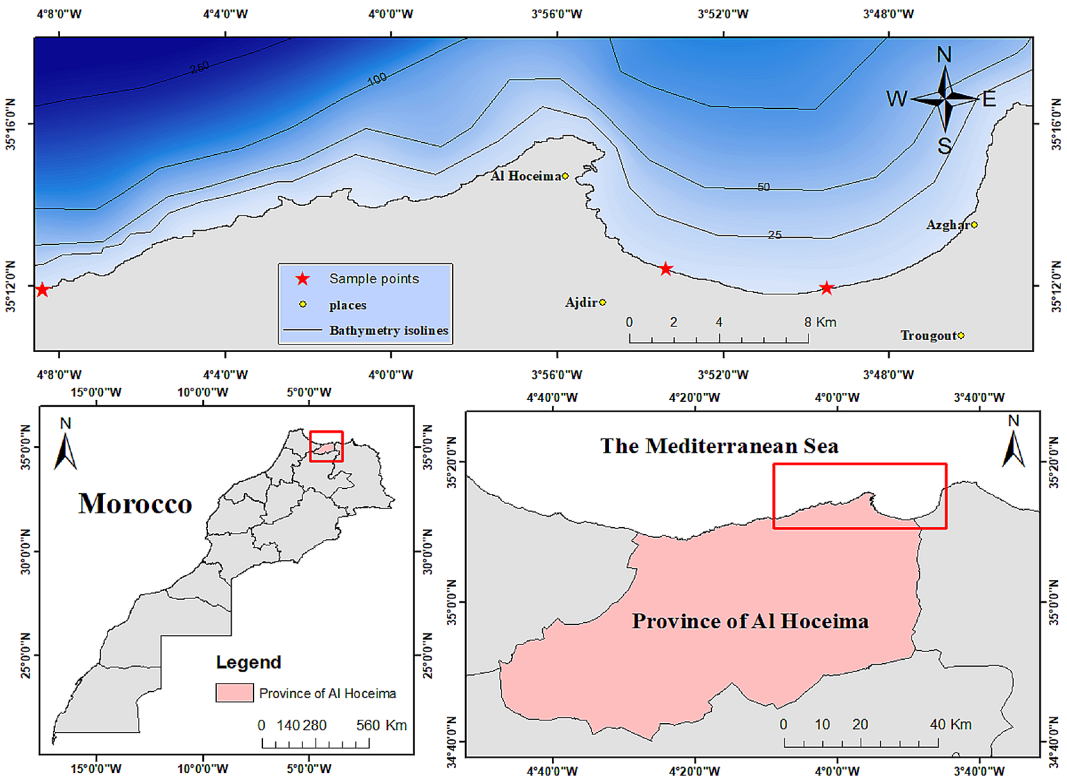


Fig. 1. Sampling sites in the Al-Hoceima bay

Table 2. Geographical coordinates, beach typology and activities in the four sampling sites

Beach	Coordinates	Beach typology	Activity
Sfiha	35.207491,–3.889892	Urban	Tourism and fishing
Souani	35.199406,–3.825318	Urban	Tourism and fishing
Tikit	35.198898,–4.140350	Remote	Tourism and fishing
Calabonita	35.234713,–3.922526	Urban	Tourism and fishing

on marine life at the shores of Sfiha, Souani, and Tikit, as well as samples from the diving club. A manta net was used to collect microplastics floating on the surface of the seawater at the shore. The samples were studied in the laboratory to identify and quantify the different types of microplastics present. Additionally, samples were taken at different depths to have an overall view of the distribution of microplastics in the water (Benaissa, Bouhmadi et al. 2020).

To obtain samples of marine fauna, we hired a local diving team to collect a few samples based on our specifications. It is not possible to use a single method to study the full range of plastics sizes, from small monomers to large plastics. Different methods are required depending on the size range being studied. For example, large plastics can be counted visually in their natural environment, but microplastics must be processed in a lab before they can be accurately quantified and identified (Fig. 2). The samples were collected and put into glass vials, and transported to the lab for analysis. There, the samples undergo a cleaning process to eliminate any organic materials and plastics larger than 5mm that could affect the microplastics analysis. The cleaned samples are then sorted using a blend of optical and mechanical techniques to distinguish the various types of plastics, these are subsequently separated into groups such as hard plastics, soft plastics, pellets, films, and filaments. Finally, samples from each group are examined to identify their chemical composition and trace their origin (Fig. 3–4).

Extraction of μPs from water and sediment samples

In order to correctly identify and measure the amount of microplastics in water samples, it is crucial to remove any natural debris that may be present. A common method to filter water samples is by using glass fiber filter paper, such as Whatman 1823-047 Grade GF/D, which has a 4.7 cm diameter and a pore size of 2.7 μm, and is obtained from Cytiva in Uppsala, Sweden (Fig. 5 and 6). However, plastic particles can be difficult to identify when they are mixed with organic debris such as algae, sediment and biological material. To solve this problem, researchers often use a pre-treatment technique such as using hydrogen peroxide for wet oxidation or using density separation to remove

Fig. 2. Near surface microplastic collecting manta net

Fig. 3. Waste recovery by flotation

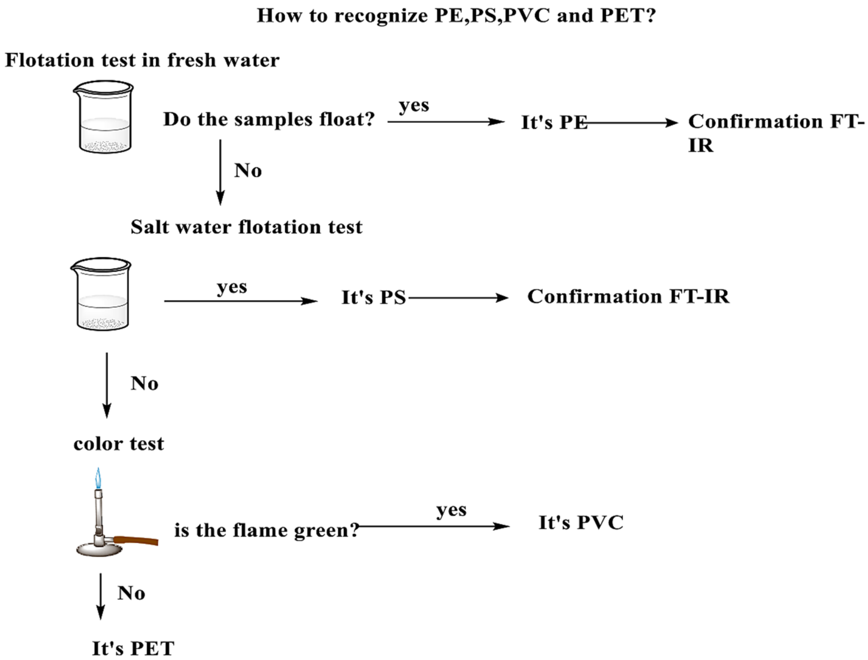


Fig. 4. Identification of a plastic material

organic debris from samples; this is to minimize identification and estimation errors of small plastic particles. In this study, a wet oxidation protocol with 30% concentrated hydrogen peroxide was performed and the sample was heated at 40°C for a time period of 24 to 48 hours.

Polymer identification by ATR-FTIR spectroscopy

Infrared spectroscopy is one of the most widely used spectral methods for the analysis of organics in general and polymers in particular. Fourier Transform Infrared Spectroscopy (ATR-FTIR) allows through the detection of characteristic vibrations of chemical bonds, to analyze the chemical functions present in the material. It is based on the absorption of infrared radiation by the material analyzed. When the energy associated with the wavelength provided by the light beam is close to the vibrational energy of the molecule, the latter will absorb the radiation to record a decrease in the reflected or transmitted intensity. The infrared range between 4000 cm^{-1} and 400 cm^{-1} (2.5–25 μm) corresponds to the fundamental vibrational energy range of molecules (Hesse et al. 1997).

The microplastics obtained were measured with a Shimadzu IRTracer-100, This system achieves excellent sensitivity with an SN ratio of 60,000:1, high resolution at 0.25 cm^{-1}, and high-speed scanning capable of 20 spectra/second. The performance of medium and higher end models is supported by high reliability including advanced dynamic alignment and an interferometer with a dehumidifier. This is compatible with applications active in a variety of circumstances, with a library of approximately 12,000 spectra and data analysis programs for contaminant analysis.

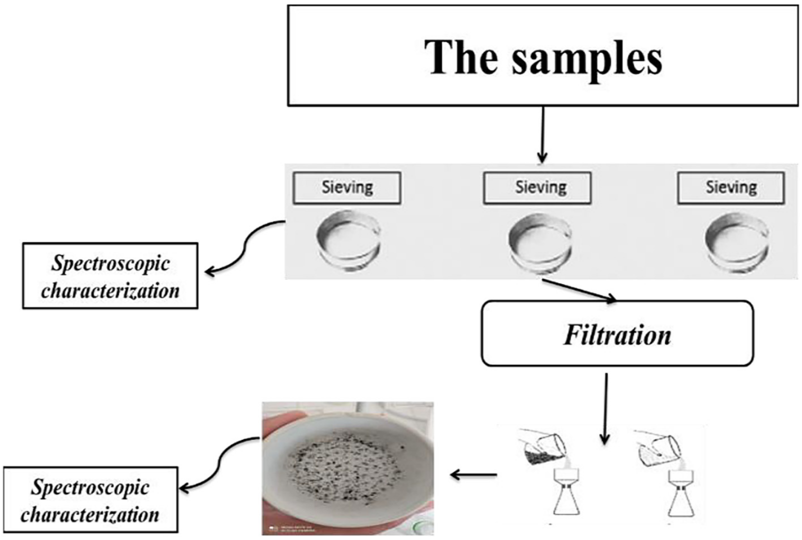


Fig. 5. Scheme of the different steps involved in sampling and analysis of MPs

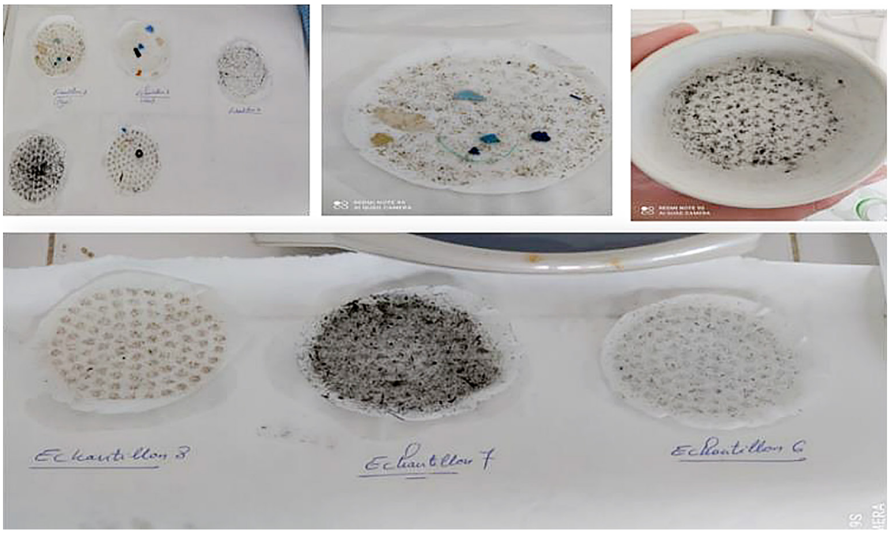


Fig. 6. Microplastics obtained

Data analysis

Data analysis and mapping were performed using Microsoft Excel 2010, ChemDraw professional 16.0 and OriginPro 8.0.

RESULTS AND DISCUSSIONS

Identification of microplastics by ATR-FTIR

The next stage in evaluating plastic materials involves determining their chemical composition. This type of analysis not only allows for more accurate assessment of the plastic's appearance, but also helps identify the origins and distribution of microplastics. Typically, microplastics are visible to the naked eye, but in this case, a Fourier transform infrared spectrometer along with an attenuated total reflectance accessory was used for specific polymer identification. The data revealed that fragments were the most common type of microplastics encountered (60%), followed by fibers (19%), films (17%), and foams (4%). Notably, no microbeads were found in this study. The majority of microplastics were identified as belonging to three polymer families: PE, PP, and PVC. We assigned the various bands observed on the spectrum (Fig. 7) based on the scientific literature reported in this topic:

- the bands between 497–822.10 cm^{-1} are due to the deformation vibration of aromatic C-Hs;

- the bands between 1115–1197 cm^{-1} corresponding to an elongation vibration of the C-N bond;
- the band at 1481 cm^{-1} represents the extension of the C = C double bond;
- the C = N double bond elongation is between 1478 cm^{-1} and 1485 cm^{-1}.

The various bands observed on the spectrum (Fig. 8) were assigned based on the scientific literature. The infrared (IR) absorption spectrum of polypropylene (PP) typically shows several strong absorption bands that are characteristic of this polymer. One of the most prominent bands in the PP spectrum is the CH stretching band, which is usually located between 2900–3000 cm^{-1}. This band is usually sharp and intense, and can be used to confirm the presence of PP in a sample. Another prominent band in the PP spectrum is the CH bending band, which is located between 1450–1550 cm^{-1}. This band is also sharp and intense, and can be used as an additional confirmation of the presence of PP. The CH2 scissoring band is also located at around 1450–1480 cm^{-1}, which is a

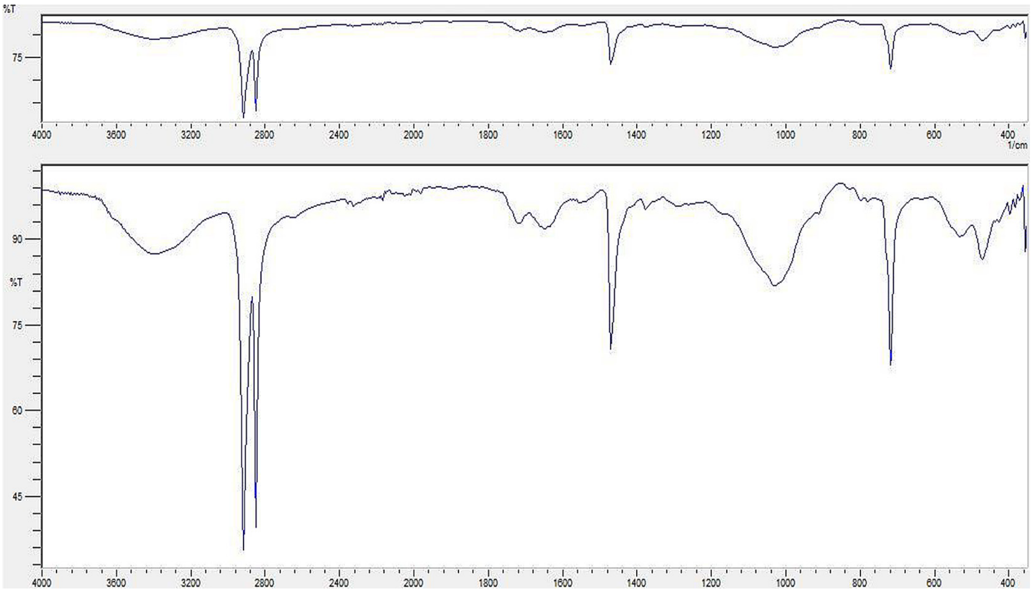


Fig. 7. ATR-FTIR spectrum of a copolymer

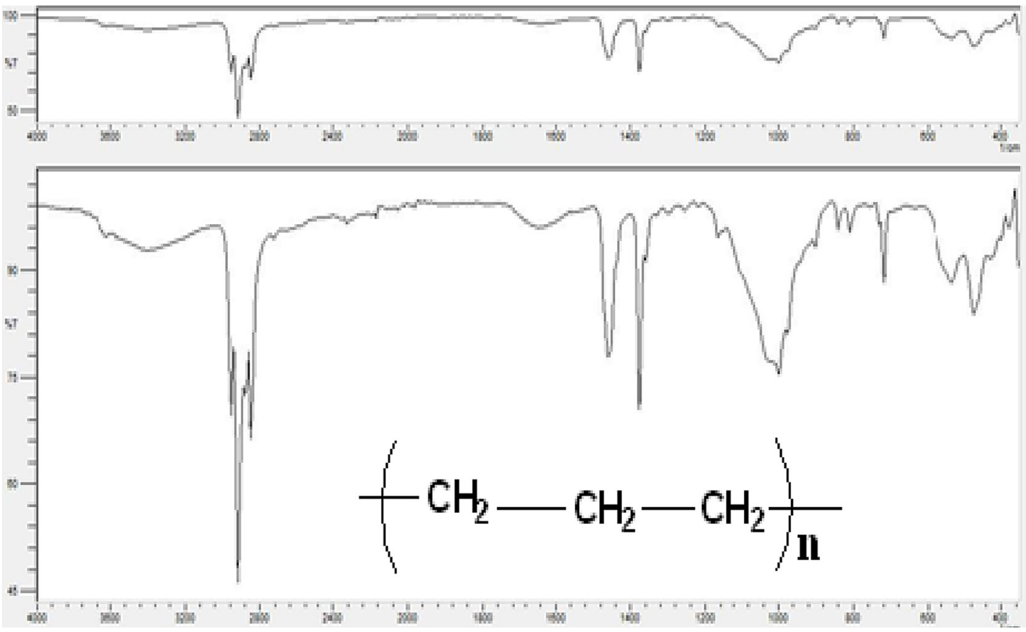


Fig. 8. ATR-FTIR spectrum of polypropylene (PP)

double. The CH2 bending band is located around 1375–1400 cm^{-1}. There are also some other bands that can be seen in the PP spectrum such as C-H out of plane bending at around 730 cm^{-1}, C-C stretching band located around 900 cm^{-1} and C-C bending at around 550–700 cm^{-1}.

We proceeded to the allocation of the various bands observed on the spectrum (Fig. 9) based on the scientific literature. One of the most prominent bands in the PE spectrum is the CH2 stretching band, which is usually located between 2900–3000 cm^{-1}. This band is usually sharp and intense, and can be used to confirm the presence of PE in a sample. Another prominent band in the PE spectrum is the CH2 bending band, which is located between 1450–1550 cm^{-1}. This band is also sharp and intense, and can be used as an additional confirmation of the presence of PE. PE is a semicrystalline polymer, the degree of crystallinity affects the shape and position of the bands, a high degree of crystallinity will give a broader band, while in a low crystalline sample the bands will be sharper and more intense. There are also some other bands that can be seen in the PE spectrum such as C-H out of plane bending at around 730 cm^{-1}, C-C stretching band located around 900 cm^{-1} and C-C bending at around 550–700 cm^{-1}. Spectrum (Fig. 10) the infrared (IR) absorption spectrum of polyvinyl chloride (PVC) typically shows several strong absorption bands that are characteristic of this polymer. One of the most prominent bands in the PVC spectrum is the C-Cl stretching band, which is usually located between 600–800 cm^{-1}. This band is usually sharp and intense, and can be used to confirm the presence of PVC in a sample. Another prominent band in the PVC spectrum is the C-H stretching band, which is located between 2900–3000 cm^{-1}. This band is also sharp and intense, and can be used as an additional confirmation of the presence of PVC. PVC is a semicrystalline polymer, so the degree of crystallinity affects the shape and position of the bands, a high degree of crystallinity will give a broader band, while in a low crystalline sample the bands will be sharper and more intense.

There are also some other bands that can be seen in the PVC spectrum such as C-H bending band at around 1450–1550 cm^{-1}, C-C stretching band located around 900 cm^{-1} and C-C bending at around 550–700 cm^{-1}. Microplastics pose a threat not only to aquatic life, but also to terrestrial organisms, potentially causing similar or even more severe harm. Scientists are concerned that the effects of microplastics on soil and sediment could have a detrimental impact on terrestrial ecosystems in the long-term. This has been supported by findings that microplastic particles were present in the samples taken from the throats and nostrils of eight individuals with diverse dietary habits and residing in different

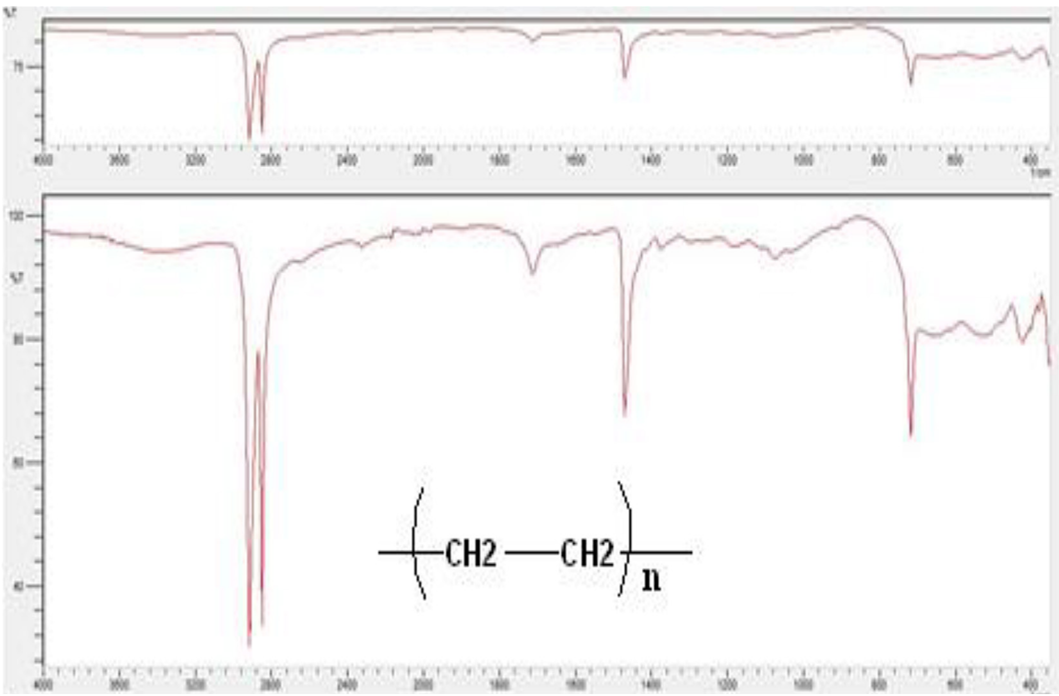


Fig. 9. ATR-FTIR spectrum of polyethylene (PE)

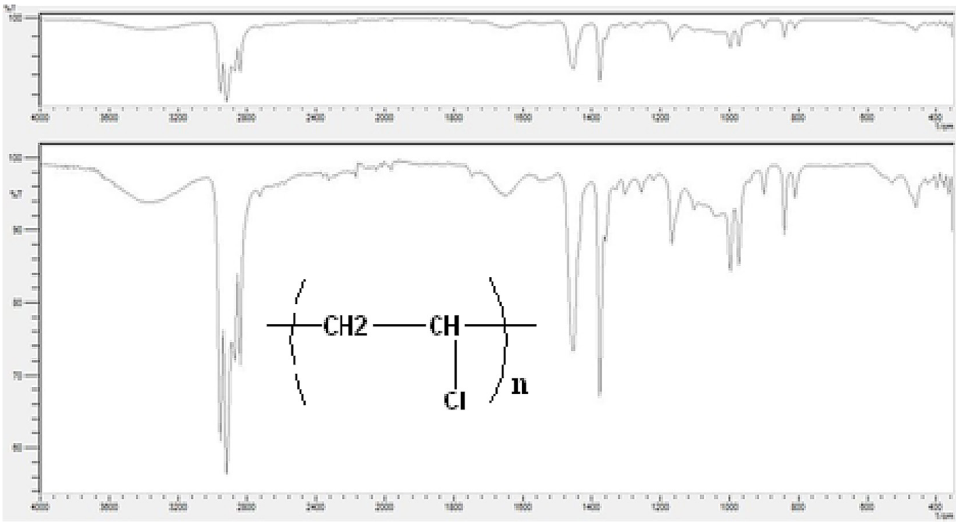


Fig. 10. ATR-FTIR spectrum of polyvinyl chloride (PVC)

countries, including Italy, Finland, Poland, the UK, Austria, Russia, Japan, and the US(Iñiguez, Conesa et al. 2017).

The fragments were almost uniformly contributed to PP, PE and PVC. They probably came from commonly used consumer products (e.g. plastic bottles, containers, toys, decoration and construction materials, etc.) which were broken down into small pieces in many ways as secondary μPs (Hidalgo-Ruz, Gutow et al. 2012). Fiber μPs appear to come from textile products. Analysis of the size distribution indicated that the majority of μPs (up to 69%) were in the range above 500 mm (40%) and between 62.5 and 125 mm (29%). The minority of MPs came from the average size of 125–250 mm (12%) coming mainly from fragments of PE, and 250–500 mm (11%) with PVC and PE as the dominance. Small size particles were 25–62.5 mm (8%) which came mainly from the fragment in plastics.

The following Table 3 shows the different plastic particles, the percentage of each type, as well as the measurement of sample sizes. In minor amounts, the Table also demonstrates the existence of PS (for example, food packaging), PA (rugs and carpets, fixtures, locksmith parts), and PVC (pipes, food packaging, etc.). They do have main or secondary sources.

Distribution of microplastics in Al-Hoceima Bay

The Al-Hoceima Bay in Morocco is an area that is heavily impacted by industrial and tourism activities. This has resulted in a high level of pollution in the bay from microplastics. Microplastics are plastic particles that are smaller than 5 mm in diameter and primarily come from the breakdown of plastic products that have been discarded into the sea, such as plastic bags and bottles.

This study has revealed that the levels of microplastics in the Al-Hoceima Bay are alarmingly high. The beaches in the bay have been found to contain high amounts of microplastics, with pollution rates reaching up to 4200 particles per square meter between june 2022 to late august 2022. Additionally, the coastal waters of the bay also have high concentrations of microplastics, reaching up to 3800 particles per liter. Microplastics have detrimental effects on marine environments, particularly on marine organisms that ingest them. They can also cause damage to coastal ecosystems and water quality. It is crucial to implement measures to reduce microplastic pollution in the Al-Hoceima Bay and in other coastal areas around the world.

The density of microplastics for each sample was determined by using the equation:

$$C = \frac{n}{A} \quad (1)$$

where: C – represents the microplastics density per square meter, n – the number of particles, A –represents the area of the beach that was examined.

The findings indicate that the distribution and concentration of microplastics vary from one area to another. These variations may be attributed to factors such as ocean currents, tides, and the breakdown of plastic waste into small particles forming microplastics. Human activity such as fishing is

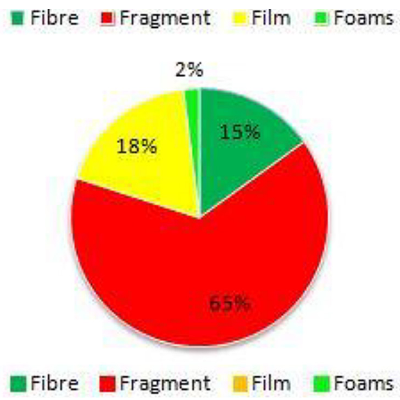


Fig. 11. Characterization of µPs particles according to their polymer speciation and size distribution

Table 3. Different plastic particles and the percentage of each type

Type of particles	Percentage (%)	Sizes
PE (polyethylene)	12%	The sizes vary between 0–5 mm and >5
PP (polypropylene)	25%	
PS (polystyrene)	27%	
PVC (Polychlorure de vinyle)	11%	

limited. However, as urban beaches become more popular among visitors, the amount of plastic waste disposed on these beaches also increases. We observed that beaches with higher tourism activity had higher densities of microplastics, such as Calabonita and Souani Beaches. High records of plastic waste were also found on recreational beaches like Sfiha Beach. Additionally, during our surveys, we noticed the lack of designated plastic waste bins on all four beaches. The analysis of water samples revealed varying levels of microplastics (MPs) concentrations, with the highest amount observed in the Sfiha sample at 114 particles per liter, followed by the Souani sample at 200 particles per liter, and the Tikit sample at 70 particles per liter. Three distinct shapes were identified among the MPs, including fibers, pieces, and foils. The majority of the MPs were fibers. In the water samples, 87–95% of MPs were fibers, while in the sediments, 24–50% were fibers. A small proportion of fragments (2–11%) were mostly seen in Sfiha and Souani samples, and a small number of foils (0–4%) were detected in the water samples.Within the same site, the proportion of different shapes varies in different compartments, for example, the quantity of fragments is much higher in the sediments (31–73%, with the highest in Souani and the lowest in Sfiha) than in the water phase (1–12%). Only Souani revealed more fibers than fragments in the sediments. Furthermore, the number of foils was higher in the sediments for Souani and Sfiha (both 18/19%) than in the other two samples (Tikit and other samples 2%). This indicates that the origin, age, and environmental factors can affect the distribution and shape of the MPs.

Various authors have discussed the existence of µPs in the world's oceans (Frere et al. 2017, Isobe et al. 2017, Suaria et al. 2020). Research estimates indicate that every year, millions of tons of plastic waste finds its way into the world's oceans, primarily from land-based sources, including secondary microplastics (Jambeck et al. 2015, Lebreton et al. 2017, Thiel et al. 2018), and carried to the oceans through freshwater (Cózar et al. 2014). It can be found in large clusters of marine debris (Singh and Sharma 2008). The prolonged and sustained degradation of larger fragments of marine plastic is the result of the environmental resilience and persistence of the plastic polymers produced. However, there is limited information available about the presence, distribution, types, and contributions of inland waters, including estuaries, rivers, and lagoons, in Africa, particularly in Morocco (Lusher et al. 2017).

This study found that the estimated number of MP particles in sediment and water was between 70–200 particles/L. In the water, the highest number of MPs was recorded in Souani (200 particles/L) and the lowest in Tikit (70 particles/L), with 87–95% of fibers. Infrared spectra analysis confirmed the presence of PE, PP, and PVC polymers, with Polyethylene (PE) being the most prevalent polymer, which has been previously reported (Singh and Sharma 2008). Martellini et al. compiled a study of MP in coastal

Table 4. Amount of particles in each site

Particle type	Sfiha beach	Souani beach	Tikit beach	Calabonita beach
Fragments	30	60	5	45
Film	6	9	0	4
Pellets	1	7	0	8
Granules	0.5	10	1	12
Foams	20	40	3	28
Total number of particles	57.5	126	9	97
Number of particle per km^2	47916	105000	7500	80833

areas in the Mediterranean Sea. The study results showed that the lagoon and estuaries were the most polluted sites, and sediment was the primary sample studied (Martellini, Guerranti et al. 2018). A study published previously has examined the presence of MPs in sediments of 7 beaches along the central Atlantic coast of Morocco (Abelouah et al. 2022). The study found higher quantities of MPs, ranging from 7680 MPs/kg to 34,200 MPs/kg, which were much higher than what was reported in this study. The significant difference in the results can be attributed to the vast size of the beaches along the central Atlantic coast, the activities conducted on the beaches, and tourism activities. For example, in 2019, Agadir (on the central Atlantic coast) received 5,887,154 visitors, significantly more than the 36,656 visitors to Al-Hoceima (Cózar et al. 2014).

In many studies, particles were first examined visually and then verified analytically. As a result, the results of these studies, like ours, are not entirely reliable as only a small portion of the estimated particles were verified through analysis. The polymers found in all studies were similar to those found in our study, with PP and PE being the most prevalent. The Microplastic Pollution Index of the study area was used to assess the presence of MPs in the environment by calculating the relationship between the number of MPs and the study area, resulting in a ranking based on five different classes, ranging from "very low presence" to "very high presence" of MPs (Table 4). In simpler terms, this index determines the degree of freedom from MPs and the likelihood of reaching and maintaining that state (Vickers 2017). The formula used to calculate the index is:

$$C = \frac{n}{A} \tag{2}$$

The Microplastic Pollution Index (MPPI) is calculated by considering the number of MPs per area surveyed, by taking into account the relationship between the number of MPs and the total surface of the quadrants. The data indicates that all the studied areas have MPs, with Tikit as the area with the lowest presence of MPs, and described as having a good environmental status, where protective measures are necessary. In contrast, Souani was found to have higher amounts of MPs, classified as high presence of MPs, with an unsatisfactory and bad environmental status, requiring urgent intervention, and even restoration measures.

Effects of microplastics on the ecology, the food chain, and human health

Microplastics (MPs) are small plastic particles measuring less than 5mm in size and are found in oceans, lakes, rivers, and other aquatic environments. These small plastic particles can have negative impacts on the ecology of the environment, the food chain, and human health.According to several research, more than 50 different fish species eat trash in the ocean. These numbers inevitably affect the 2.9 billion people who rely on it for 20% of their protein requirements.

First, regarding the ecology, MPs can affect the entire ecosystem by altering the physical and chemical properties of the environment. They can also harm or kill aquatic organisms by ingestion, entanglement, or suffocation, and also can absorb toxic compounds such as persistent organic pollutants that can be harmful to the organisms. Secondly, MPs can enter the food chain by being ingested by aquatic organisms, and then passed up through the food chain to larger organisms, including fish and shellfish, which are consumed by humans. This can lead to the accumulation of MPs and toxic pollutants in the tissues of these organisms, posing a risk to human health.

Finally, regarding human health, the ingestion of MPs can lead to the accumulation of toxic pollutants in the body, which can cause a range of health problems such as gastrointestinal problems, respiratory issues, and developmental and reproductive disorders. Also, the presence of MPs in drinking water and food can pose a health risk.

In summary, Microplastics are a growing problem in the world's oceans, lakes, rivers, and other aquatic environments, and they can have negative impacts on the ecology, the food chain, and human health. It is important to take action to reduce the production and use of single-use plastics and to increase recycling and waste management efforts to reduce the amount of MPs in the environment.

Fig. 12 illustrates the formation of microplastics and the effects they have on the food chain and human health. Marine animals such as turtles, fish, and birds are particularly vulnerable to plastic pollution. Some fish species may even lose their agility and become smaller as a result. These impacts ripple through the food chain, ultimately harming the consumer, who is affected by pollution caused by others. Furthermore, even if they do not experience direct health impacts, terrestrial animals are still at risk of infection through vectors such as insects.

CONCLUSIONS

In conclusion, the study of microplastics in the Mediterranean coastal areas, specifically in Al-Hoceima Bay, has highlighted the significant presence and distribution of these pollutants in the area. The investigation found a variety of types of microplastics, with fibers being the most prevalent. It was also discovered that the highest concentrations of microplastics were found in the coastal areas, particularly in the vicinity of human activities such as fishing ports and tourist beaches. This research emphasizes the need for continued monitoring and management of microplastic pollution in the Mediterranean coastal

Table 5. The MPPI calculates the relationship between the amount of MPs and the area surveyed to determine the presence of MPs in study area

Microplastics pollution index (MPPI)	Type	Description	Study area
0 to 2	Very low abundance/ absence	No MPs are seen	Tikit
2 to 5	Low abundance	Some MPs are in the sample	Sfiha
5 to 15	Moderate abundance	A considerable number of MPs seen	Calabonita
15 to 25	High abundance	A lot of MPs are in the sample	Souani

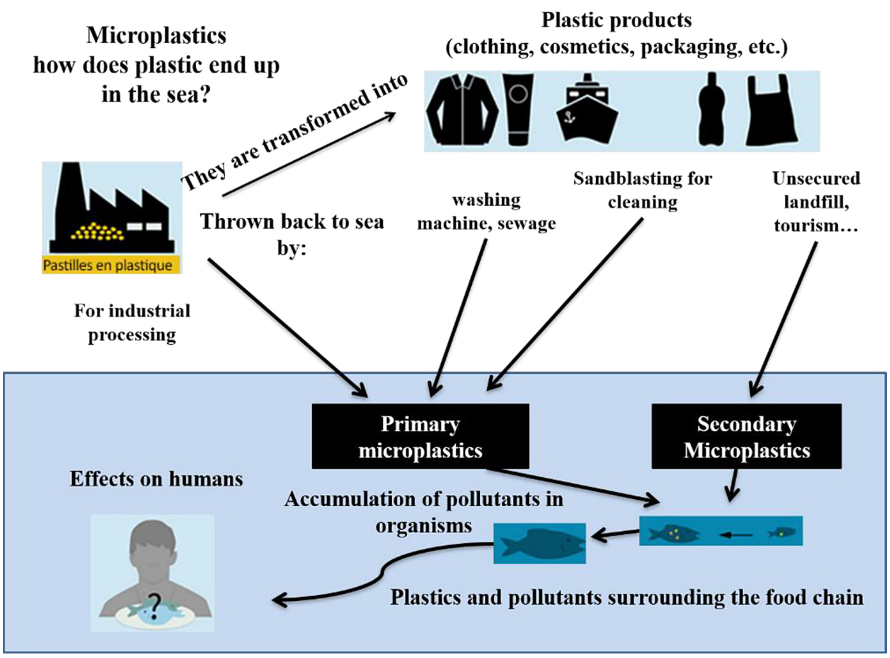


Fig. 12. Plastic and microplastic cycle

areas to protect the ecosystem and human health. It also suggests the importance of raising awareness and implementing preventive measures such as reducing plastic use and properly disposing of waste to curb the influx of microplastics in the marine environment.

Additionally, the study highlights the importance of international cooperation in addressing the issue of microplastic pollution. The Mediterranean Sea is a semi-enclosed sea, bordered by several countries, and the problem of microplastics cannot be effectively addressed by a single country alone. A coordinated approach is needed to effectively manage and reduce the influx of microplastics into the sea. Furthermore, the study also emphasizes the need for further research to understand the long-term impacts of microplastics on the marine ecosystem and human health. As microplastics can persist in the environment for hundreds of years and can absorb toxic chemicals, they can have severe consequences on the health of marine organisms and ultimately on human health through the food chain. It is crucial to continue monitoring and investigating microplastics in the Mediterranean coastal area to fully understand the extent of the problem and to develop effective solutions to address it.

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