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إلى أبي رحمه الله ... عرفانا و امتنانا لا يفي أن منحني اسمي و معناي

إنّا قصائدُك الجميلة يا أبي

الله أبدعنا وأنت رويتنا

نثر هي الأيام نثر باهت

وتصير شعراً كلما اتقدت بنا

يبقَى معي منك الحياة قصيدة

والموت شعرًا والخلود مؤذنا

أنصتْ لصوتي فيك صدقاً جارحاً

فالموت يعجز أن يبدّل صوتنا

لا تحمل اسمي فوق صدرك صخرة

أسمائنا وطنٌ يعمّره السنا

كنْ ما أُحبك.. كمْ أحبك فارساً

لا ينحني فقرًا ولا يطغَى غنى

لا يُشبه الشعراءَ ، يُشبه شِعرَه

إن البنَاء الفذ يُشبه من بَنى

لا دمعَ يبقى ، كلُّ دمع زائل

إلاّ الذي بالحبُ يغسلُ صدرنا

أ . ب

Abstract

The Mediterranean Sea has been identified as a hotspot for plastic pollution. The present study is the first attempt to provide original data on plastics debris occurrence in beach sediments along 50 km of the Skikda Gulf in Algeria (southwestern Mediterranean Sea). Sediment samples from seven beaches along the Skikda coastline were collected to extract, quantify, and characterize plastic debris. Plastics particles were classified regarding their size into macroplastics (particles > 25 mm), mesoplastics (particles ranging between 5 and 25 mm), and large microplastics (particles ranging from 1 µm to 5 mm). Overall, microplastic was the most abundant size fraction in terms of number of items. At the same time, the average mass of mesoplastics doubled that of microplastics, revealing a noticeable reservoir of plastics that is hardly ever reported in the literature. The predominant plastic types were fragments and pellets, and white/transparent color. The average concentrations of plastic were 1067.19 ± 625.62 item/m², and 50.65 ± 9.82 g/m² (Autumn 2018), 7860.74 item/m² (Spring 2019), and 6744.44 item/m² (Autumn 2019). Showing variability among beaches and within sampling sites. The Skikda coast presented high pollution levels compared to other areas in the Mediterranean Sea and further regions of the world. Kef Fatma and Guerbes were the most contaminated sites, large and open beaches located on the eastern coast of Skikda with low anthropic development. The spatial differences suggest transport and accumulation of plastics far away from the urban and industrial sources because of local winds and the west-east currents, revealing the spread of the anthropic impact in the area.

Keywords: Plastic pollution, Beach sediments, Mediterranean Sea, Skikda.

الملخص:

يعتبر البحر المتوسط منطقة ساخنة للتلوث البلاستيكي. تقدم هذه الدراسة أول محاولة لتوفير بيانات أولية حول وجود نفايات البلاستيك في رمال الشواطئ على طول 50 كيلومترا من خليج سكيكدة في الجزائر (جنوب غرب البحر الأبيض المتوسط). تم جمع عينات الرمال من سبعة شواطئ على طول الشريط الساحلي لسكيكدة لاستخراج نفايات بلاستيكي وقياس أبعادها ووزنها إضافة إلى تحديد خصائصها. صنفت جسيمات البلاستيك من حيث حجمها إلى جسيمات بلاستيكية كبيرة (جسيمات > 25 مم)، وإلى جسيمات بلاستيكية متوسطة (جسيمات تتراوح بين 5 و25 مم)، وجسيمات بلاستيكية دقيقة (جسيمات تتراوح من ميكرومتر 1 إلى 5 مم).

بصفة عامة حسب نتائج البحث، فإن البلاستيك الدقيق هو أكثر شيوعا من بين أصناف البلاستيك الموجودة في عينات الرمال. كما أن، كتلة البلاستيك المتوسط قاربت ضعف كتلة البلاستيك الدقيق. من حيث الأنواع البلاستيكية فان الأجزاء والكريات البلاستيكية كانت السائدة ومن حيث الألوان البيضاء/الشفافة. وبلغ متوسط تركيز البلاستيك 1067.19 ± 625.62 صنفا/م^2، و 50.65 غرام/م^2 (خريف عام 2018)، و 7860.74 صنفا/م^2 (ربيع عام 2019)، و 6744 صنفا/م^2 (خريف عام 2019). تعتبر مستويات تلوث البلاستيكي بساحل سكيكدة عالية مقارنة بمناطق أخرى في حوض البحر المتوسط وحول العالم. كان كل من كاف فاطمة وقرباز أكثر الشواطئ تلوثا، حيث أنهما شاطئان كبيرتان ومفتوحتان يقعان على الساحل الشرقي لسكيكدة بعيدا عن تأثير الضغط البشري. وتشير الاختلافات المكانية إلى انتقال وتراكم البلاستيك بعيدا عن المصادر الحضرية والصناعية بسبب الرياح المحلية والتيارات الغربية الشرقية، مما يكشف عن انتشار التأثير البشري في المنطقة.

الكلمات المفتاحية: التلوث البلاستيكي، رواسب الشواطئ، البحر المتوسط، سكيكدة.

Résumé :

La mer Méditerranée a été identifiée comme un hotspot de la pollution en plastique.

La présente étude est la première à fournir des données originales sur la présence de débris plastiques dans le sable des plages situées le long du golfe de Skikda en Algérie (sud-ouest de la mer Méditerranée). Des échantillons de sable provenant de sept plages du littoral de Skikda ont été collectés pour extraire, quantifier et caractériser les débris plastiques. Les particules de plastiques collectées ont été classées en fonction de leur taille en macroplastiques (particules > 25 mm), mésoplastiques (particules comprises entre 5 et 25 mm) et microplastiques (particules comprises entre 1 µm et 5 mm). Dans l'ensemble, le microplastique représente, en termes de nombre de particule, la fraction de taille la plus abondante. Par ailleurs, la masse moyenne des mésoplastiques fait le double de celle des microplastiques et révélerait un réservoir notable de plastiques qui n'est pratiquement jamais signalé dans la littérature. Les types de plastique prédominants étaient représentés par les fragments et les granulés de couleur blanche/transparente. Durant la campagne de l'automne 2018, les concentrations moyennes de plastique étaient de l'ordre de 1067,19 ± 625,62 particule/m², de 50,65 ± 9,82 g/m² ; mais en 2019, les valeurs enregistrées sont de l'ordre de 7860,74 particule /m² au printemps et 6744,44 particule /m² en automne ; nos résultats montrent une variabilité entre les plages et au sein des points d'échantillonnage. La côte de Skikda a présenté des niveaux de pollution élevés par rapport à d'autres zones de la mer Méditerranée et d'autres régions du monde. Bien que situées sur la côte est de Skikda et faiblement impactées par les activités anthropiques, les deux grandes plages ouvertes, Kef Fatma et Guerbes, étaient les sites les plus contaminés. Les différences spatiales suggèrent que la propagation et l'accumulation des plastiques loin des sources urbaines et industrielles à forte activité anthropique seraient engendrées par les vents locaux et les courants Ouest-Est.

Mots-clés : Pollution plastique, sable de plage, mer Méditerranée, Skikda.

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List of abbreviations

ABH - Agence du Bassin Hydrographique

ANAAT - Agence Nationale à l'Aménagement et à l'attractivité des Territoires

AND - Agence Nationale des déchets

ATR - Attenuated Total Reflectance

CNL – Conservation Nationale du Littoral

FTIR - Fourier Transform InfraRed

LEM - Laboratoire d’Etude Maritime

MATET - Ministère de l'Aménagement du Territoire et de l'Environnement

MPs - Microplastics

NOAA - National Oceanic and Atmospheric Administration

Introduction

What Lies Under – Ferdi Rizkiyanto

http://ferdi-rizkiyanto.blogspot.com/

"Only we humans make waste that nature can't digest"

Charles Moore

INTRODUCTION

Since its first invention a century ago, plastic became a key material which changed notably human lives; because of its low cost, the wide range of applications, versatility, durability, and adaptability (Barnes et al., 2009; Cole et al., 2011; Plasctic Europe, 2020). Many of today's applications and predicted benefits of plastic are similar to those outlined by Yarsley and Couzens with much optimism in 1945 (Thompson et al., 2009):

"It is a world free from moth and rust and full of colour, a world largely built up of synthetic materials made from the most universally distributed substances, a world in which nations are more and more independent of localised naturalised resources, a world in which man, like a magician, makes what he wants for almost every need out of what is beneath and around him." (Yarsley & Couzens., 1945).

Plastic production had its mass growth only in 1950s, since then, plastic production has increased exponentially from 2 million tons to 367 million tons in 2020 (Thompson et al. 2004; Plastic Europe., 2021). Over than 56% of plastic ever produced have been made since 2020 (Plastic Atlas, 2019). Hence, it is very persistent, generating large amounts of plastic waste in the environment, which increases significantly year after year (Lau et al., 2020; Lebreton and Andrady, 2019). Actually, the predictions were "how much brighter and cleaner a world [it would be] than that which preceded this plastic age." (Yarsley & Couzens 1945 *in* Thompson et al., 2009)

Regardless of whether the waste is discharged accidentally, carelessly, or intentionally, oceans and seas are ultimately responsible for disposing of anthropogenic waste entering continental, coastal, and marine environments (Veiga et al., 2016). By being transported by wind, continental wastes eventually end up in the oceans from the highest peaks of watersheds, where they drift for miles at the surface and settle in the deepest and most remote abyssal areas (Constant, 2018).

However, Plastic debris have become a source of international anthropogenic pollution both on land and in water, due to mismanagement of waste. Jambeck et al., (2015) estimated that 4.8-12.7 million metric tons generated by coastal countries entered the ocean annually. While over 5 trillion plastic litter may be floating at sea (Eriksen et al., 2014). Geyer et al. (2017) estimated that only 9% of plastic waste was recycled and 79% accumulated in landfills, while 1.7 to 4.8% of total plastic waste generated by coastal countries entered the ocean. Eriksen et al. (2014) reported that 5.25 trillion plastic debris may be floating at sea. Floating plastic debris tends to be carried over vast distances by wind and surface currents and to settle on the seafloor or accumulate on shorelines (Barnes et al., 2009; Cole et al., 2011; Derraik, 2002; Eriksen et al., 2014; Galgani et al., 2015). Plastic debris larger than 2.5 cm constitutes macroplastics, the most visible fraction, and can be easily cleaned.

In addition, macroplastics gradually break down into smaller fragments under the influence of biological, chemical and physical degradation processes (Galgani et al., 2015). The fragmentation process can occur in all areas where plastics are present and continue after they are introduced into the ocean or washed ashore (Gündoğdu and Çevik, 2019). With regard to their size, the fragments obtained can be classified into mesoplastics (particles between 5 and 25 mm) and microplastics (particles smaller than 5 mm) (Andrady, 2011; Barnes et al., 2009; Thompson et al., 2004)which constitute 92.4% of floating plastics (Eriksen et al., 2014).

Small size plastics, unlike macroplastics, often escape cleanup operations (Galgani et al., 2015) and thus can persist and accumulate in the marine environment for many years, posing a high risk to the marine environment and human health (Cole et al., 2011). Plastics can be harmful to marine biota and cause injury, entanglement or ingestion (Nelms et al., 2016; Thiel et al., 2018). Small plastic particles are more likely to be ingested by many marine species (Barnes et al., 2009; Cole et al., 2011; Derraik, 2002). Gall and Thompson (2015) found that at least 690 marine species had encountered marine litter, 92% had encountered plastic debris and 10% had ingested microplastics. In addition, plastic particles can carry non-native species and toxic chemicals into the oceans, where they can be released and concentrated in the tissues of organisms (Barnes et al., 2009; Mato et al., 2001).

The Mediterranean Sea is a semi-enclosed basin that hosts 10% of the world's coastal population and is characterized by significant maritime traffic. These factors make it one of the hotspots of plastic accumulation worldwide (Cózar et al., 2015; Deudero and Alomar, 2015; Llorca et al., 2020; Martellini et al., 2018)with an estimated concentration of about 250,000 floating plastic particles per km² (Cózar et al., 2015).

Marine litter poses a significant threat to marine biodiversity and habitats, particularly in the western coastal regions of the Mediterranean (Soto-Navarro et al., 2021). Deudero and Alomar (2015) reported that 134 Mediterranean species were affected by plastic debris (including sea turtles, marine mammals, pelagic fish and crabs).

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Several studies have reported moderate to high levels of marine litter on Mediterranean beaches (Constant et al., 2019; Fastelli et al., 2016; Filgueiras, 2019; Kaberi et al., 2013; Lots et al., 2017; Munari et al., 2017; Renzi et al., 2019)including on the southwestern shores of the Mediterranean (Abidli et al., 2017; Bouchentouf and Aïnad Tabet, 2013; Chouchene et al., 2019; Mankou-haddadi et al., 2021; Rigatos et al., 2012; Taïbi et al., 2021; Tata et al., 2020). In addition, Macias et al. (2019) and Mansui et al. (2015) predicted that large amounts of plastic litter would wash up on beaches.

In Algeria, the Ministry of Environment (under the European SWIM H2020 program) organized a marine debris monitoring campaign on the sandy beaches of 14 coastal provinces in 2018/2019. The National Waste Agency highlighted that 87% of marine debris on the Algerian coast was plastic, 66% was single-use (disposable) plastic, and 78% of the marine debris found stranded on the coast of Skikda was plastic (AND, 2020). The main sources of marine debris collected were local waste mismanagement (sewage systems and industrial waste) and tourism.

However, research on plastic pollution in Algerian coasts is still limited. One study assessed microplastics in the surface waters of Bou-Ismail Bay (Setiti et al., 2021). Another study made an assessment of marine litter on the bottom of the sea of Bejaia (Mankou-haddadi et al., 2021). Three studies analyzed plastic debris (microplastics and macroplastics) on the surface sediments of the beaches of Annaba (Tata et al., 2020)the west coast in Arzew (Bouchentouf and Aïnad Tabet, 2013) and Mostaganem (Taïbi et al., 2021). To the authors' knowledge, no research has been carried out in the Gulf of Skikda (east coast of Algeria).

In order to fill these existing gaps concerning plastic pollution magnitudes on the Skikda coast. Our study presents the first data on plastic pollution in the sediments of Skikda beaches. The main aims of this study are:

- To evaluate the plastic pollution magnitudes in the surface sediments of the Skikda coast.
- To determine the abundance, size (microplastics, mesoplastics and macroplastics), weight, type (fragment, pellet, foam, etc.), color, polymer types of plastic debris stranded on the beaches of Skikda.
- To assess spatial-temporal variability of microplastics.
- To evaluate the environmental impacts, and possible sources of microplastics.

In this context: this manuscript is organized as follows:

Chapter I: Review of the literature on plastic pollution

The first chapter is devoted to a literature review. It begins by presenting definitions and proprieties of plastic materials. Then the history of plastic production.

The marine plastic pollution issue will then be introduced and the main articles dealing with the definition of macro-, meso- and microplastics, their types, sources, impacts and threat will be briefly discussed.

Chapter II: Description of the study sites and methods used to quantify and characterize plastics

This chapter has two main purposes. First, it will present the Skikda Gulf, as well as sampling sites. The second, the methodologies employed to analyze microplastics will be discussed. While the specific sampling procedure, the subsequent steps (Physical analysis of sediments, extraction, separation from mineral fraction, observation and characterization) are common to all samples and therefore included in this chapter in order to avoid redundancy.

Chapter III: Plastic pollution in beach sediments of the Skikda coast (northeast of Algeria): First evidence

Chapter III will focus on the case of plastics (all plastic particles larger than 1 mm mainly: mesoplastics and large microplastics). Presenting the first data on plastic pollution magnitude along seven sandy beaches of Skikda coast.

Chapter IV: Tiny microplastics

Chapter IV will focus on small microplastics size fraction (microplastic particles smaller than 1 mm). Presenting the first data on the abundance and the distribution of small microplastic hiding in sediments of seven beaches of Skikda coast.

Chapter V: Seasonal variation of mesoplastics and microplastics in the Skikda Coast

This chapter presents the microplastics and mesoplastics problem along five beaches located on Skikda (central and eastern coast of Skikda), defining MPs magnitudes and spatial-temporal distribution. Focusing on the environmental impacts of microplastics, and possible sources.

Conclusion

The final chapter will discuss the main findings of this PhD thesis.

Chapter I: Literature review on plastic pollution

Hokusai’s great wave – Bonnie Monteleone

“Water and air, the two essential fluids on which all life depends, have become global garbage cans…”

Jacques Yves Cousteau

General information on plastics:

1. Definition and properties

The word "plastic" predates the first "modern" plastic and refers to anything that is easily molded or shaped. The term derived from the Latin "plasticus" and the Ancient Greek " πλαστικός " (plastikos), and it literally means "moldable." (Driss, 2016)

The term "plastic" existed long before the first "modern" plastic and refers to anything that may be easily molded or formed. Derived from the Latin "plasticus" and the Ancient Greek "πλαστικός" (plastikos), the term literally means "capable of being shaped". (Dris., 2016)

Plastics are also defined as low-cost, durable, strong, lightweight, corrosion-resistant materials, with excellent thermal and electrical insulating properties (Thompson et al., 2009).

The term refers to a group of hydrocarbon-based synthetic materials formed by polymerization of monomers (Derraik., 2002; Cole, 2011., Saunders, 2013., Plastic atlas., 2019).

Polymerization: a series of chemical reactions on organic (carbon-containing) raw materials, extracted from natural gas and crude oil (Saunders, 2013; Plastic atlas, 2019). Polymerization techniques allow the creation of polymers with specific properties such as hardness or softness, opaqueness or transparency, flexibility or stiffness (Plastic atlas, 2019).

Polymers can be classified according to their chemical composition, their physical properties, and their end uses:

- Chemistry
  - Nature of the monomeric units
  - Average chain length and molecular weight
  - Homopolymers (one kind of monomeric unit) or copolymers;
  - Chain topology: how the monomeric units are connected
  - Presence or absence of cross-branching
  - Method of polymerization
- Properties
  - Density
  - Thermal properties

- Degree of crystallinity
- Physical properties such as hardness, strength, machineability.
- Solubility, permeability to gases

The physical properties of a polymer such as its strength and flexibility depend on:

- Chain length: the longer the chains the stronger the polymer. Polymer strength may be measured as the amount of force required to break the chain;
- Polar side groups (including those that contribute to hydrogen bonding) provide increased attraction between polymer chains, thus enhancing their strength;
- cross-linking: Polymer chains that are extensively linked by covalent bonds is harder and more difficult to melt.

Thermoplastic resins

Can be softened again by heating. As pellets, they are used in industry and can be melted and re-pelletized for reuse and recycling.

Thermosetting resins:

Unlike thermoplastic resins, these resins cannot be re-softened once thermally hardened.

2. History of Plastic production

The first plastic, known as "Parkesine", was exhibited at the Great London Exposition in 1862. This organic material, created by Alexander Parkes from cellulose, could be shaped when heated and retained its shape when cooled (Plastic atlas, 2019). However, Plastics may be traced back twenty tree years earlier (1839), when Charles Goodyear discovered the method of vulcanization, in which natural rubber heated with Sulphur preserved its elasticity over a broader temperature range than raw rubber and was more resistant to solvents (Strong, 2006).

Early plastics were made of natural raw materials. It would take years to make an entirely synthetic plastic. Leo Hendrik Baekeland created Bakelite, the first material that did not include any naturally occurring components, in 1907. Bakelite was touted as an excellent insulator as well as a heat-resistant and durable material.

Plastics held a relatively modest market niche until the mid-twentieth century. During World War II, demand of PVC skyrocketed because it was utilized to insulate cables aboard military ships. Despite growing evidence that PVC manufacture was harmful to both the environment and human health, the petrochemicals sector took advantage of the new opportunities to transform a waste product into profit. Since then, PVC has become the most significant plastic in a wide range of consumer and industrial items. Polyethylene, like PVC, has gained popularity. It is used mainly in packaging industry (drink bottles, shopping bags and food containers). Polypropylene, a plastic with characteristics similar to those of polyethylene. It began to gain popularity in the 1950s and is now used for many common items like pipes, child seats, and packaging (Plastic atlas, 2019).

Since then, the production of plastics has increased exponentially from 2 million tons to more than 360 million tons in 2019. It is predictable to increase to 700 million tons by 2040 (Napper & Thompson, 2020; PlasticEurope, 2020). Four main areas—North America, the Middle East, Northeast Asia, and Western Europe—produce and consume the majority of the world's plastic (Plastic atlas, 2019).

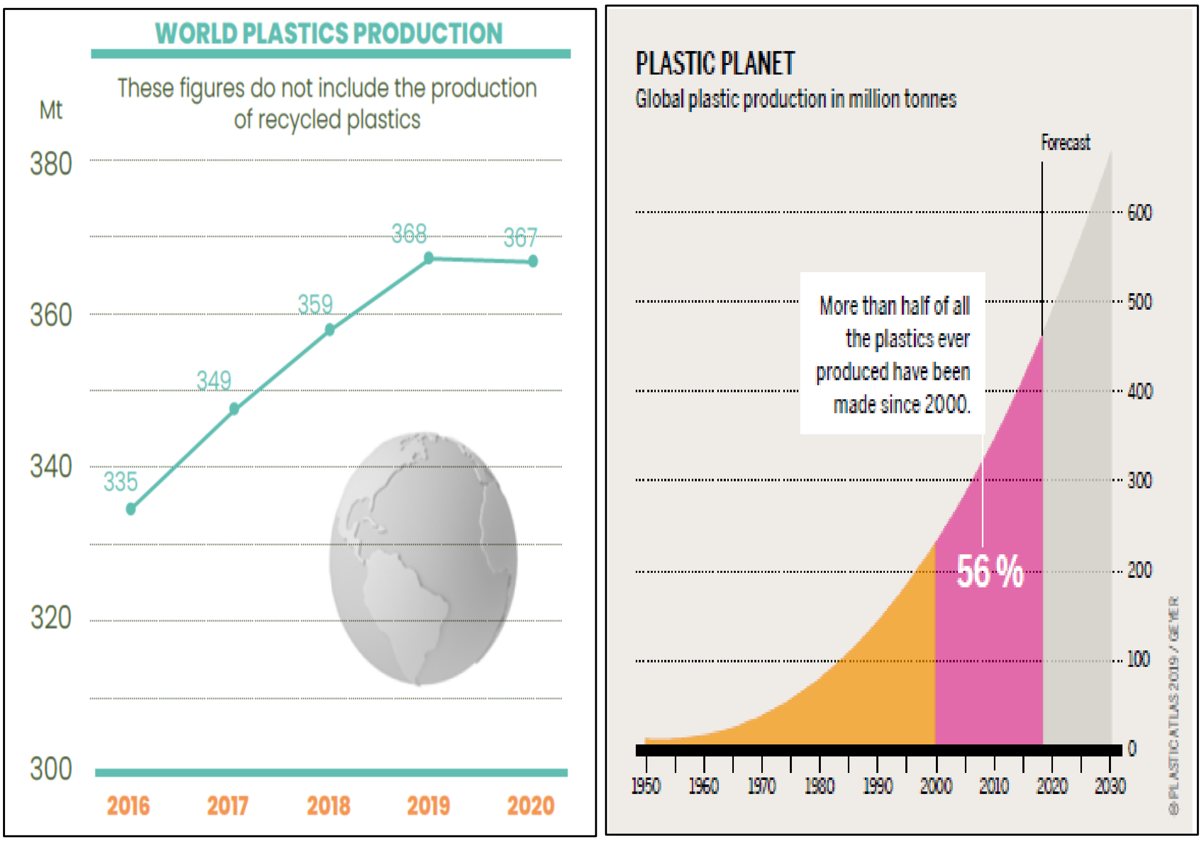


Figure 1: World plastic production (Plasticatlas, 2019)

3. Marine plastic pollution

As far back as 1870, i.e., about 150 years ago, Jules Verne provided a graphic description of the accumulation of floating debris in ocean gyres of the North Atlantic Ocean in the chapter on the Sargasso Sea in his famous novel entitled “Twenty Thousand Leagues under the Sea” (Galgani, 2015; Ryan, 2015). *"Above us, huddled among the brown weeds, there floated objects originating from all over: tree trunks ripped from the Rocky Mountains or the Andes and sent floating down the Amazon or the Mississippi, numerous pieces of wreckage, remnants of keels or undersides, bulwarks staved in and so weighed down with seashells and barnacles, they couldn't rise to the surface of the ocean."* (Verne, 1870). In 1901, Jules Verne also mentioned the venerability of marine animals to the anthropogenic litter in his novel entitled: the yarns of Jean-Marie Cabidoulin. He portrayed the items of marine debris found in stomach of shark in comical way. *“Here is what was taken from the belly of this shark, where there would have been room for poor Gastinet: a number of objects that had fallen into the sea, an empty bottle, three tin cans, also empty, several fathoms of bitord, a piece of mop, bits of bone, an oilcloth, an old fisherman's boot, and a post from a chicken coop. It is understandable that this inventory particularly interested Dr. Filhiol.*

“It's the garbage can of the sea!…” he exclaimed. » (Verne, 1901).

These lines are the earliest written descriptions of the accumulation of anthropogenic waste in the North Atlantic Ocean and their ingestion by marine mammals.

Early in the 1970s, scientific concern of plastic pollution in the ocean started to appear, but more than 40 years later, there are still no accurate estimates of the quantity and source of plastic debris entering the marine environment. 5.8 million metric tons (MT) or 6.4 million tons were estimated to be the annual flux of all types of trash into the ocean in 1975 (Jambeck et al., 2015).

Due to poor waste management, plastic debris have emerged as a major source of anthropogenic pollution both on land and in water (Jambeck et al., 2015). Geyer et al. (2017) estimated that only 9 % of plastic waste was recycled and 79 % accumulated in landfills, while 1.7 to 4.8 % of total plastic waste generated by coastal countries entered the ocean, equivalent to 4.8–12.7 million metric tons (Jambeck et al., 2015).

For a long time, the threat of plastics to the marine ecosystem was ignored, and its seriousness was only recently recognized (Derraik, 2002). Eriksen et al. (2014) reported that 5.25 trillion plastic debris may be floating at sea.

This tremendous plastic input into the marine ecosystem has led to the formation of Great Pacific Garbage Patch, located between California and Hawaii in the North Pacific gyre, encompasses an area of 1.6 million km² and is expected to contain about 79 thousand tons of plastic debris (Lebreton et al. 2018).

The Mediterranean Sea is one of the hotspots of plastic accumulation worldwide (Cozar et al., 2015; Deudero and Alomar, 2015; Llorca et al., 2020; Martellini et al., 2018) with an estimated concentration of about 250,000 floating plastic particles per km² (Cozar et al.,2015). Even if persistent plastic accumulation zones are not present in the Mediterranean Sea, it seems that plastic debris transits across crossroads regions (Baudena et al., 2022).

Most of plastic debris originates from land-based sources such as single-use consumer items (80%), while the remaining 20% comes from shipping lanes and fishing vessels (Liubartseva et al., 2018). Floating debris tends to be carried over vast distances by wind and surface currents and to settle on the seafloor or accumulate on shorelines (Barnes et al., 2009; Cole et al., 2011; Derraik, 2002; Eriksen et al., 2014; Galgani et al., 2015).

4. From macroplastics to microplastics

Macroplastics represents plastic debris larger than 25 mm, the most visible fraction, routinely observed from boats everywhere on the planet, and can be easily cleaned (Galgani et al., 2015; Barnes et al., 2009; Thompson et al., 2009). During the fragmentation process macroplastics gradually break down into smaller fragments under the influence of various degradation processes: biological, chemical and physical (Galgani et al., 2015). The fragmentation process can occur in all areas where plastics are present and continue after they are introduced into the ocean or washed ashore (Gündogdu and Çevik, 2019).

According to Andrady, 2011; Barnes et al., 2009; Thompson et al., 2004 the resulting fragments can be classified with regard to their size into:

Mesoplastics: particles between 5 and 25 mm;

Microplastics: particles ranging between 1µm and 5 mm which are also divided into to size fractions: Large microplastic (1-5mm) and Small microplastics (1 µm -1mm)

Small size plastics, constitute 92.4 % of floating plastics (Eriksen et al., 2014) frequently escape cleanup operations (Galgani et al., 2015) and thus can persist and accumulate in the marine environment for many years, posing a high risk to the marine environment and human health (Cole et al., 2011).

4.1. Microplastics types:

Primary microplastics: manufactured raw-plastic material directly at small size such plastic pellets (nurdles) used in processing manufactories, microbeads in personal care products (tooth paste and facial cleansers), and plastic fibers used in synthetic textiles (Arthur et al., 2009; Andrady, 2011).
Secondary microplastics: are formed as a result of the fragmentation of larger plastic objects (mesoplastics and macroplastics).

5. Plastics threats:

Plastics is ubiquitous, it is not just found in terrestrial and marine environment, but also in fresh water, the air we breathe, water we drink, food web, even human blood and breast milk.

The first reports of plastic in the environment were made from seabird carcasses that were collected from shorelines in the early 1960s. From there, the extent of the problem quickly became clear, with plastic debris contaminating oceans from the poles to the equator and from shorelines to the deep sea (Thompson et al., 2009).

Gall and Thompson (2015) stated that at least 690 marine species had encountered marine litter, 92% had encountered plastic. Plastics can be harmful to marine biota and cause injury, entanglement or ingestion (Nelms et al., 2016; Thiel et al., 2018). Plastic particles of different size: mesoplastics (5–25 mm), macroplastics (>25 mm), and microplastics (<5 mm) in the stomach of large pelagic fish such as swordfish, Bluefin tuna, and albacore (Acharya et al., 2021).

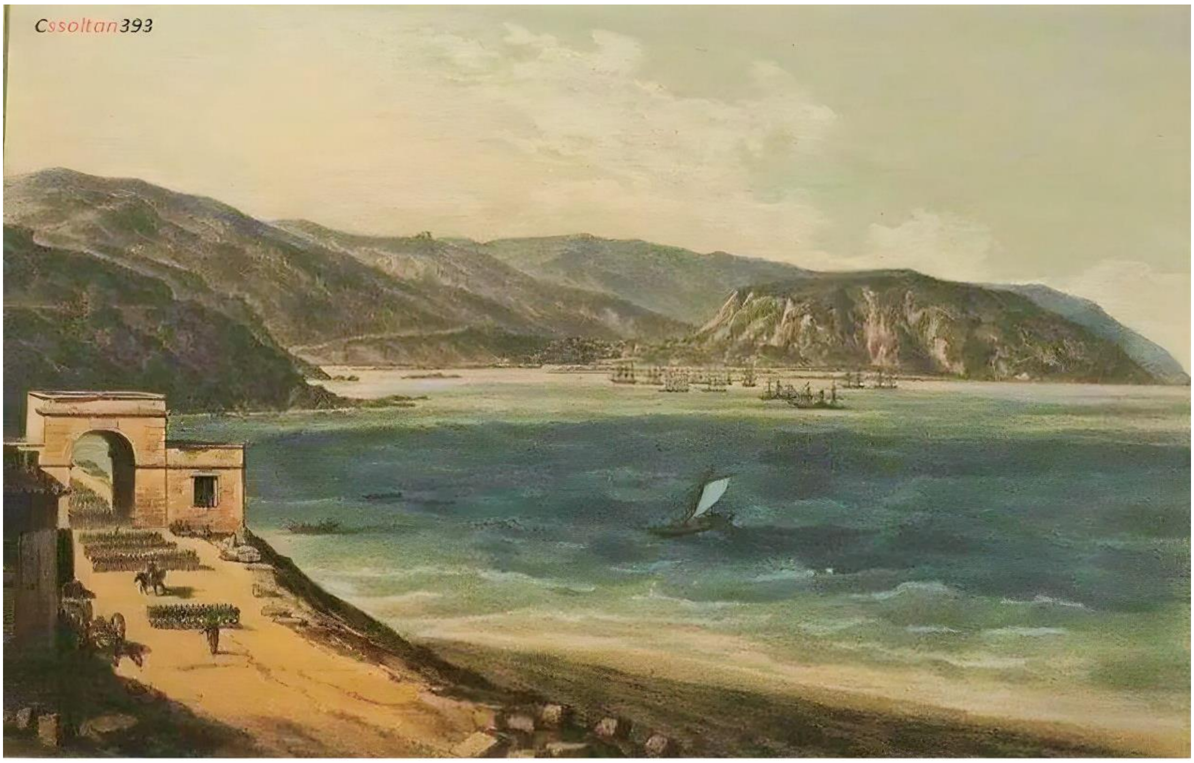
Several studies stated that, the ingestion of small plastics, by marine organisms causes physical hazards such as gut blockage, disturb the physiological processes, disruption of the endocrine system, reproductive impairment, oxidative stress, and disruption in body functions such as respiration, segregation of digestive enzymes, nutrient absorption, and energy reserve storage (Acharya et al., 2021).

Moreover, plastic particles have the ability to carry alien species and toxic substances into the oceans, where they can be released and accumulate in organism and transfer through the food web (Barnes et al., 2009; Mato et al., 2001).

Humans are most exposed to microplastics through inhalation, ingestion, and skin contact. Consumption of seafood, particularly mussels, oysters and sea salt are a significant source of microplastic. These small plastics have potentially hazardous effects through particle toxicity, chemical toxicity, and as vehicle of harmful chemicals and pathogenic microorganisms and parasites. Even though the researches on the interaction of plastic particles with tissues and cells in humans is limited, the data shows that exposure to plastic particles may cause: lung and gut injuries, and that very small particles can cross cell membranes, the blood-brain barrier, and the human placenta, inducing oxidative stress, cell damage, inflammation, and impairment of energy allocation functions (Acharya et al., 2021). Moreover, microplastics, which often transport chemical compounds such as dyes and other chemical additives, may permeate cell membranes and enhance the bioavailability of the chemicals (Acharya et al., 2021).

Chapter II:

Description of the study sites and methods used to quantify and characterize plastics



Henri Walter "Beb L'bhar" 1847 – Sami Soltane/ Skikda Illustration et souvenirs

1. Presentation of the research area

The Gulf of Skikda is located in northeastern Algeria, with a coastline of 140 km from Cap Bougaroune in the west to Cap de Fer in the east. The study area is located in northeastern Skikda, with a coastline of 50 km, from Ain El-Zouïte (Grande Plage) in the west to Remila in the east. The area is characterized by intense anthropogenic pressure: urban areas constitute 15% of the Skikda coastline with 38 km (Meghzili, 2015) the surface of the urban spot has increased with more than 51 % since 2003 to 2015 (Fenchouch A., Tamine R., 2019). The Skikda gulf is characterized by high shipping traffic, the study area is located between two fishing ports and marinas (Stora and El-Marsa) and near to the oil port and the mixed port the 2nd most important port in Algeria (MATET, 2010), where transits 90% of the oil export volume of Algeria. The petrochemical complex receives crude oil directly via the Hassi-Messaoud Skikda pipeline (Meghzili , 2015) which includes Refinery: number one in Africa, Polymed: high density polyethylene industry (MATET, 2010). Two main rivers flow in the study area: Oued El Saf-Saf, (center west) and Oued Kebir (east) bounded by wetlands RAMSAR protected area (Guerbes-Sanhadja Complex). Between the two main streams, small Wadis (El-Gat, El-Gsab, Righa, Saboun) flow in the area.

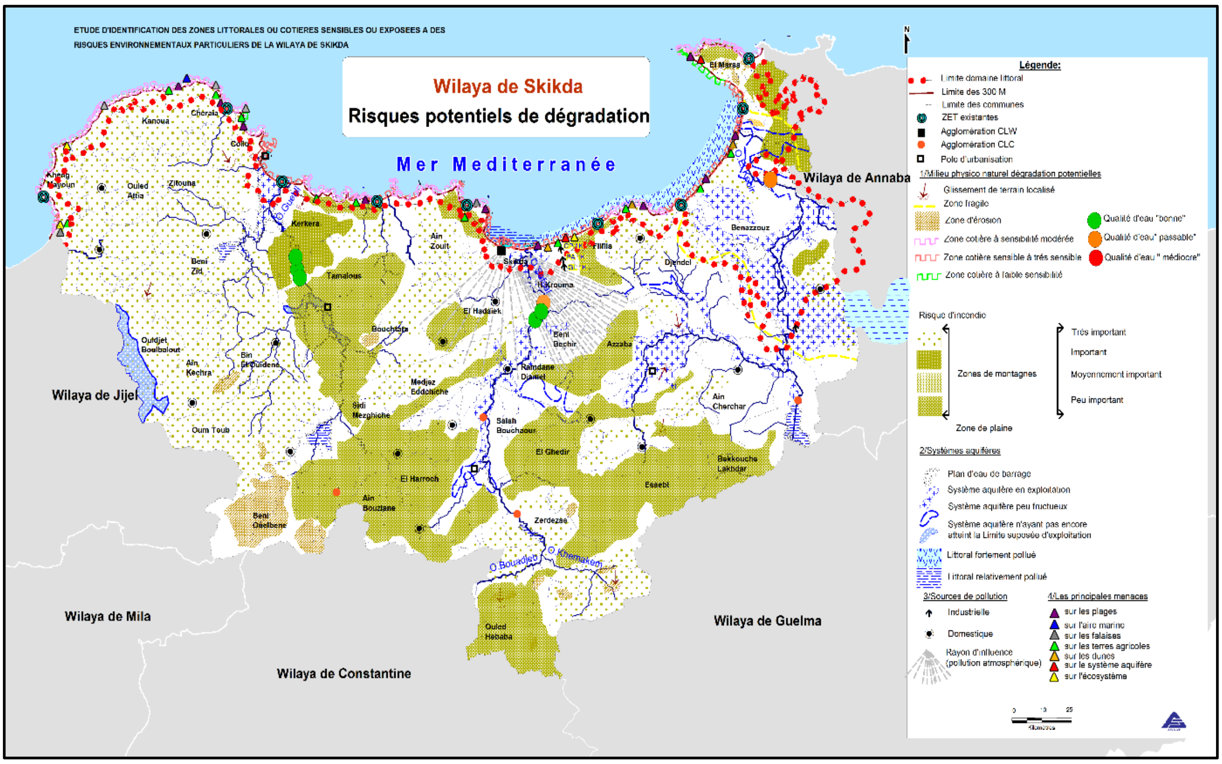


Figure2: Identification of sensible littoral area and exposed to environmental risks

1.1.Urban zones

The area is characterized by intense anthropogenic pressure: urban areas constitute 15% of the Skikda coastline with 38 km (Meghzili, 2015) the surface of the urban spot has increased with more than 51 % since 2003 to 2015 (Fenchouch & Tamine ., 2019).

1.2. Industrial zones

The petrochemical complex receives crude oil directly via the Hassi-Messaoud Skikda pipeline (Meghzili , 2015) which includes Refinery: number one in Africa, Polymed: high density polyethylene industry (MATET, 2010).

1.3. Wadis

The most important of these basins is the Saf-Saf Wadi, the most extensive river system in Constantinian Coastal basin, Occupying the central part of the Skikda area, with a drained area covering 1158 km^2 with a debit of 569 m^3/s (SCI, 1989), with a population of meadows of 460 thousand inhabitants (49% of the total population of the Skikda area) with an urbanization rate reaching 98% in Skikda city (Khelfaoui, 2008). The second basin is the Kebir basin which drains an area of 1135 Km^2, with hydraulic apport estimated of 282 m^3, receive 4.6 million m^3/year of waste water (PAM/PNUE, 2011). The basin characterized by intense agriculture activity, the aval part of the stream bordered by wet lands RAMSAR protected area (Guerbes-Sanhadja Complex).

Between the two main streams small Wadis (El-Gat, El-Gsab, Righa, Saboun) flow in the area.

1.4. Discharge

The Saf-Saf Wadi receives the discharge of 23.23 million m^3/year of wastewater (PAM/PNUE, 2011). The aval part of the basin receive different types of sewage: 22 discharges of urban areas and several industries (industrial zones, petrochemical platform). The Kebir basin receive 4.6 million m^3/year of wastewater (PAM/PNUE, 2011).

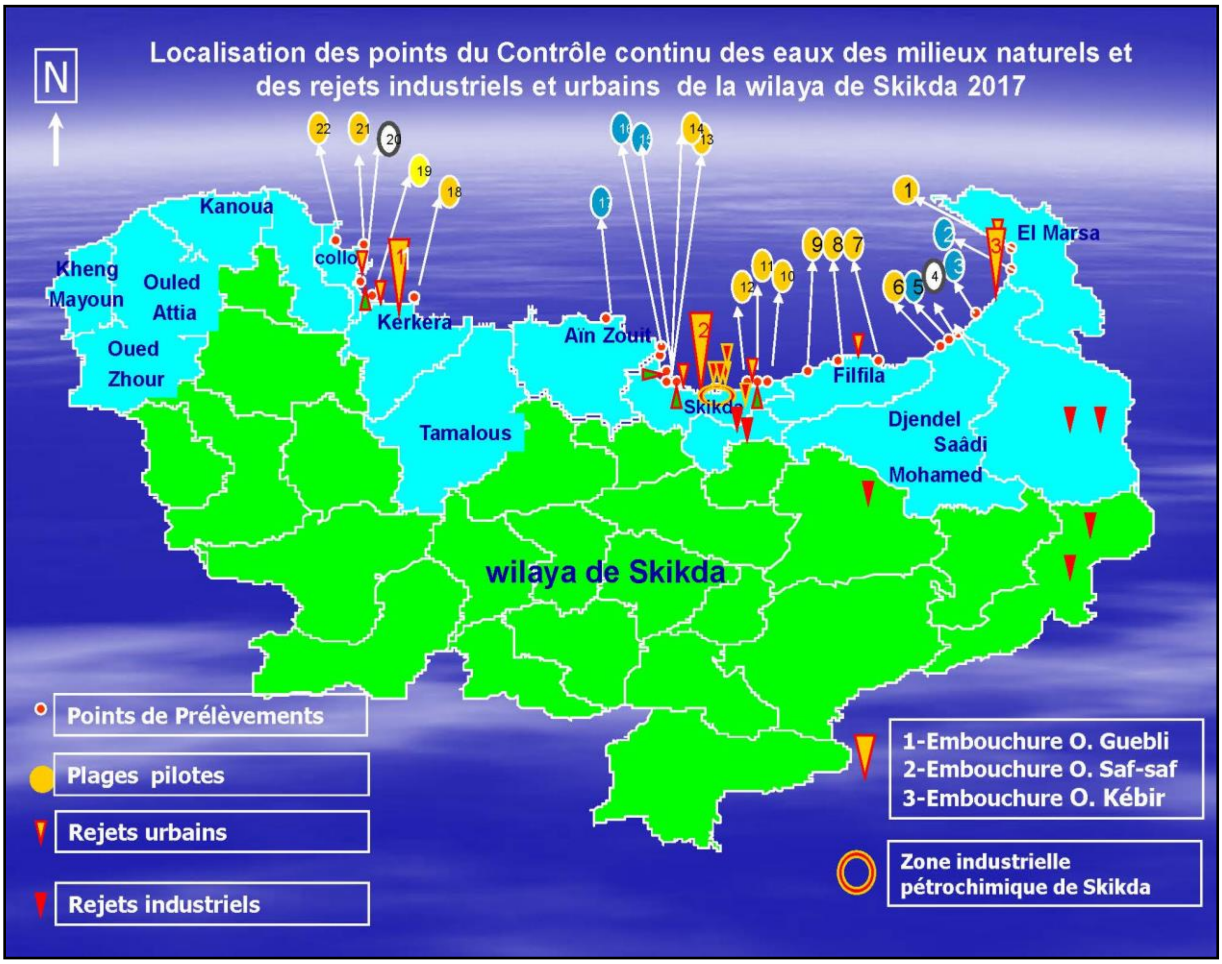


Figure 3: Location of discharge points along the coastline of Skikda (ANAAT, 2021).

1.5. Currents and waves

According to ANAAT (2021), the observation of the general and local orientation of the coastline shows that the waves of the NORTH-WEST, NORTH and NORTH-EAST sectors are the directions (sectors) that can impact the coastline of Skikda.

The SE part of the coastline of the commune of El Marsa, the port part of the commune of Skikda and the bay of Collo are relatively well protected against marine attack (waves).

On the Algerian coast, the water masses coming from the Atlantic form currents that run along the Algerian coast (West-East). This current can reach the nearby coastal bottoms and thus be added to other coastal currents (eg, wave-induced current). On the Algerian coast, the general current speeds can reach 40 to 60 cm.s-1 near the continental shelf.

Since these currents can originate from the open sea to the coast, they can therefore carry possible pollution from the open sea to the coast.

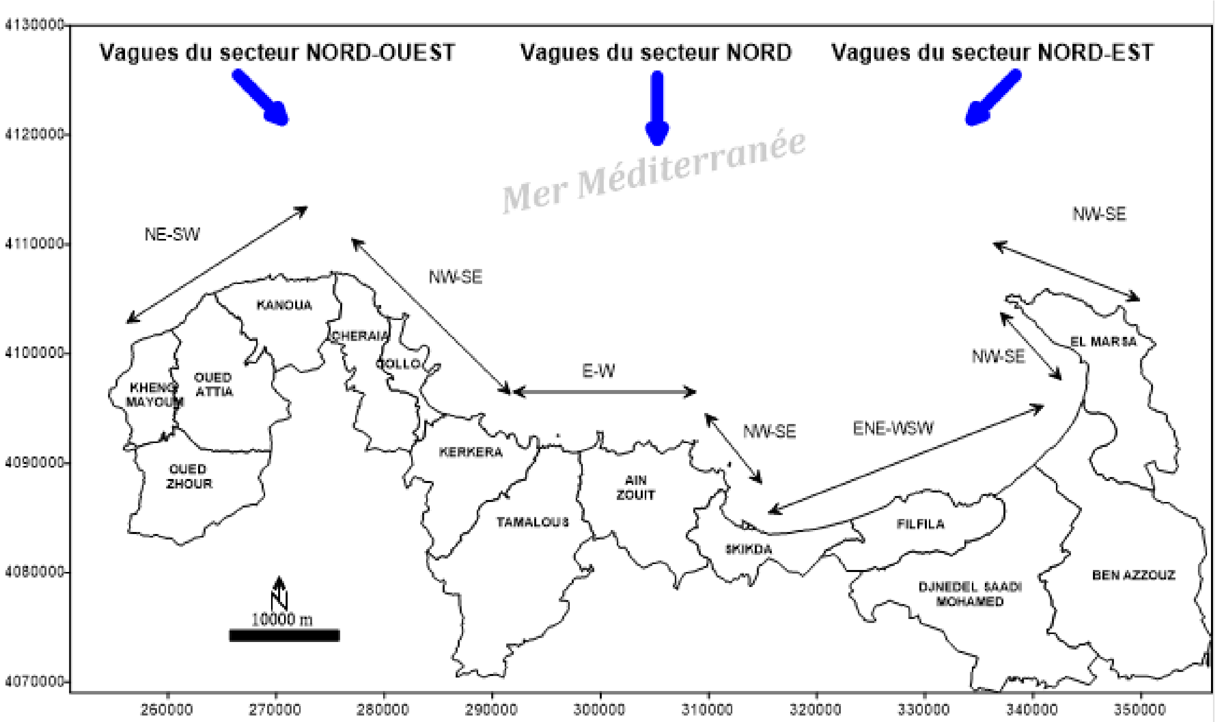


Figure 4: Coastal morphology and oceanographic conditions (offshore waves) (ANAAT, 2021).

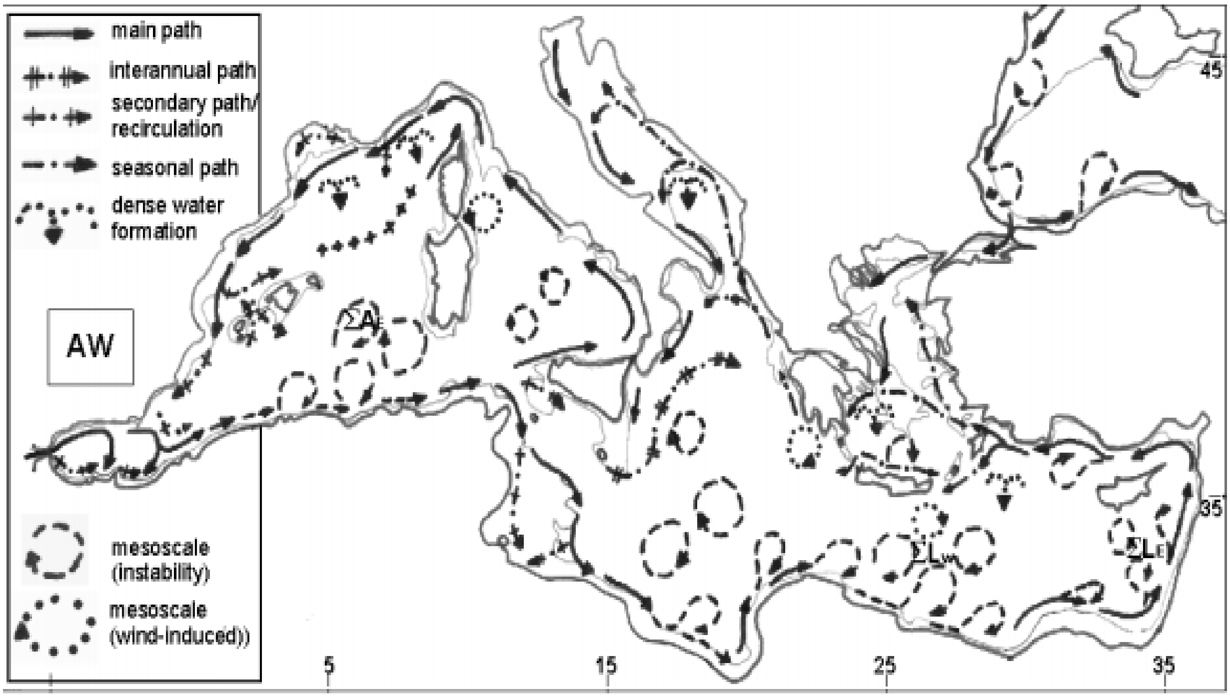


Figure 5: Surface circulation in the Mediterranean Sea (Millot and Taupier-letage, 2005)

1.6. Winds:

According to the meteorologic station of Skikda, winds along the study area mainly come from the W, and NW. The mean wind velocities reach more than 13 m/s during November–February. During the third trimester, (Jully- September) winds blow from the E, and the NE with a low velocity, with values that fall below 11 Km/h in August (Figure5).

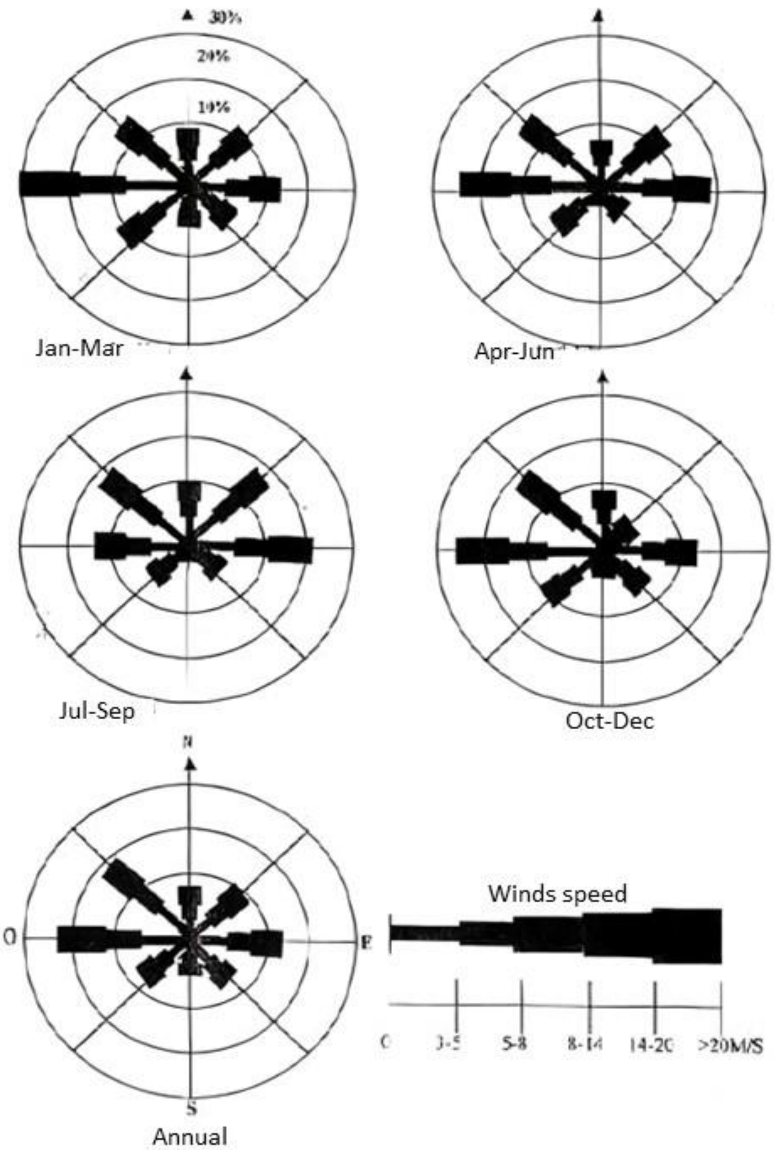


Figure 5: Wind roses in the Gulf of Skikda (LEM, 1998)

2. Sampling sites

Sampling sites were selected based on proximity to rivers, anthropogenic pressure, and orientation to the main current (west-east) (Figure 3) (Table 1).

The Grande Plage (S1), on the west coast, was chosen as a reference station away from anthropogenic pressure. The other six were located east of the city. Titanic (S2), Oued Elgat (S3) and Belle Vue (S4) are affected by different types of anthropogenic pressure: the proximity of the petrochemical platform, the 2nd most important port in Algeria, the mouth of Oued El Safsaf, and a very high touristic pressure during the summer. Guerbes (S5) and Kef Fatma (S6) are large open beaches located near a RAMSAR protected area (Guerbes-Sanhadja Complex). S7 Remila is close to the fishing port of El Marsa and the mouth of Oued Kebir.

2.1 Sampling and analysis

Data presented in this study were collected in three field surveys carried out in October/November (autumn/fall) 2018, May (spring) and September/October (autumn/fall) 2019.sampling was conducted according to the approach described by Frias et al. (2018) with some modifications. Given the Mediterranean Sea's microtidal regime, a 100-meter transect parallel to the water's edge was selected in the intertidal zone between the low and high tide lines. Then, surface sand samples (first 2 cm) were collected in three random 30×30 cm quadrats using a stainless-steel spoon. The samples were preserved and transported to the laboratory for analysis.

Table 1: Characteristics of the beaches studied

Station	Location	Coordinates	Length	Sediment type	Touristic pressure	Cleaning	Stream mouth	Urban	Harbor
S1	Grande Plage	36°55'56.37"N6°51'20.28"E	1400 m	Coarse sand	High (summer) low (winter)	Seasonal	no	no	7 km
S2	Titanic	36°53'14.35"N6°58'45.53"E		Medium sand	Very High (summer) medium (winter)	Seasonal/ volunteers	4 km West Wed El Safsaf	Yes	3 km
S3	Oued Elgat	36°54'5.47"N 7° 2'6.42"E	11 km	Medium sand	Very High (summer) medium (winter)	Seasonal/ volunteers	100 m West Wed Elgat	Yes	-
S4	Belle vue	36°54'16.05"N7° 2'37.46"E		Medium sand	Very High (summer) medium (winter)	Seasonal	1 km East Wed Righa	yes	-
S5	Guerbes	36°54'58.70"N7° 9'34.05"E	1200m	Medium sand	High (summer) low (winter)	Seasonal	no	no	-
S6	Kef Fatma	36°56'37.65"N7°12'9.83"E	1400 m	Medium sand	High (summer) low (winter)	Seasonal	1 km East Wed Remila 8 km West Wade Kebir	no	-
S7	Remila	37° 0'50.17"N 7°15'17.28"E	700 m	Fine sand	High (summer) low (winter)	Seasonal	1.5 km	no	2 km

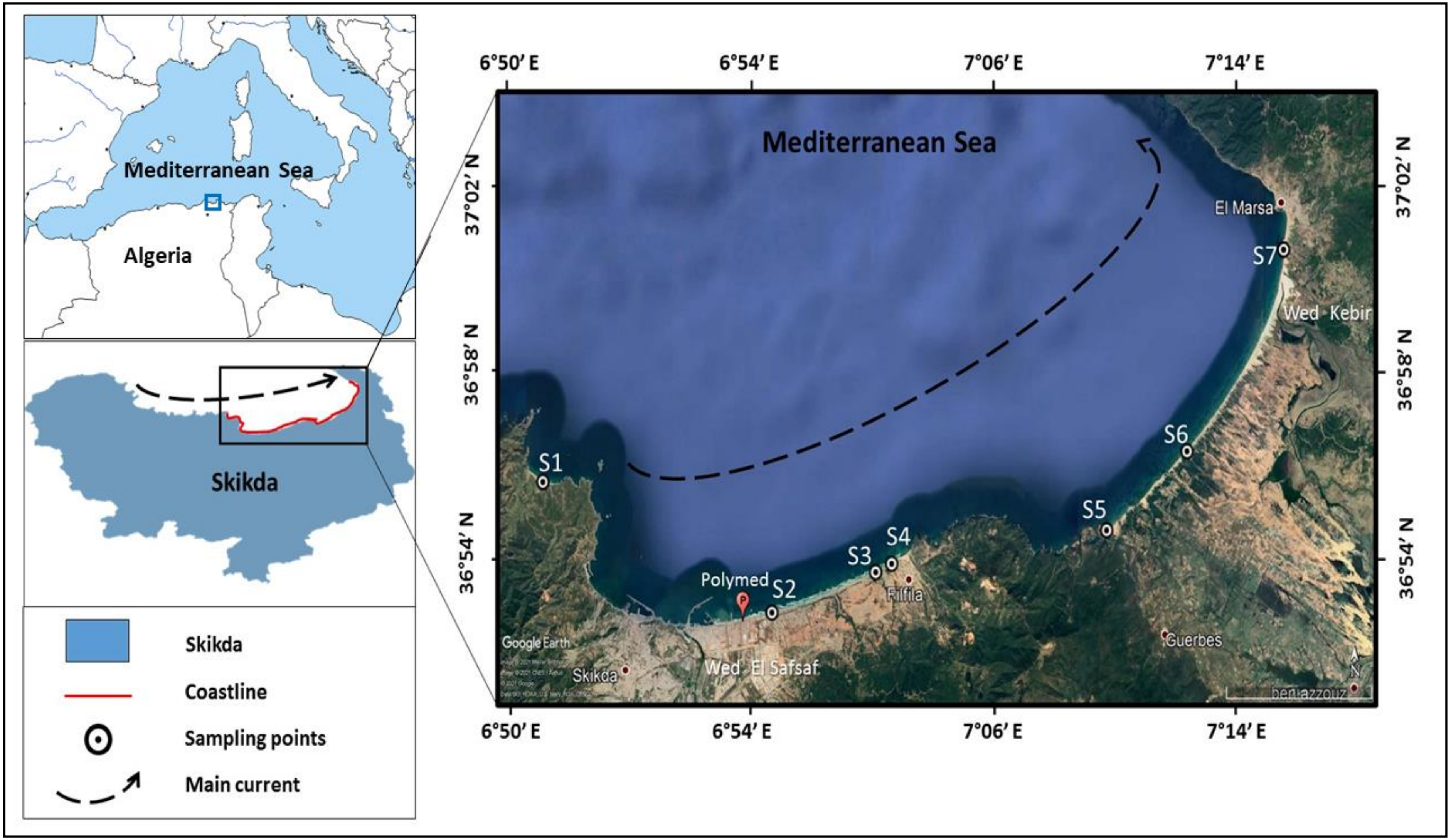


Figure 6: The study area and sampling sites (S1: Grande Plage, S2: Titanic, S3: Oued Elgat, S4: Belle Vue, S5: Guerbes, S6: Kef Fatma, S7: Remila). Polymed stands for high-density polyethylene industry location. The outlets of the main rivers, Oued El Safsaf and Oued Kebir, are also included.

Figure 7: Sampling sites a: (S2):Titanic, b: (S3) Oued Elgat, c: (S5) Guerbes, d: (S7) Remila.

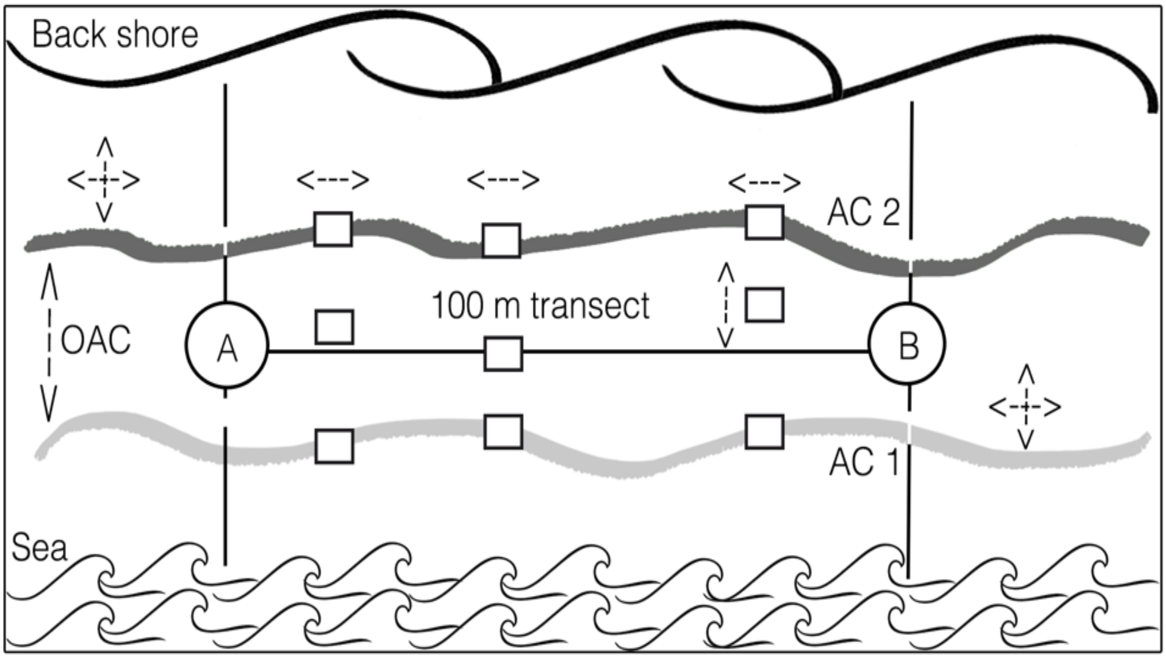


Figure 8: Example of 100m transect (adapted from OSPAR, 2010 and NOAA, 2013) (Frias et al., 2018)(AC – accumulation area, OAC – outside accumulation area)

Figure9: Sampling transect in Grande Plage beach

3. Laboratory analysis

3.1. Plastics extraction and characterization

3.1.1. Plastic >1mm

In the laboratory, dried sediments were weighed and sieved through 5 mm and 1 mm mesh stainless steel sieves. All anthropogenic material larger than 1 mm was manually retained and visually analyzed under the Leica S8APO stereomicroscope, all non-plastic and organic material was discarded. Plastics were recognized according to several criteria such as: homogeneous color, no cellular structure is visible, particles can be dented with tweezers but do not break easily, color (Hidalgo-Ruz et al., 2012; Mani et al., 2015). The retained plastic particles were washed with demineralized water to remove adherent particles such as sand, counted, measured, sorted by type (fragment, pellet, film, filament, fiber, cigarette butt, ear stick, cap, rubber, foam, microbead) and by color category (white/transparent, black, blue, red, green, other), and weighed in a precision balance (SCALTEC, Min. 0.001g) (Frias et al., 2018; Hanke et al., 2013; Hidalgo-Ruz et al., 2012). Large plastic items were measured with a precision caliper. Plastic items were classified by size to calculate the abundance of microplastics (< 5 mm), mesoplastics (5 to 25 mm), and macroplastics (> 25 mm). For macroplastics, although present in the samples, the results should be interpreted with caution because our sampling approach was not designed to obtain representative data for this size class. Data were represented as number of plastics per square meter (item/m^2), number of plastics per kilogram of dry weight (item/kg), and grams of plastics per square meter (g/m^2).

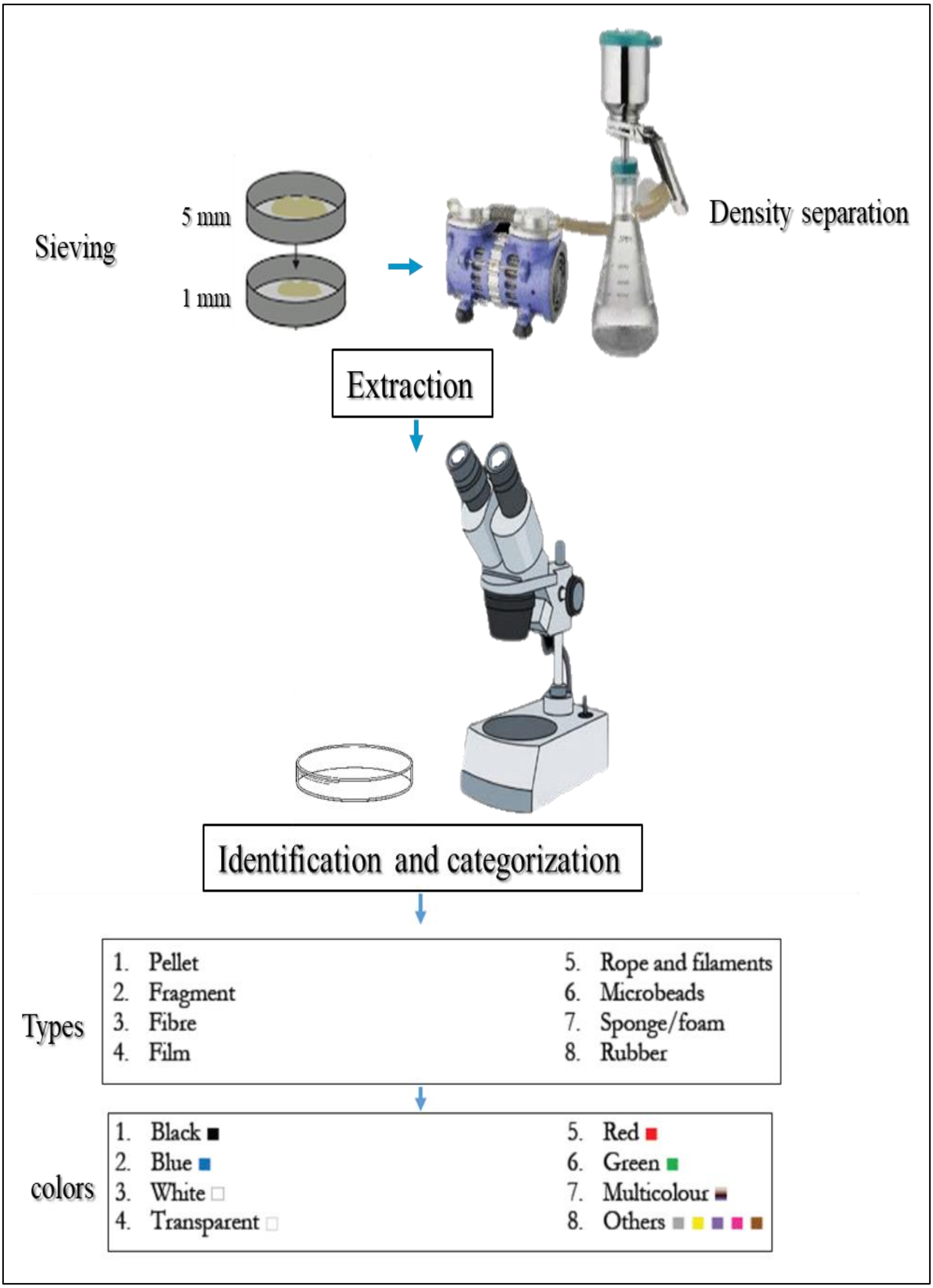


Figure 10: Extraction and characterization of microplastics

3.1.2. Plastics <1mm:

Extraction:

The extraction of small microplastics was performed with density separation according to Frias et al. (2016) and Filgreias et al. (2019) in the ONEDD laboratory (Observatoire National de l'Environnement et du Développement Durable, Skikda).

In a 500 ml beaker, 100 g of sediment was dissolved in 250 ml of hypersaline sodium chloride solution (NaCl solution 358.9 g/l) and vigorously stirred for 5–10 minutes.

Samples were then left for 30 min to stand so that heavy particles (sand grains) would settle while lighter materials would remain suspended or float in the surface solution (plastics).

The supernatant was then filtered with a vacuum pump onto a Millipore ® Glass Fiber filter (2 μm pore and 47 mm diameter).

Filters were then placed in Petri dishes, covered, dried, and stored till the identification.

3.2. Microscopic identification:

Microscopic identification was performed in Laboratory of Biosystematic and Ecology of Arthropods, University of Mentouri-Constantine, Algeria and Laboratory of Plant Biology and Environment, University of Badji Mokhtar-Annaba, Algeria.

Filters were carefully analyzed under the Leica S8APO stereomicroscope. Plastics were recognized according the criteria mentioned above Hidalgo-Ruz et al., (2012); Mani et al., (2015). Small microplastics were then counted and sorted by type and color (Figure 10)

3.3 Quality assurance and control

To minimize the risk of cross-contamination, synthetic fiber clothing and plastics were avoided, the laboratory windows were kept closed, and only one operator remained in the laboratory during all analytical processes. All materials used were thoroughly rinsed with deionized water and covered with aluminum foil when not in use.

In order to evaluate cross-contamination, controls were run in parallel during the entire procedure. No fragment or fibers were observed in controls.

Figure 11: Density separation

Figure 12: Microscopic identification (Leica S8APO stereomicroscope)

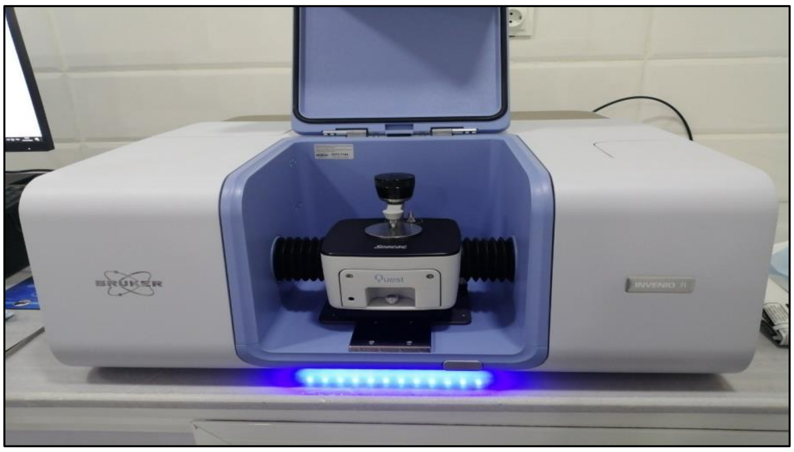


Figure 13: ATR-FTIR identification (ATR-FTIR BRUKER INVENIO R)

3.4 Infrared analysis

Polymer characterization was performed for random subsets of the most common plastic shapes identified in the study area (180 particles in the microplastic size fraction): 117 fragments, 32 pellets, 4 films, 26 foams, and 2 filaments. The predominant plastic types were selected from Figure 3.C. Using Attenuated Total Reflectance Fourier Transform Infrared (ATR-FTIR) (BRUKER INVENIO R for research and development version 1.200 8-5-5, Germany) in a range between 200 cm^{-1} - 5000 cm^{-1}. Each spectrum was obtained with 30 scans at a resolution of 4 cm^{-1}.

The spectra were compared to several potential spectra from the spectral database of known polymers using the Know ItAll Informatic System (2021) with IR Spectral Libraries. The software provides a list of likely matches; the best match was selected based on peak position. The minimum similarity of spectra was set at 70% (Frias et al., 2016).

The FTIR analysis were performed at The Technological Platform “Materials Elaboration and Manufacturing” (National Polytechnic School, Constantine, Algeria) and (Laboratory of Applied Organic Chemistry, University of Badji-Mokhtar Annaba, Algeria)

3.5. Physical analysis of sediments:

3.5.1. Analysis organic matters OM%:

Samples preparation:

Sand samples were sieved trough 2mm mesh stainless sieve. The cup was placed in an oven at 105° C for 15 minutes, cooled in a desiccator for 15-20 minutes, and weighed as the weight of the cup (M0). 10 g of the sediment sample was added to the cup, weighted. The sample was dried in the oven for 24 hours at 105°C. After that, cooled for 10 minutes in a desiccator and the final weight was noted as (M1). The sample was placed in a muffle furnace at 250°C for 4 hours for calcination, cooled in a desiccator, weighed and noted as (M2). A second calcination of the samples was performed in a muffle furnace at 450°C for 4 hours. Then, the sample was left to cool in a desiccator, weighted as (M3). MO% was calculated using the following formula:

$$\boxed{OM\% = \frac{M_2 - M_3}{M_1 - M_0} \times 100}$$

Where M_0: empty cup, M_1: sample weight at 105°C, M_2: sample weight at 250°C and M_3: sample weight at 450°C.

The results of OM can be interpretated as: OM < 1: low, 1 < OM< 2: medium, OM> 2: high

3.5.2. Analysis of total organic carbon TOC%

The total organic carbon is calculated according to the following formula:

$$\boxed{TOC\% = \frac{OM\%}{1,72}}$$

OM% is the rate of organic matter.

3.5.3. Granulometry

Sediment granulometry was analyzed using the methodology described by Clément and Pieltain (1998).

The granulometric analysis consists on separating the mineral part of the sand and classifying it into categories according to the size range of the mineral particles smaller than 2 mm, then calculating the percentage of each category in relation to the total mass of the sand (Clément et Pieltain., 1998).

The mineral particles were categorized by size according to the international scale (International Soil Science Association, 1930) as follows:

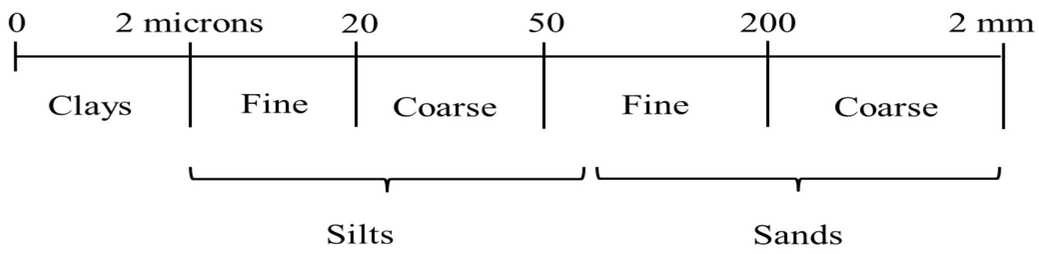


Figure 14: Classification of Atterberg adapted by International Soil Science Association (Clémentet Pieltain., 1998).

The granulometric analysis consists in:

-The determination of particles larger than 2 mm by dry sieving.

-Elimination of organic matter: Sediments with less than 1.5% organic carbon can avoid this step (Clément et Pieltain, 1998).

-Separation of the two sand fractions by wet sieving with 200 micron and 64-micron sieves. Using distilled water, the sieve contents are transferred to capsules.

-Evaporation and drying of the sand fractions at 105°C during one night. Cooled and weighted the two fractions.

In the case of sand, the fractions silt and clay are trace and can be deduced after calculation of the two fractions sand (fine and coarse) according to the following formula:

$S\%+C\%= 100 - (FS+CS)$

S%: Silts

C%: Clays

FS: fine sand

CS: coarse sand

4. Statistical analysis

Normality was assessed using the Shapiro-Wilk test for abundance (concentration), color, and type of plastic in the size ranges of total, mesoplastic, and microplastic among the sampling stations. When the normal distribution was confirmed, the ANOVA test was performed. For non-normal distributions, the Kruskal-Wallis test was applied. The relationship between the abundance of the three plastic size classes was tested by linear regression.
CPA and Agglomerative Hierarchical Clustering (AHC) and Multidimensional Scaling (MDS). All statistical analyses were performed using XLSTAT software.

4.1. Indexes

4.1.1. Pellet Pollution Index:

The degree of plastic pollution along the studied beaches was assessed using the Pellets Pollution Index (PPI) proposed by Fernandino et al. (2015). The PPI was calculated using the following formula:

$$PPI= [n\ (item) / a(m^2)] \times P \quad (1)$$

Where, n is the number of pellets, *a* is the area of sediment sampled, and *P is* the correction coefficient (*P*= 0.02) to obtain values in the zero to three scale. The PPI classifies beaches into 4 categories: very low ($0.0 < PPI \leq 0.5$); low ($0.5 < PPI \leq 1.0$); moderate ($1.0 < PPI \leq 2.0$); high ($2.0 < PPI \leq 3.0$); and very high ($PPI > 3.0$).

Microplastic's environmental impacts over the studied beaches were assessed using three indices.

4.1.2. Environmental Status Index (ESI):

According to Schulz et al., (2013); Rangel-Buitrago et al., (2019, 2020, 2021) the ESI is an indicator that defines the beaches quality in terms of direct and indirect impacts toward the health of organisms existing in beach generated by MPs with a scale ranging from 1 to 4 (where 1 = Good, 2 = Mediocre, 3 = Unsatisfactory, 4 = Bad).

Following this value assignment, a weight table was created through the Jenks optimization method for the identified microplastic typologies (i.e., fragments, pellets, etc.) found in the study area (Table 3). Hence, all values were calculated according to the formula: where

$$ESI = \frac{\sum_{i=1}^{n} wi^{*}xi}{\sum_{i=1}^{n} wi}$$

ESI is the final score (or weighted average value of the environmental status) as a result of the weighted average of all the single weights (wi) of all MPs shapes found on a specific beach, multiplied for the class (xi) assigned to the beach based on the presence and abundance of that specific shape. According to the classification system, each beach was evaluated based on classes of the environmental status (1, 2, 3, and 4 corresponding to good, mediocre, unsatisfactory, and bad, respectively) that are assigned according to the total number of MPs found along the sampling unit.

Table 3: MPPI determines the presence of MPs in an environment by calculating the existing relation between MPs amount and surveyed area.

Microplastics pollution index (MPPI)	Type	Description
0 to 2	Very low abundance/ absence	No MPs are seen
2 to 5	Low abundance	Some MPs are in the sample
5 to 15	Moderate abundance	A considerable number of MPs seen
15 to 25	High abundance	A lot of MPs are in the sample
More 25	Very high abundance	Most of the sample is composed by MPs

4.1.4. Coefficient of Microplastics Impact (CMPI):

This index was used to evaluate the impact of all microplastic shapes, as an impact indicator. The CMPI is defined as the existing relationship between the total number of a specific shape of MPs and the total number of MPs found in a sampling unit (Rangel-Buitrago et al., 2021). This coefficient of each beach was calculated as follows:

$$CMPI = \frac{Specific\ MPs\'{}Shape}{Total\ MPs}$$

According to this methodology, four categories of microplastic impact degree can be defined ranging from minimum at CMPI = 0.0001–0.1; average when CMPI = 0.11–0.5; maximum if CMPI = 0.51–0.8 and extreme if CMPI = 0.81–1.

4.2. Sectoral analysis:

Sectoral analysis was processed by integrating two indexes, the MPPI and ESI. A dynamic table was formed for each beach, with the ESI columns and the MPPI in rows. Following the percentile technique (Langford, 2006), the table consists of three sections:

• The green area which represents beaches with good environmental status with very low MPs presence where protection measures are necessary.

• The orange area shows beaches with a mediocre environmental status with a low to moderate MPs presence where cleaning actions are necessary.

• The red area describes areas with an unsatisfactory and bad environmental status with high to very high MPs presence where urgent intervention and even restoration measures are necessary.

4.3. Agglomerative Hierarchical Clustering

Using Ward’s method with squared Euclidean distance agglomerative hierarchical clustering (AHC) and multidimensional scaling (MDS) analyses. A dendrogram graph was generated to illustrate hierarchical relationships existing between MPs magnitudes and calculated environmental variables of the surveyed beaches.

4.4. Principal Components Analysis (PCA):

The Principal Components Analysis was performed using MPs shapes as “variables” and beaches as “cases”. The PCA assesses the relationships between MPs typologies and identifies whether the changes in these forms on certain beaches differ from those on others. F1 and F2 (which account for most of the variance in the data) were represented as scatter plots (beaches) and vector plots (MPs typologies). Patterns of distribution of sites on the PC axes were interpreted concerning the corresponding typology vectors' orientation and additional information such as beach location and beach management. All statistical analyses were performed using XLSTAT software.

Chapter III:

Plastic pollution in surface sediments of Skikda coasts (northeast of Algeria): First evidence

Aerial view of L'rbi Ben M'hidi the late in the 1950s – Sami Soltane/Skikda Illustration et souvenirs

This chapter is aimed at surveying and examining the plastics pollution presence in the sediments of Skikda Gulf.

In this chapter, we present the first baseline data on plastic pollution levels in the sediments of Skikda beaches. The main purpose is to determine the abundance, size, weight, type (fragment, pellet, foam, etc.), color and spatial variability and polymer types of plastic debris stranded on the beaches of Skikda.

Seven sandy beaches were explored along the 50 km coastline of Skikda between October and November 2018 (autumn period). An overview of the surveyed beaches: The Grande Plage (S1), Titanic (S2), Oued Elgat (S3), Belle Vue (S4), Guerbes (S5) Kef Fatma (S6) and Remila (S7) is given in (Table 1) and (Figure 6).

The data presented in this chapter is published in: Marine Pollution Bulletin

Title**:** First evidence of plastic pollution in surface sediments of Skikda coasts (northeast of Algeria)

Halima Grini*, Sophia Metallaoui, Daniel Gonzalez-Fernandez, Mourad Bensouilah

Results

Plastic abundance and spatial distribution

The average abundance of plastics is (1067, 19 ± 625, 62 item/m²), (66, 87 ± 38, 73 item/kg), and (51, 64 ± 23, 39 g/m²) with important variation among beaches. The highest amounts of plastic was recorded in Kef Fatma (1829,63 ± 1481,34 item/m²), (113,43 ± 93,92 item/kg), (90,41 ± 56,78 g/m²) since the minimum concentration was observed in Grande Plage (229,63 ± 23,13 item/m²), (14,35 ± 1,45 item/kg) (Tab.2). The Shapiro-Wilk test showed a normal distribution of plastic debris along with the study sites (Figure 15, Table 4).

The average mesoplastic concentration was 307 ± 167 item/m^2 (32 ± 17 item/kg). Mesoplastic abundances ranged between 141 ± 17 item/m² (15 ± 2 item/kg) in Grande plage and 563 ± 412 item/m² (59 ± 43 item/kg) in Ket Fatma (Figure 15, Table 5). Microplastics showed an average concentration of 734 ± 475 item/m² (73 ± 47 item/kg), ranging between 6 ± 11 item/m^2 (1.9 ± 0.6 item/kg) in Grande Plage and 1233 ± 855 item/m^2 (123 ± 85 item/kg) in Guerbes. Kef Fatma presented also a very high concentration of microplastics (1226 ± 1025 item/m^2 and 123 ± 102 item/kg) (Figure 15, Table 6).

In general, total plastic, mesoplastic and microplastic concentrations showed similar spatial distributions (Figure 16). Plastic concentrations peaked in Kef Fatma and Guerbes, which are large open beaches located on the eastern coast of Skikda, away from the main population and industrial sites. The Shapiro-Wilk test showed a normal distribution of plastic debris abundances among the study sites (data not shown). Moreover, no significant differences in the plastic concentrations were observed among beaches with the one-way ANOVA.

Table 2: Microplastics shapes and corresponding weights obtained by means the Jenks optimization method in the study area.

Shape	Classification (xi – number of items)				Weight Wi
	Good	Mediocre	Unsatisfactory	Bad	
Pellet	Less 34	35 to 572	573 to 887	more than 888	1
Fragment	Less 90	91 to 145	146 to 909	more than 910	1
Fiber	Less 124	125 to 140	141 to146	more than 147	1
Film	Less 124	2 to 3	4 to 9	more than 10	1
Microbead	Less 0	1	2 to 15	more than 16	1
Foam	Less 12	13 to 24	25 to 165	more than 166	1
Filament	0	1	2 to 5	more than 5	1
Rubber	0	1	2	3	1

4.1.3. Microplastics Pollution Index (MPPI):

This index assesses the presence of MPs in an environment by calculating the existing relationship between the total surface of the quadrants and the total number of MPs or between MPs shapes collected in the surveyed beaches. In short, this index determines the abstract state of being free of MPs and the tendency to reach and sustain this state (Rangel-Buitrago et al., 2021). Allowing the classification of beaches on five different categories ranging from “very low presence” to “very high presence” of MPs (Table). All MPPI values have been processed according to the formula:

$$MPPI = \frac{\sum Mps}{Surveyed\ Area}$$

Where MPs' is the number of “MPs per m²”

Table 4: Total plastics abundance

Total plastics												
Location	Value [Item / m^2]				Value [Item / kg]				Value [g / m^2]			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Grande Plage	229,63 ±	23,13	211,11	255,56	22,96 ±	2,31	21,11	25,56	69,26 ±	15,05	55,89	85,56
Titanic	1374,07 ±	830,17	777,78	2322,22	137,41 ±	83,02	77,78	232,22	44,48 ±	16,54	33,00	63,44
Oued Elgat	1092,59 ±	809,08	200	1777,78	109,26 ±	80,91	20	177,78	45,59 ±	50,91	14,11	104,33
Belle Vue	462,96 ±	89,81	366,67	544,44	46,30 ±	8,98	36,67	54,44	24,15 ±	16,87	13,00	43,56
Guerbes	1762,96 ±	1101,59	977,78	3022,22	176,30 ±	110,16	97,78	302,22	60,04 ±	19,39	45,78	82,11
Kef Fatma	1829,63 ±	1481,34	411,11	3366,67	182,96 ±	148,13	41,11	336,67	83,81 ±	54,21	26,11	133,67
Remila	718,52 ±	624,63	277,78	1433,33	73,70 ±	61,32	27,78	143,33	27,19 ±	15,48	12,78	43,56
Total	1067,19 ±	625,62			106,98 ±	62,39			50,65 ±	9,82		

Table 5: Mesoplastics abondance

Mesoplastics												
Location	Value [Item / m^2]				Value [Item / kg]				Value [g / m^2]			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Grande Plage	140,74 ±	16,98	122,22	155,56	14,81 ±	1,79	12,87	16,37	23,89 ±	9,85	13,44	33,00
Titanic	292,59 ±	150,03	144,44	444,44	30,80 ±	15,79	15,20	46,78	22,74 ±	8,78	15,11	32,33
Oued Elgat	270,37 ±	233,42	33,33	500	28,46 ±	24,57	3,51	52,63	13,44 ±	11,13	1,22	23,00
Belle Vue	129,63 ±	63,18	77,78	200	13,65 ±	6,65	8,19	21,05	15,56 ±	18,28	1,11	36,11
Guerbes	496,30 ±	263,25	333,33	800	52,24 ±	27,71	35,09	84,21	40,59 ±	14,09	25,67	53,67
Kef Fatma	562,96 ±	411,91	166,67	988,89	59,26 ±	43,36	17,54	104,09	39,56 ±	25,12	20,89	68,11
Remila	255,55 ±	164,43	144,44	444,44	26,90 ±	17,31	15,20	46,78	21,15 ±	11,98	8,67	32,56
Total	306,88 ±	165,65			32,30 ±	17,44			25,28 ±	10,79		

Table 6: Microplastics abundance

Microplastics												
Location	Value [Item / m²]				Value [Item / kg]				Value [g / m²]			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Grande Plage	18,52 ±	6,41	11,11	22,22	1,85 ±	0,64	1,11	2,22	0,15 ±	0,13	0,00	0,22
Titanic	1066,67 ±	694,25	622,22	1866,67	106,67 ±	69,42	62,22	186,67	15,07 ±	10,72	8,56	27,44
Oued Elgat	796,30 ±	554,37	166,67	1211,11	79,63 ±	55,44	16,67	121,11	9,59 ±	6,51	2,22	14,56
Belle Vue	322,22 ±	125,22	244,44	466,67	32,22 ±	12,52	24,44	46,67	4,96 ±	2,16	3,56	7,44
Guerbes	1233,33 ±	854,69	577,77	2200	123,33 ±	85,47	57,78	220	15,63 ±	8,80	9,22	25,67
Kef Fatma	1225,92 ±	1024,66	244,44	2288,89	122,59 ±	102,47	24,44	228,89	29,07 ±	25,08	5,22	55,22
Remila	477,78 ±	453,79	122,22	988,89	47,78 ±	45,38	12,22	98,89	6,00 ±	4,37	2,89	11,00
Total	734,39 ±	474,87			73,44 ±	47,49			11,50			

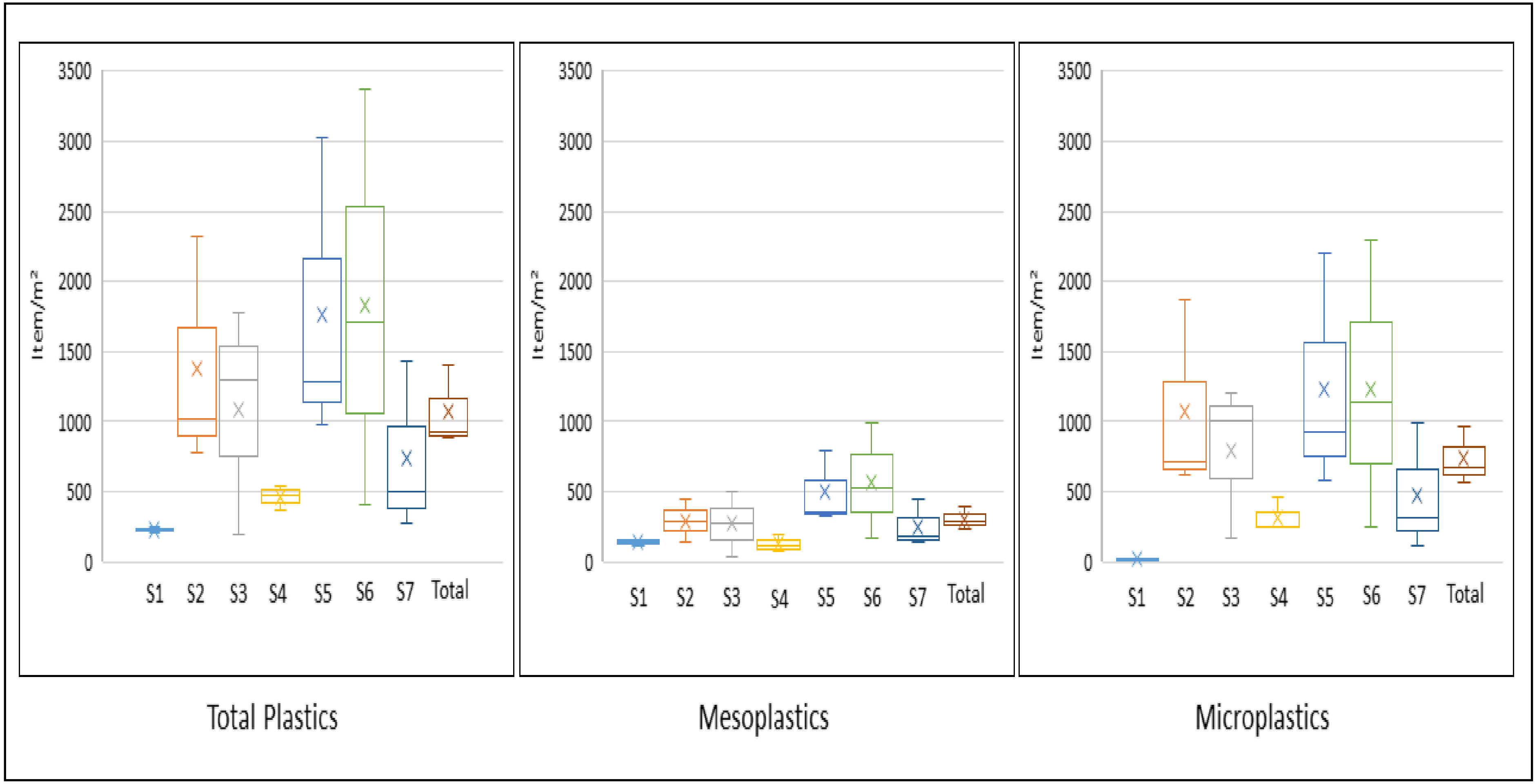


Figure 15: a) Total Plastic, b) Mesoplastic and c) Microplastic abundances in item/m². The box-whisker plots present the 50th (median), 25th−75th (box), 10th−90th (whiskers) percentiles and the mean (x symbol). (S1: Grande Plage, S2: Titanic, S3: Oued Elgat, S4: Belle Vue, S5: Guerbes, S6: Kef Fatma, S7: Remila)

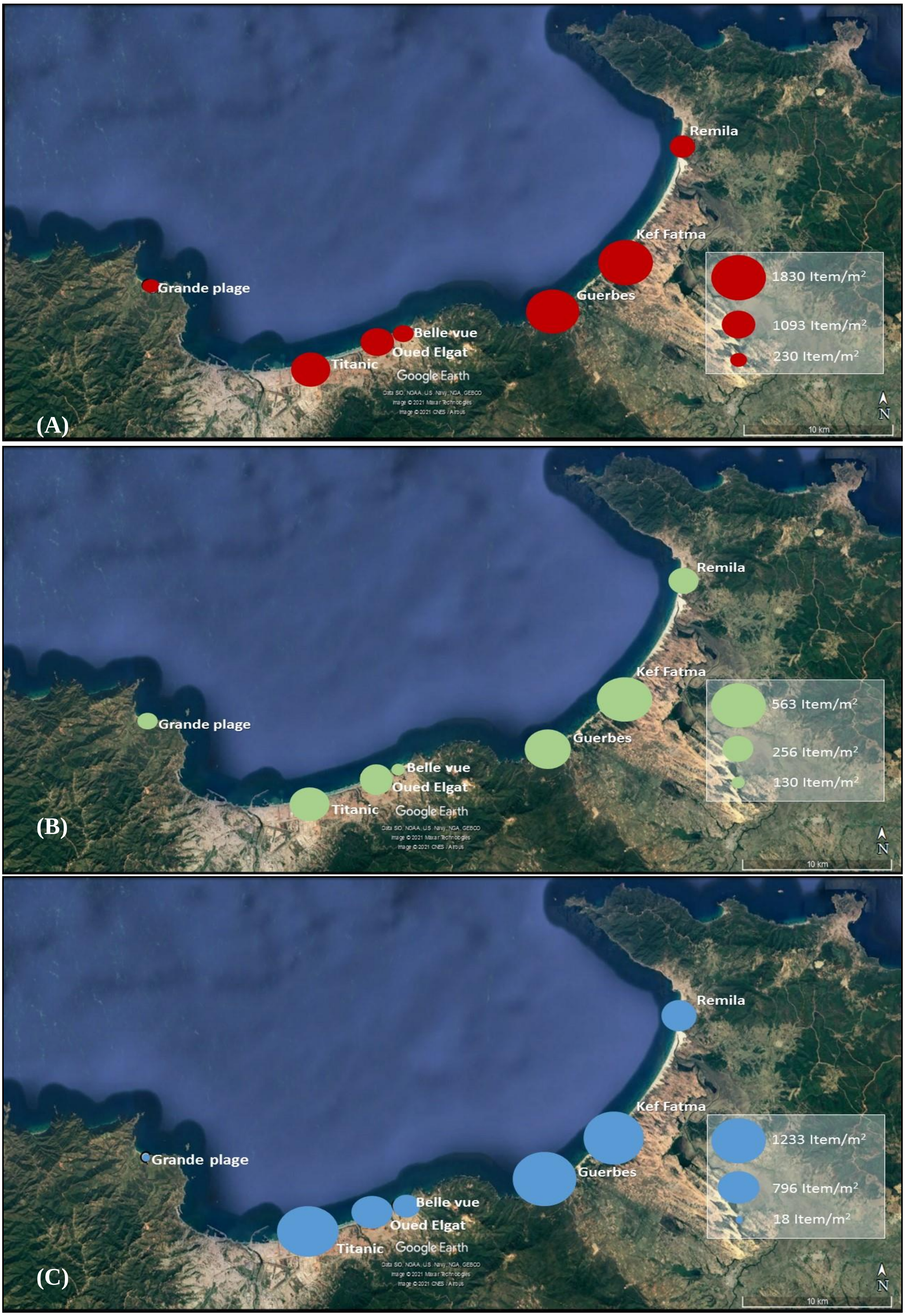


Figure 16 : Spatial distribution **(A)** Plastique total, **(B)** Mesoplastique, **(C)** Microplastique

3.2. Classification of plastics:

Plastic type, color, and size

The two most common plastic types were fragments 57% and pellets 35%. Fragments presented the highest percentage in all the study areas except in Belle vue, where pellets were more abundant (46%) (Figure17, 18). Grande Plage showed a different distribution of plastic types, where fragments remained the most abundant (27%) and pellets the least one (2%). In general, there were significant differences between study locations (Kruskal-Wallis < 0.05).

Plastic color

The white/transparent color category was significantly higher across beaches 63% (Kruskal-Wallis < 0.05). The rest of color groups were respectively other > blue > black > green > red. Moreover, White/transparent was the most dominant color within the plastic types except for rubbers where others were the main color category (Figure19).

Plastic size

Microplastic was the predominant size fraction (average 68%), reaching more than 60% in sites 2 to 7, followed by mesoplastics (average 29%). In Grande Plage (Site 1), mesoplastics (61%) and macroplastics (31%) were more abundant than microplastics (8%) (Figure20.A). In the rest of the sampling sites, the macroplastic fraction was lower than 2%. Linear regressions were used to verify the relationship between concentrations of the three size classes of plastics, finding a strong correlation between micro and mesoplastics R^2= 0.79. Pellets (49%) were significantly the most dominant microplastic type (Kruskal-Wallis < 0.05), followed by fragments (hard pieces) 46% and foams 4%. The remaining 1% were films > microbeads > rubbers (Figure17.C). The highest value of microplastics was observed in the size classes C3 (3-4 mm) with 39% and C4 (4-5 mm) with 32%. The size class C1 (1-2 mm) showed the lowest number of microplastics 12% (Figure21). Regarding mesoplastics, fragments (85%) were predominant in all the study sites. The remaining 15% was shared among film > pellet > foam > rubber> cigarette butt > filament > fibers > cap (Figure17.B).

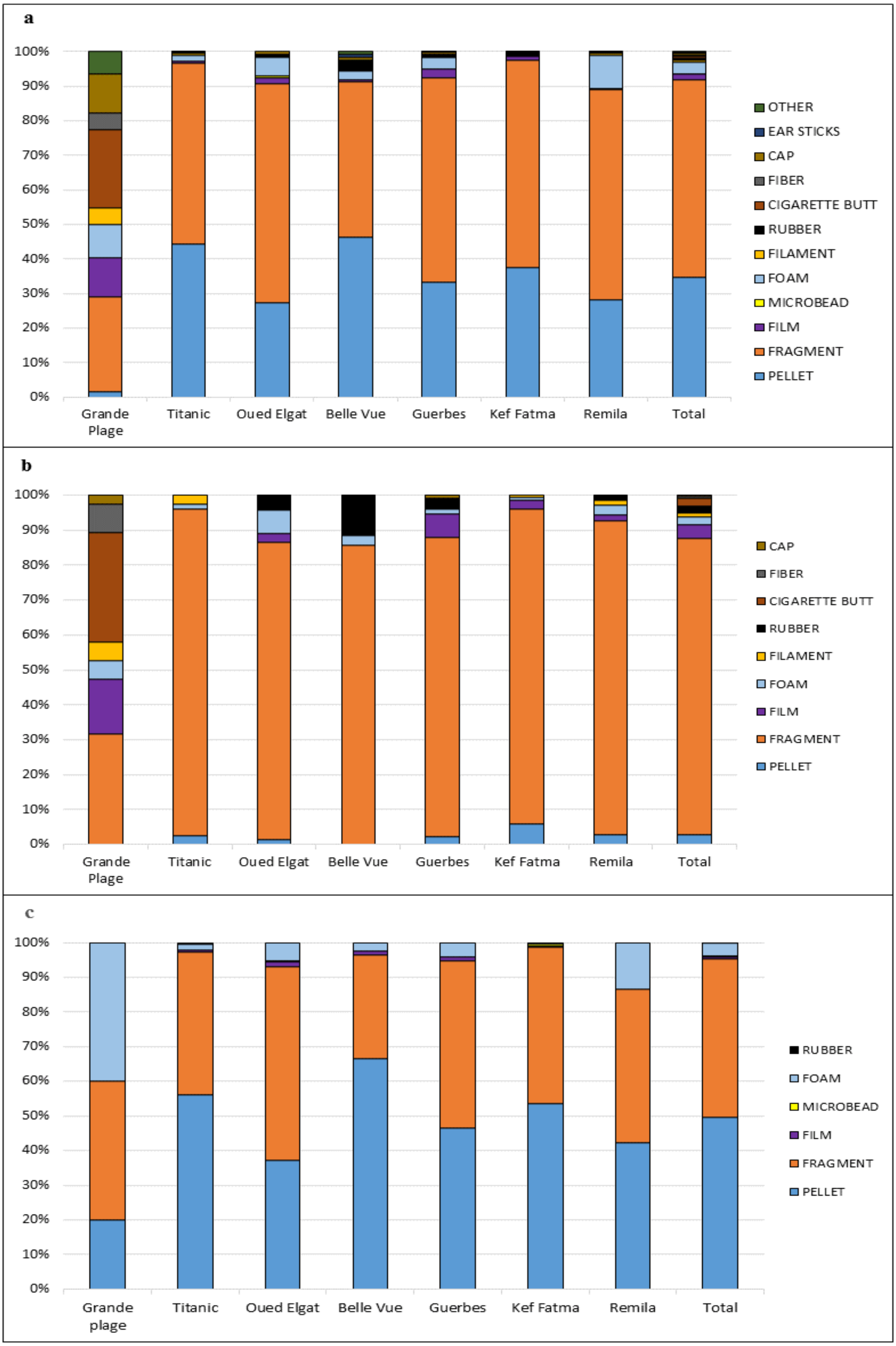


Figure17: Classification of a) total plastic b) mesoplastic and c) microplastic types.

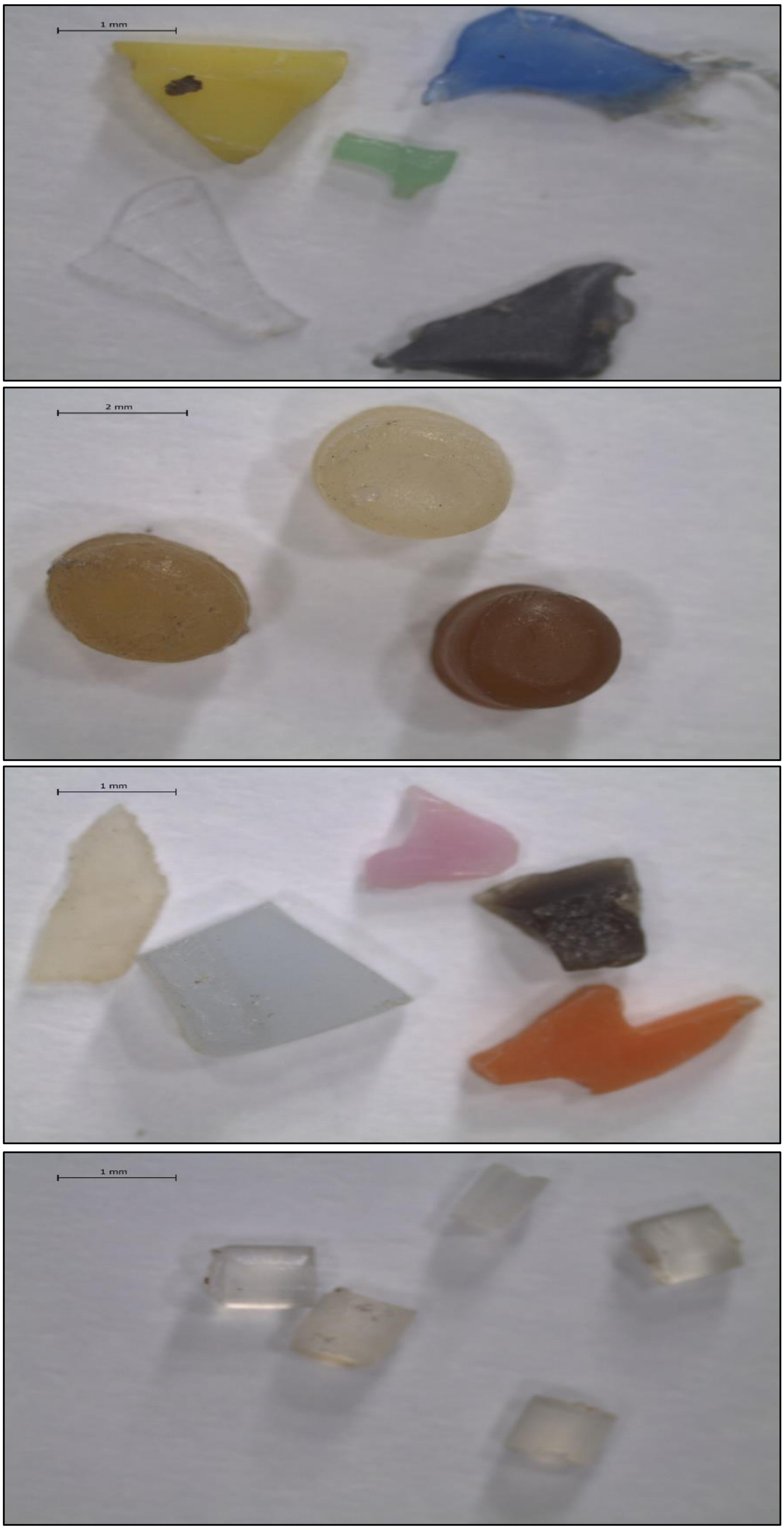


Figure 18: Microscopic photos of different types and colors of microplastics: Pellets, fragments.

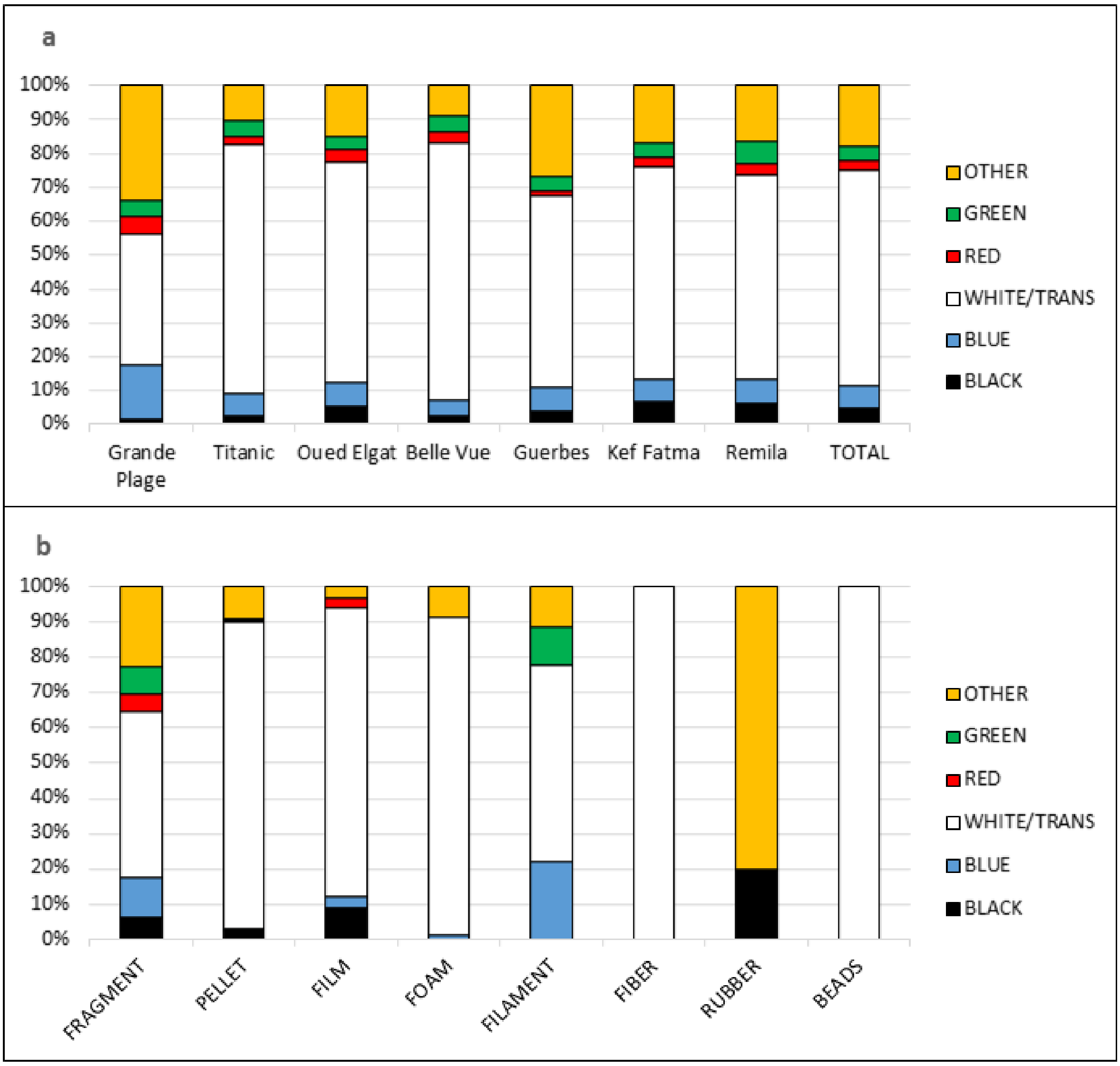


Figure 19: Colors classification for a) total plastic by location and b) plastic type.

Plastic weight

Considering the mass of plastic by size fraction, mesoplastics shared the largest percentage (53% on average), followed by macroplastics (24% on average) and microplastics (23% on average) (Figure20.B). Grand Plage showed a very low fraction of microplastics and a predominance of macroplastics; Oued Elgat showed a major contribution from macroplastics but a more balanced distribution between mesoplastics and microplastics. Moreover, the average ratio between the mass concentration (g/m^2) of mesoplastics and microplastics was 2.2:1. Excluding Grande Plage, this mass concentration ratio decreased to 1.9:1.

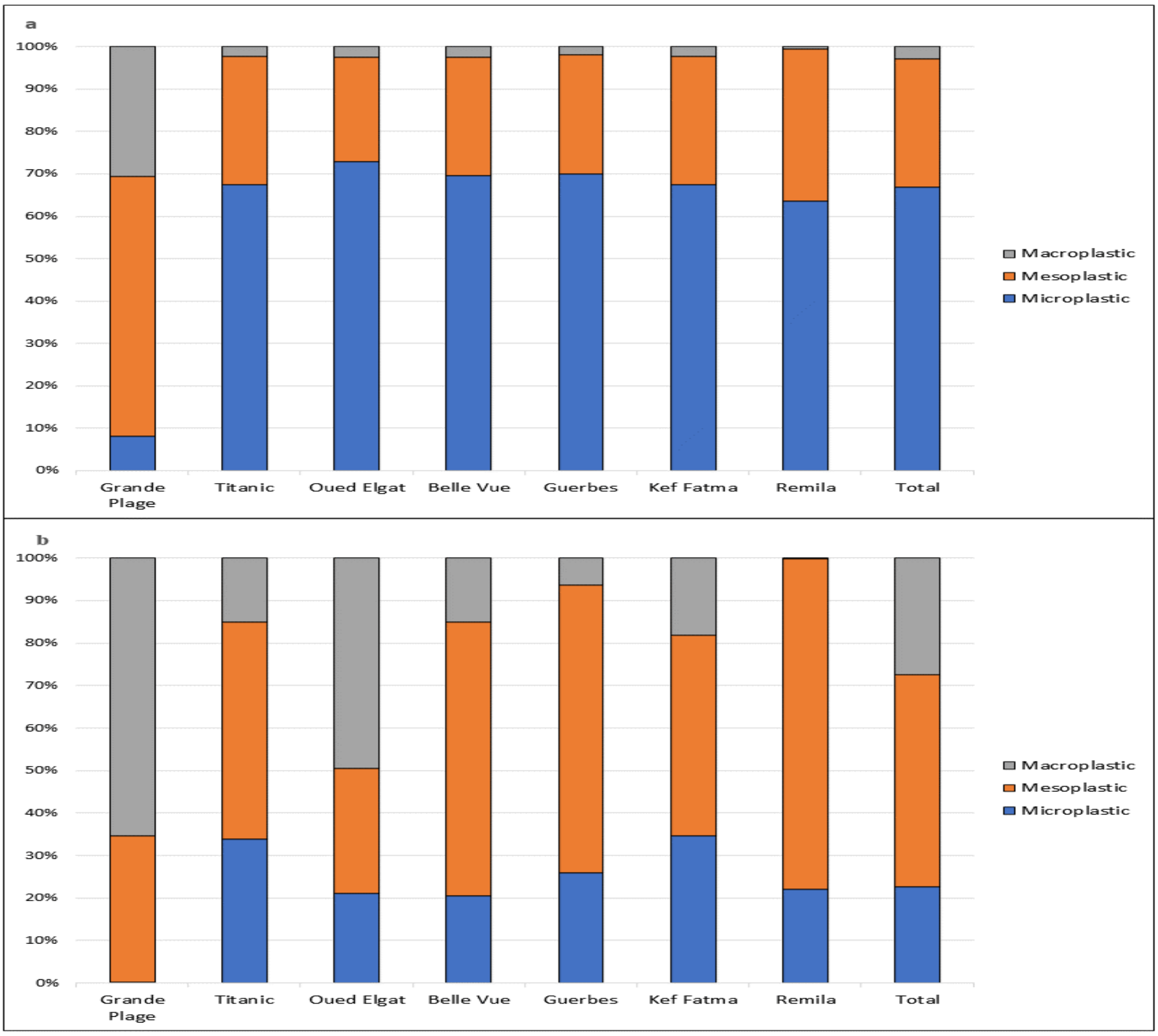


Figure20: Size classification as percentage of Total Plastic a) by number of particles and b) by weight**.**

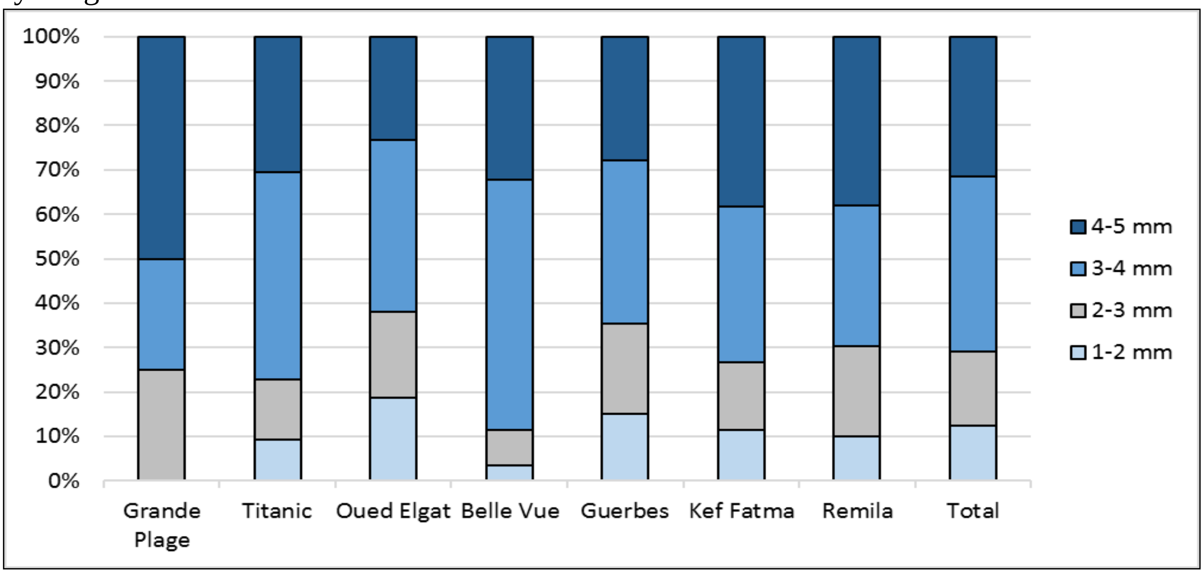


Figure 21: Size classification as percentage of microplastic size classes.

3.3. Plastics polymer characterization

For the 50 analyzed potential plastic particles, Fragments (n=23) were identified as Polyvinyl Alcohol PVA (n=7), Polyamides PA (n=5), Polyethylene PE (n=4), Polypropylene PP (n=3), Polystyrene PS (n=2), Polyvinylchlorides PVC (n=1), Phenol Formaldehyde resins PF (n=1); Pellets (n=18) were identified as PE (n=13), PVA (n=4), PP (n=1); Films (n=4) and Filaments (n=2) were identified as PE; and foams (n=3) were identified as PS (Material: Table 7, Figure22, and Figure23).

Table 7: Polymer profile of microplastics

Polymers types	Fragments	Pellets	Films	Foams	Filaments	Total
PE	4	13	4	-	2	23
PP	3	1	-	-	-	4
PS	2	-	-	3	-	5
PA	5	-	-	-	-	5
PVA	7	4	-	-	-	11
PVC	1	-	-	-	-	1
PF	1	-	-	-	-	1
Total	23	18	4	3	2	50

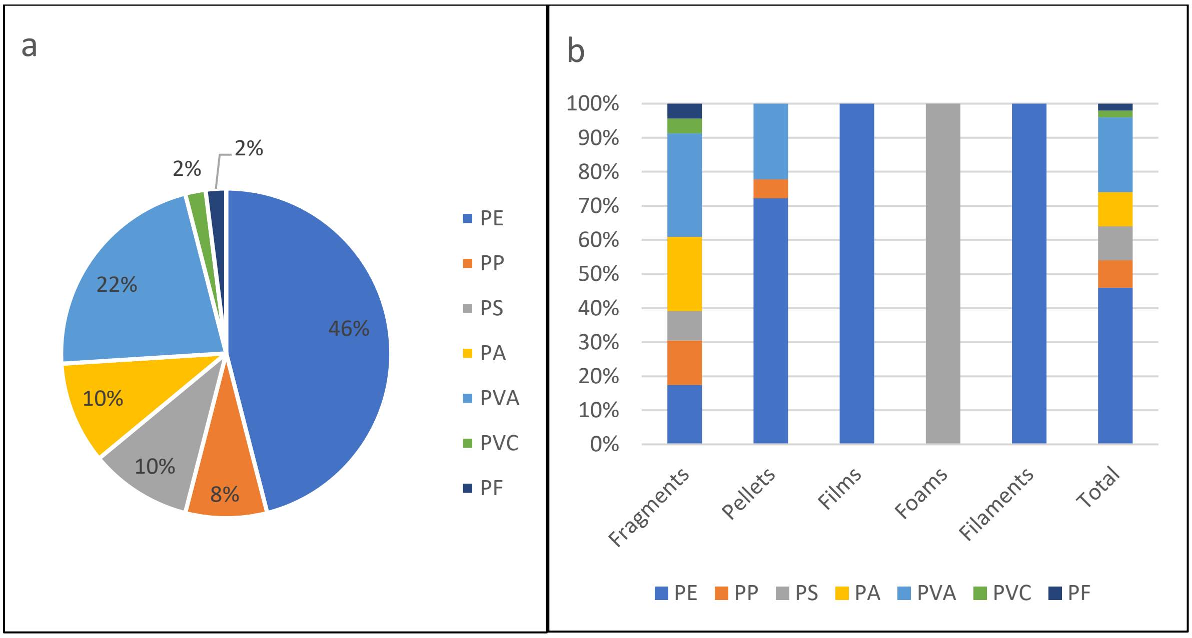
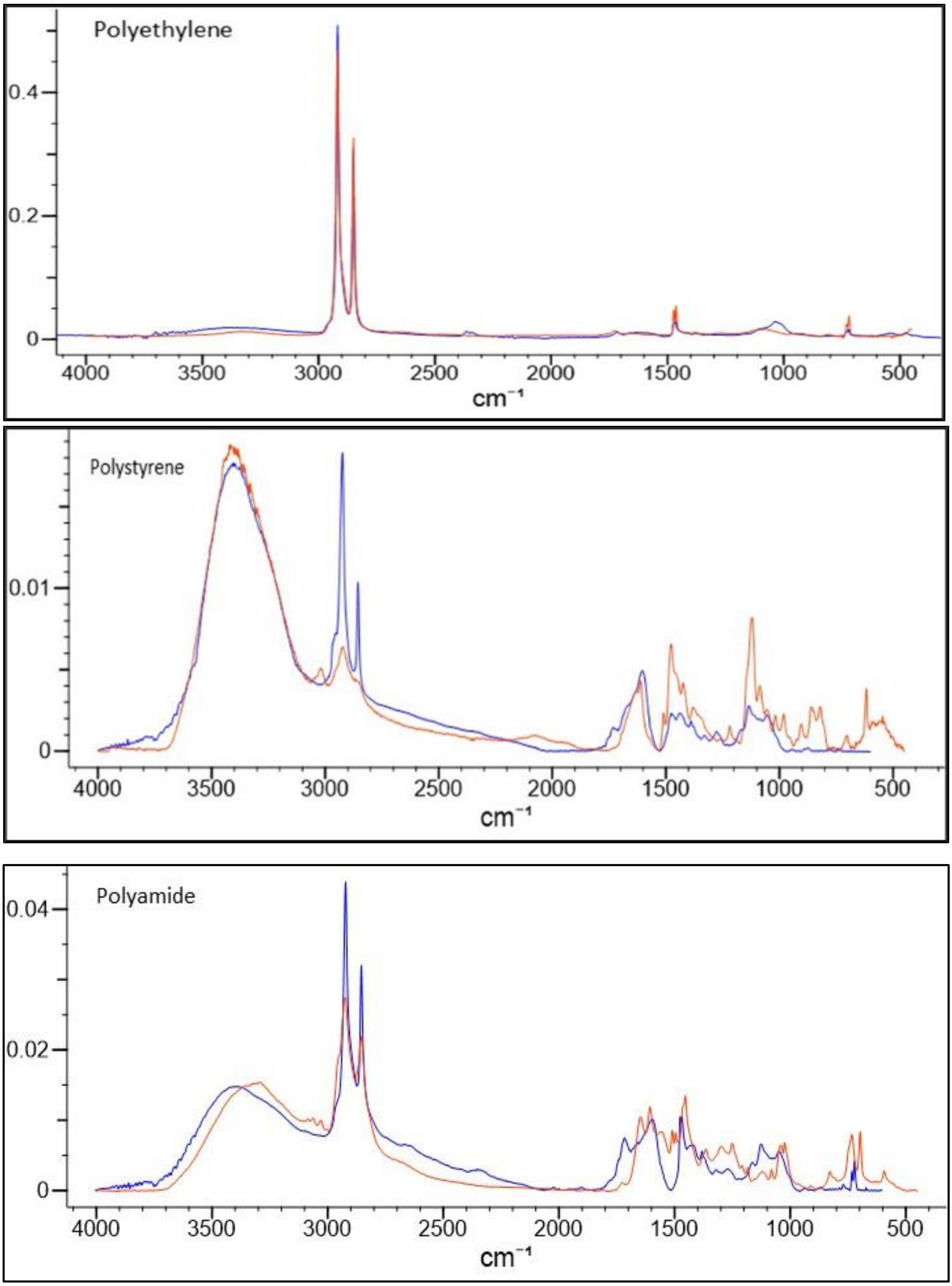


Figure 22: a) Polymer profile of total microplastics. b) Polymer profile of microplastic types.


Polyethylene
0.4
0.2
0
4000
3500
3000
2500
2000
1500
1000
500
cm⁻¹
Polystyrene
0.01
0
4000
3500
3000
2500
2000
1500
1000
500
cm⁻¹
Polyamide
0.04
0.02
0
4000
3500
3000
2500
2000
1500
1000
500
cm⁻¹

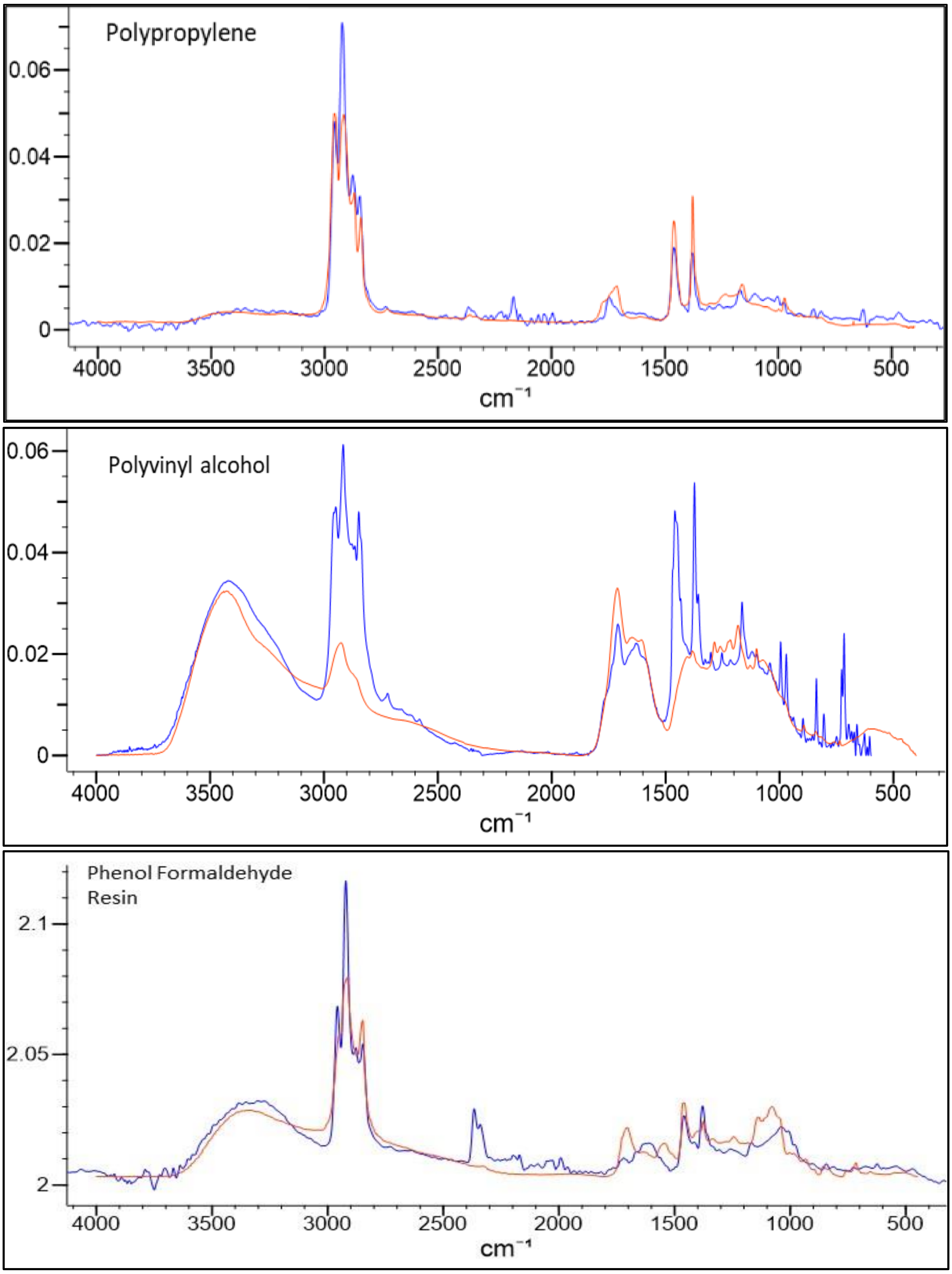


Figure 23 Spectra obtained for the most common polymers found in this study: polymers spectral database (orange line) and analyzed particles (blue line). Polymers: a) Polyethylene, b) Polystyrene, c) Polypropylene, d) Polyamide, e) Polyvinyl alcohol, f) Phenol Formaldehyde Resin.

3.4. Pellets pollution index PPI

The PPI results allowed us to classify the beaches studied according to the degree of pollution into four categories: Very High pollution (Kef Fatma, Guerbes, Titanic), High (Oued Elgat), Moderate (Remila, Belle Vue), and very low (Grande Plage) (Table 8). The average PPI value (3.45) classified the Skikda study area as very heavily polluted.

Table 8: Pellets Pollution Index

Site	Items/m²	PPI	Category
Grande Plage	1.67	0.03	Very low
Titanic	281.22	5.62	Very high
Oued Elgat	138.89	2.78	High
Belle Vue	99.44	1.99	Moderate
Guerbes	270.89	5.42	Very high
Kef Fatma	318.89	6.38	Very high
Remila	96.00	1.92	Moderate
Mean	172.43	3.45	Very high

4. Discussion

This study assessed for the first time the plastic debris occurrence in beach sediments along 50 km of the Skikda coastline. The data highlighted the variability of plastic amounts between sites and within sampling sites on each beach up to an order of magnitude. Total plastics ranged from 230 - 1830 items/m², 23 - 183 items/kg, and 24 - 83 g/m² between sites, presenting a moderate to high level of pollution compared to the concentrations of microplastics and mesoplastics found in other areas of the Mediterranean Sea and other regions of the world.

Mesoplastic abundances were higher than those reported for this specific size fraction in different regions of the world, with the exception of the maximum levels observed in South Korea (Lee et al., 2013) (Table 5). The most common type of mesoplastic was fragments (85%). Fragments are secondary plastics, resulting from the mechanical and chemical degradation of large plastics into smaller pieces. (Andrady, 2011; Galgani et al., 2015; Thompson et al., 2004; Zhao et al., 2016). At Grande Plage, the percentage of mesoplastic fragments and cigarette butts were in similar proportions (Figure17.B). Cigarette butt pollution may be related to beach visitors (Kataržytė et al., 2020).

As observed in other regions, microplastics were the most abundant litter size fraction (68% in our study) (Fok et al., 2017; Martins and Sobral, 2011; Munari et al., 2017). The average microplastics abundance was 734.39 ± 474.87 items/m² and 73.44 ± 47.49 items/kg, which can be considered as moderate to high pollution levels when compared to other studies (Table 9). These concentrations were within the range of those reported in other parts of the world by (González-Hernández et al., 2019; Herrera et al., 2018; Lee et al., 2015; Kaberi et al., 2013).

Some researchers have stated that the eastern Mediterranean coasts present the highest concentrations of plastic debris (Gündoğdu and Çevik, 2019; Liubartseva et al., 2018). At the same time, as cited in the introduction, Mansui et al. (2015) and Macias et al. (2019) predicted that a high concentration of stranded plastics could be found on the southern Mediterranean coasts. The high level of plastic pollution reported in this study corresponds to the predicted accumulation described in the models.

The Gulf of Skikda (southwestern Mediterranean), characterized by high anthropogenic pressure, receives different types of wastewaters without prior treatment. AND (2020) estimated that 78% of marine debris washed up on the Skikda coastline in 2018 was plastic. Local activities, tourism, and fishing were identified as the main sources of macro-waste. The sites most vulnerable to factors that can influence plastic pollution were Titanic and Oued Elgat, both of which had high levels of plastic in this study. In addition, Belle Vue and Remila were also affected, but lower amounts of plastic were recorded. Titanic and Oued Elgat are affected by different types of anthropogenic pressure such as: the proximity of the petrochemical platform, the port, the river mouth, and very high touristic pressure during the tourist season. The lack of garbage cans and the low environmental awareness of beachgoers with poor waste management and seasonal cleaning of the beaches that together contribute to the accumulation of plastic waste in these areas. Although Belle Vue is also affected by these factors, especially tourism, low concentrations of plastic have been recorded. This could be due to the regular cleaning of this beach.

In contrast, plastic concentrations peaked at Kef Fatma and Guerbes, located on the east coast of Skikda, far from anthropogenic impact. These two wide and open beaches are more exposed to the winds and the main west-east currents (circulation) and can constitute accumulation areas in the region. The mismanagement of waste generated in the city can lead to the escape of plastic debris into the marine environment, plastic waste could be dragged and dumped on these beaches. On the other hand, Grande Plage, also a large open beach located on the west coast of Skikda, showed the lowest amount of plastic. These values may be related to the influence of the main west-east currents (Millot and Taupier, 2005) which transport plastic waste to the eastern coasts. According to LEM (1998) the Gulf of Skikda is subject to the main west-east current which can reach 1 to 2.5 knots and the near shore current of 0.5 to 1.5 knots.

The variability in plastic concentrations between sampling sites observed at some beaches (SD values) may explain the non-significance of the ANOVA test. Waves, wind direction, hydrodynamic factors, local activities, anthropogenic intensity, and tourism may influence the distribution of marine litter and plastics (Andrady, 2015; Debrot et al., 1999; Galgani, 2015). Constant et al. (2019) suggests that the spatial distribution of microplastics (quantity and type) on Mediterranean beaches, which are microtidal coasts, can exhibit high heterogeneity at small scales and can change within a short time span (one month), and that microplastic concentrations depend on the sampling strategy in addition to hydrodynamic and anthropogenic factors. Thus, further monitoring would be needed to understand the distribution pattern and temporal variability of plastics stranded along Skikda beaches, such as microplastics, which represent the most abundant size fraction (68% of items) of collected plastic samples.

Table 9: Review of mesoplastics and microplastics abundance in beach sediments from different regions of the world.

Area	Size range		Concentrations		References
	Mesoplastics				
South Korea		Min - Max	0-940	items/m²	Lee et al. (2013)
Croatia			0 – 4.8	items/m²	Renzi et al. (2019)
South Korea		Mean	37.7	items/m²	Lee et al. (2015)
South Korea			13.2	items/m²	Lee et al. (2017)
China			163	items/m²	Fok et al. (2017)
Southeast India			9.38	items/m²	Jeyasanta et al. (2020)
Northern Adriatic coast, Italy			3.50	items/kg	Munari et al. (2017)
Canary Islands			17.9	g/m²	Herrera et al. (2018)
Playa Grande, Tenerife Island			18	g/m²	González-Hernández et al. (2019)
Skikda, Algeria			306.88 32.30 25,28	items/m² items/kg g/m²	Present study
		Min – Max	140.74-562.96 14,07 -56.30	items/m² items/kg	
	Microplastics				
South Korea	1-5 mm	Min - Max	56 - 285,673	items/m²	Kim et al. (2015)
South Korea	1-5 mm		1.6 - 92,217	items/m²	Lee et al. (2013)
Russian Baltic coast	0.5-5 mm		1.3–36.3	items/kg	Esiukova (2017)
South Korea	1-5 mm	Mean	880.4	items/m²	Lee et al. (2015)
South Korea	1-5 mm		252.1	items/m²	Eo et al. (2018)
Canary Islands	1-5 mm		987	items/m²	Herrera et al. (2018)
Playa Grande, Tenerife Island	1-5 mm		1277	items/m²	González-Hernández et al. (2019)

Tenerife Island	1-5 mm		532.8	items/m²	Álvarez-Hernández et al. (2019)
Gran Canaria Island	1-5 mm		250.7	items/m²	Rapp et al. (2020)
Portugal	1-5 mm		125.87	items/m²	Martins and Sobral (2011)
India	1-5 mm		28.83	items/m²	Jayasiri et al. (2013)
Chile	1- 4.75mm		22.95	items/m²	Hidalgo-Ruz and Thiel (2013)
Famara, Lanzarote Island	1-5 mm		541.66	items/m²	Cedex (2016)
Maldives Islands	1-5 mm		22.6	items/m²	Imhof et al. (2017)
Persian Gulf	1-4.7 mm		34.16	items/kg	Naji et al. (2017)
Lanzarote Island	1-5 mm		23.7	g/m²	Edo et al. (2019)
Mediterranean Sea					
Aegean Sea Greece	1-2 mm 2-4 mm	Min - max	0 -1218 10 – 977	items/m²	Kaberi et al. (2013)
Tyrrhenian sea, Italy	1-5 mm	Mean	231.77	items/kg	Fastelli et al. (2016)
Northern Adriatic coast, Italy	1-5 mm		7.38	items/kg	Munari et al. (2017)
Croatia	2-5 mm		10.64	items/kg	Renzi et al. (2019)
	0.5- 2 mm		42.26		
	100-500 µm		37.27		
	<100 µm		8.64		
Mostaganem, Algeria	1-5 mm		3.05	items/m²	Taïbi et al. (2021)
Skikda, Algeria	1-5 mm	 Min – max	734.39 73.44 11,50 18.52 - 1233.33 1.85 - 123.33	items/m² items/kg g/m² items/m² items/kg	Present study

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Most microplastic particles were found in size classes C3 (3-4 mm) and C4 (4-5 mm) (Figure 21), showing similarity with the most frequent size classes found in several studies worldwide: 3-4 mm in the Portuguese coastline (Martins and Sobral, 2011)2-4 mm in Greece (Kaberi et al., 2013)2.8-4.75 mm (McDermid and McMullen, 2004) and 2-4 mm in Hawaii (Young and Elliott, 2016)2-4 mm in the Persian Gulf (Iran) (Naji et al., 2017) and 2-4 mm in Tenerife (Canary Islands). (Álvarez-hernández et al., 2019). In contrast to these results, Arifur Rahman et al. (2020) noted that most microplastics belonged to the 1.5-3 mm size class, followed by the 3-4.5 mm size class in Cox Bazar (Bangladesh). Other researchers found that the predominant size distribution of microplastics was 0.5-2 mm in Croatia, 0.06-1 mm in Italy and 0.06-1 mm in France (Renzi et al., 2019) 0.06-1 mm in Italy (Fastelli et al., 2016) 0.04-0.5 mm for fragments in Spain (Filgueiras et al., 2019) 0.315-1 mm in South China (Fok et al., 2017)0.5-2.5 mm in the northwestern part of the Mediterranean (Constant et al., 2019) 0.81-2.16 mm on the east coast of Algeria (Tata et al., 2020)0.7-2.18 mm (for pellets) in northern Tunisia (Abidli et al., 2017) and 0.1-1 mm in southeast Tunisia (Chouchene et al., 2019). The fraction of microplastics < 1 mm was not considered in this study. The variability of the methods used between studies makes it difficult to draw a firm conclusion on the level of pollution and the size range distribution of microplastics from the literature. Harmonization of protocols for monitoring plastics in sediments (sampling, extraction, identification, analytical methods, size fractions and units) is strongly recommended; to ensure consistency of results, taking into account environmental factors, geographical context and adapting them to each size range (microplastics, mesoplastics and macroplastics).

Regarding colors, the white/transparent category was dominant for both fragment and pellet types. This result is in agreement with those reported by several authors (De Ramos et al., 2021; Pan et al., 2019; Rapp et al., 2020; Reinold et al., 2019; Taïbi et al., 2021; Young and Elliott, 2016) and in particular with respect to three types of microplastics: fragments, beads, and films (Tata et al., 2020).

The ATR FTIR analysis identified seven types of polymers, namely PE (46%), PVA (22%), PA (10%), PS (10%), PP (8%), PVC (2%) and PF (2%). These results are consistent with those of a similar study on microplastics in the Gulf of Annaba, on the east coast of Algeria (PE 48%). (Tata et al., 2020). PE is used in a wide range of applications, mainly in packaging, bottles, caps, trash bins, etc. (PlascticEurope, 2020). PVA represents 22% of the analyzed plastics. Due

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to its low toxicity, PVA is used in food packaging, coatings, textile, paper, cosmetics and pharmaceutical industries (D'Amelia and Mancuso, 2020).

Pellets and fragments were the most abundant plastic types, accounting for 95% of the microplastics. Similar results were found on Famara beach in Lanzarote, with high percentages of fragments (43.1%) and pellets (44.3%) (Herrera et al., 2018) and on the island of Kea in Greece, with up to 70% of pellets (Kaberi et al., 2013). In contrast, fibers were found in very low numbers (Figure 3), which may have been influenced by the target size range (particles >1 mm) and the dry sieving method. The dry sieving method may not be effective in retaining fibers or filaments (Phuong et al., 2021). In addition, the pellets are primary plastics transported into the marine environment accidentally during transport or due to poor waste management by the processing industries (Cole et al., 2011; Turner and Holmes, 2011). The high amounts of pellets found in the Titanic could be due to the proximity of the flow from plastic plants (Figure 6).

However, the number of pellets peaks at Kef Fatma, located 30 km from the plastic industry. Ocean currents and wind may bring these large quantities of pellets. Other evidence supports this possibility; the percentage of pellets at Belle Vue, which is regularly cleaned, was much higher than other types. Because of their small size, pellets can escape during cleaning. Also, 87% of the pellets were white/transparent, the most common color of virgin pellets. (Redford et al., 1997) recently stranded on the sediment (Karkanorachaki et al., 2018). The abundance of white pellets along the beaches could prove their common origin. But, also further evidence of the influence of major currents. Moreover, most of the pellets identified by ATR-FTIR were light polymers (polyethylene, polypropylene). This property of low density allows them to be dispersed over long distances by wind and strong currents (Ryan, 2015).

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Teuten et al. (2009) and Camacho et al. (2019) pointed out that pellets are more likely to accumulate and transport organic contaminants. Indeed, substantial levels of persistent organic pollutants POPs (such as hydrocarbons) and heavy metals have been identified in the marine environment, particularly in the sediments of the Gulf of Skikda (Gueddah, 2003; Rouidi, 2014; Rouidi et al., 2013). Stranded pellets could be used in the monitoring of organic contaminants on beaches (Teuten et al., 2009; IPW http://www.pelletwatch.org/). Fernandino et al. (2015) also suggested an index to evaluate pellet pollution (PPI: Pellet Pollution Index). The PPI value reported by Taïbi et al. (2021) classified the west coast of Algeria as moderate. In contrast, our PPI results (Table 8) classified the Skikda study area as very heavily polluted, supporting the idea that the area may be accumulating a large number of small plastics compared to other regions.

Most of the total plastics collected (97% of items) were meso- and microplastics, showing a strong correlation R= 0.79 between them. A similar correlation between micro and mesoplastics has been reported previously (Jeyasanta et al., 2020; Lee et al., 2015), suggesting that microplastics may be the result of fragmentation of mesoplastics. In this case, high concentrations of mesoplastics could be an indicator of high microplastic abundance. Mesoplastics could be useful as a screening indicator to locate hot spots of microplastic accumulation on beaches, while reducing monitoring and analysis efforts. Large microplastics and mesoplastics have been also considered appropriate indicators for regional-scale marine litter assessment (Haseler et al., 2020; Schernewski et al., 2018). Relative to the mass of plastic by size fraction, the mass concentration of mesoplastics can double that of microplastics (2.2:1 ratio). Despite the lack of studies on mesoplastic concentrations at beaches, the results presented here indicate that mesoplastics may play an important role in assessing plastic pollution, not only because of their mass relative to microplastics, but also as a fraction of plastic available to biota through ingestion (Jâms et al., 2000) and as a potential source of additional microplastics due to degradation and fragmentation processes (Efimova et al., 2018). In addition, the random distribution of macroplastics in the samples, although in low numbers, can have a large influence on the total plastic mass results. Because the sampling approach used in this work (30x30 cm quadrats of surface sediment) was not designed to assess macroplastics, additional sampling, for example, a 100-meter transect for macro-litter monitoring (González-Fernández and Hanke, 2020), should be used to obtain additional knowledge about the number and mass distribution of plastics in the different size fractions found in the study area.

Monitoring of large microplastics and mesoplastics is a new approach that could complement current beach monitoring approaches (usually based on macro-waste surveys) in several regional seas, e.g., the Marine Strategy Framework Directive (2008/56/EC) for European Regional Seas and the UNEP/MAP Barcelona Convention (https://www.unep.org/unepmap/) for the Mediterranean Sea (González-Fernández and Hanke, 2020).

Chapter IV:
Tiny microplastics

Skikda: general view of the city and the port in 1900 – Sami Soltane / Skikda Illustration et souvenirs

In this chapter we present the first data on the abundance and the distribution of small microplastic (plastic particles smaller than 1 mm) hiding in sediments of seven beaches of Skikda coast.

The main aim is to determine the abundance, type (fragment, fibers, microbeads, etc.), color, spatial variability and sources of small microplastic found at the beaches of Skikda.

Seven sandy beaches were explored along the 50 km coastline of Skikda between October and November 2018 (autumn period). An overview of the beaches surveyed: The Grande Plage (S1), Titanic (S2), Oued Elgat (S3), Belle Vue (S4), Guerbes (S5) Kef Fatma (S6) and Remila (S7) is given in (Table 1) and (Figure 6).

Results:

1. Abundance and spatial distribution of small microplastics in costal sediments

The average abundance of small microplastics is (1111± 1357) Item/m² with important variation among beaches. The highest amounts of plastic were recorded in Kef Fatma (4059± 2731) item/m², while the minimum concentration was observed in Belle Vue (241± 72) item/m², (Tab.2). The Shapiro-Wilk test showed a normal distribution of plastic debris abundances among the study sites. Moreover, the total accumulation significant of small microplastic particles along the study area showed significant differences among beaches with one-way ANOVA (p-value < 0.05).

Table 10: Small microplastics abundance

Site	Mean	SD	Min	Max
Grande Plage	563	39	522	600
Titanic	533	416	256	1011
Oued Elgat	1452	1615	111	3244
Belle Vue	241	72	167	311
Guerbes	552	496	111	1089
Kef fatma	4059	2731	1467	6911
Remila	374	28	344	400
Mean	1111	1357	-	-

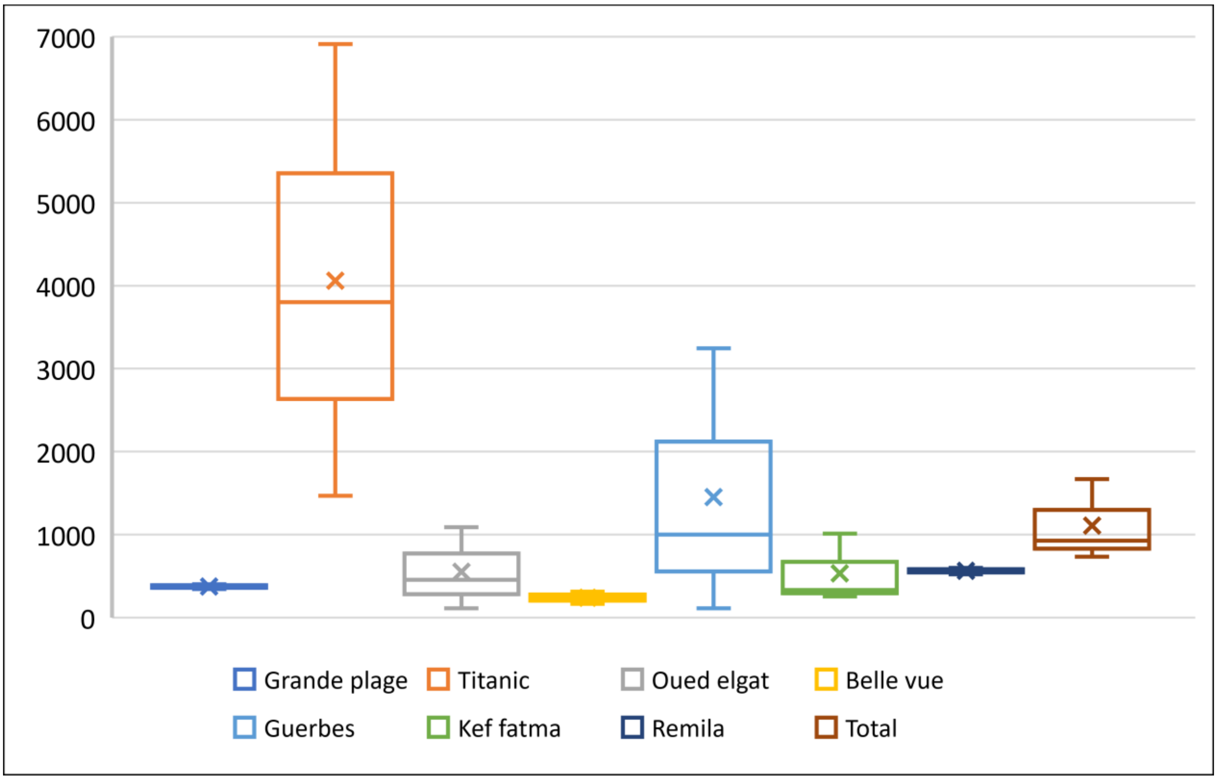


Figure 24: Small microplastic abundances in item/m². The box-whisker plots present the 50th (median), 25th–75th (box), 10th–90th (whiskers) percentiles and the mean (x symbol). (S1: Grande Plage, S2: Titanic, S3: Oued Elgat, S4: Belle Vue, S5: Guerbes, S6: Kef Fatma, S7: Remila)

2. Classification of small microplastics:

Small microplastic type

The two most common plastic types were fragments 74% and fibers 20%. Fragments presented the highest percentage in 3/7 beaches of the study areas: Oued Elgat (89%), Guerbes (58%) and Kef Fatma (91%) where the highest level of small microplastics were identified. However, fibers showed high abundances in 4/7 of the studied beaches: Grande Plage 76%, Belle Vue 69%, Remila 63%, and Titanic 46% (Figure 25).

In general, there were significant differences between study locations (Kruskal-Wallis < 0.05).

Small microplastic color

The white/transparent color category was significantly higher across beaches 77%, followed by black 12% (Kruskal-Wallis < 0.05). The rest of color groups were respectively blue > red > other > Yellow > grey > orange > green. Moreover, White/transparent was the most dominant color within fragments and foams, for microbeads and fibers the main color category was black (Figure 26).

3. Plastic size fractions and abundance

Overall, the average abundance of small microplastic was higher than large-microplastic and mesoplastic along the study area (Figure 28). Level of small microplastic picked at Kef Fatma beach reaching 4059 item /m² of small microplastics. However, large microplastic showed the highest concentrations at Guerbes beach. For mesoplastics the levels were never higher than microplastics (small, large) except for Grande Plage where mesoplastic abundance was higher than large microplastics.

Small microplastic C1 (< 1mm) was the predominant size fraction (average 60%), reaching more than 70% in sites 1 and 6, followed by the size classes C4 (3-4 mm) with 16% and C5 (4-5 mm) with 12% (Figure 27).

Linear regressions were used to verify the relationship between concentrations of the three size classes of plastics, No relationship was found between small and large microplastic (R^2= 0.25), small microplastic and mesoplastics (R^2= 0.47). However, a strong correlation was found between total microplastic and mesoplastic R^2= 0.68.

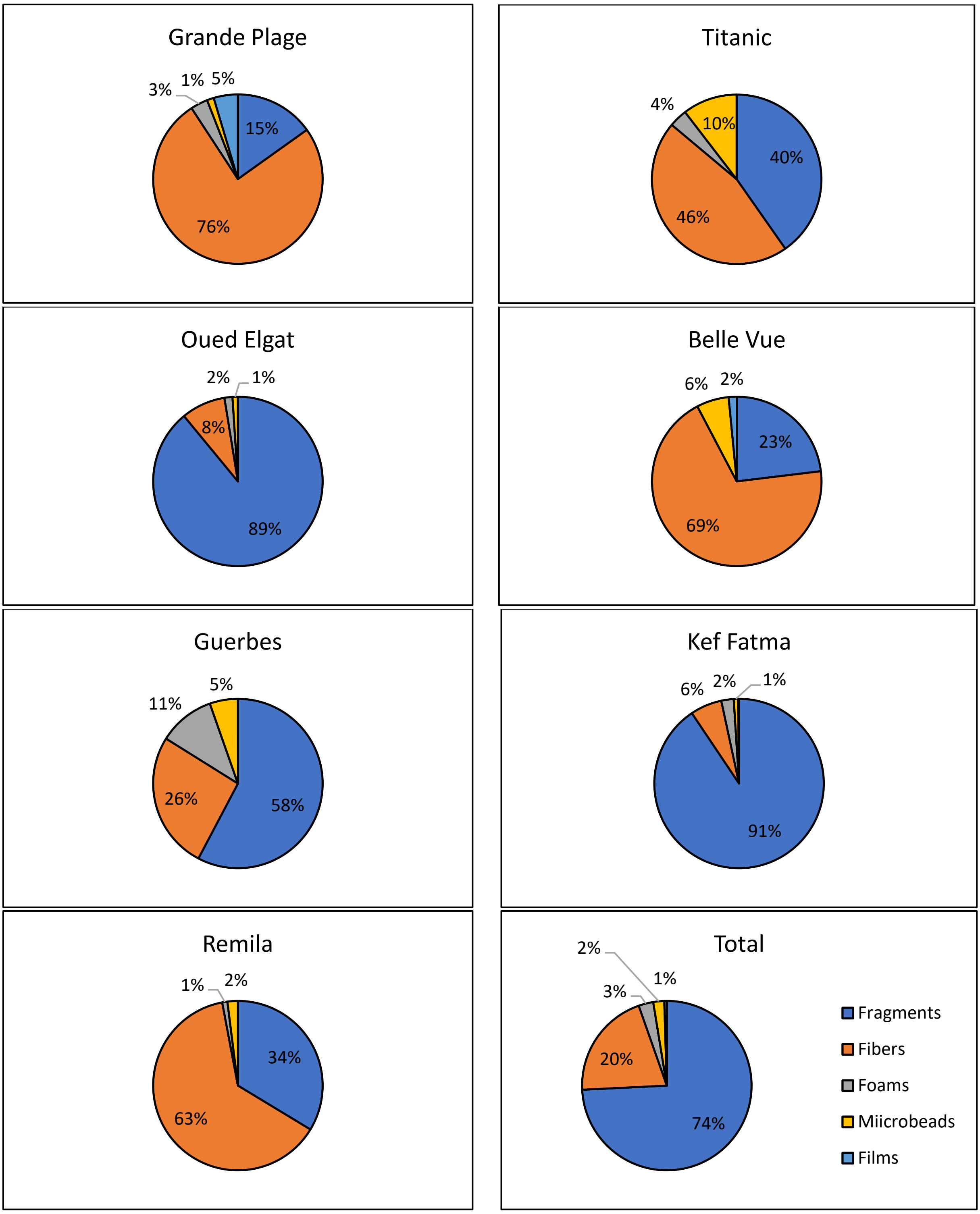


Figure 25: Classification of small microplastic types.

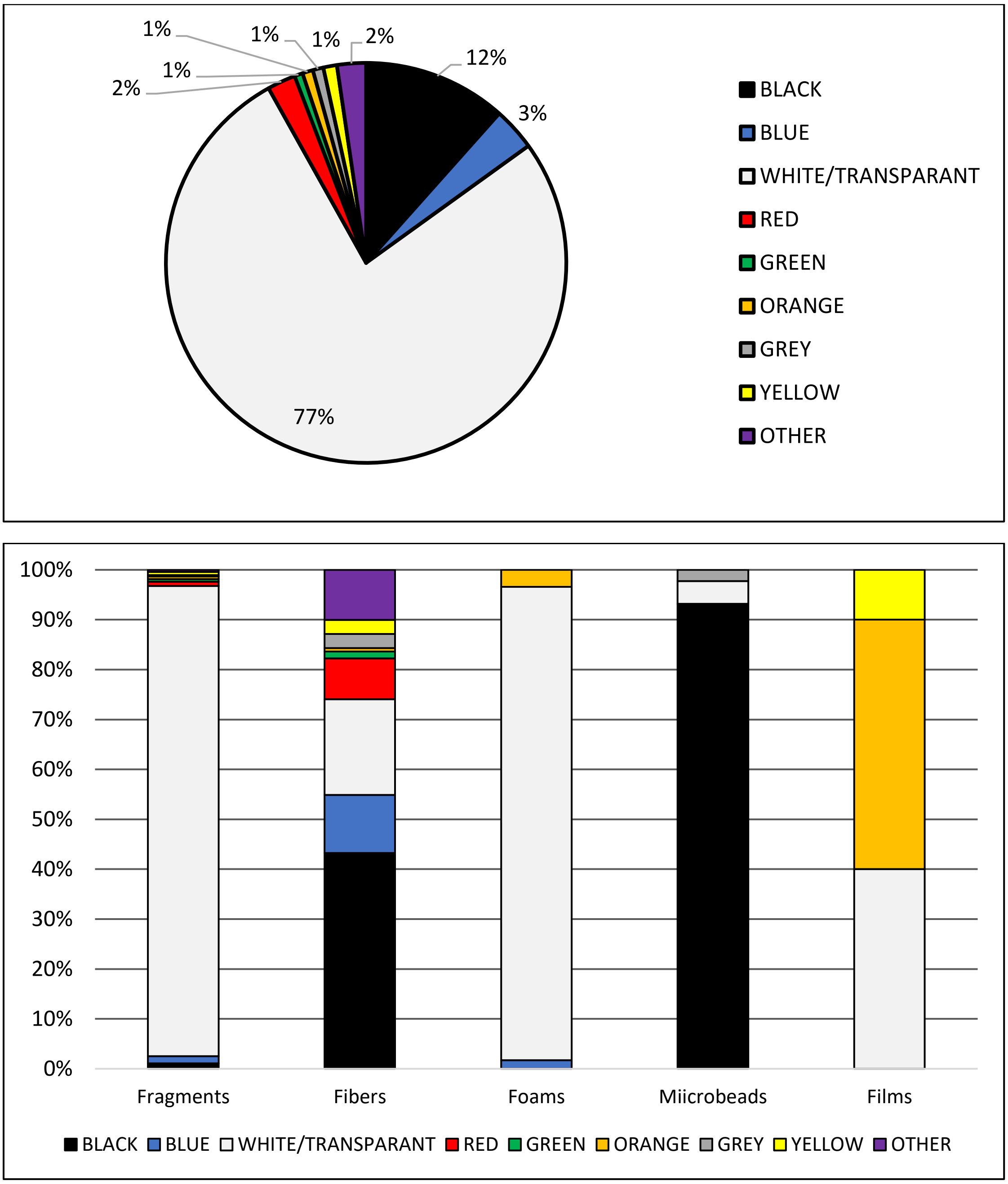


Figure 26: Classification of small microplastic colors by type.

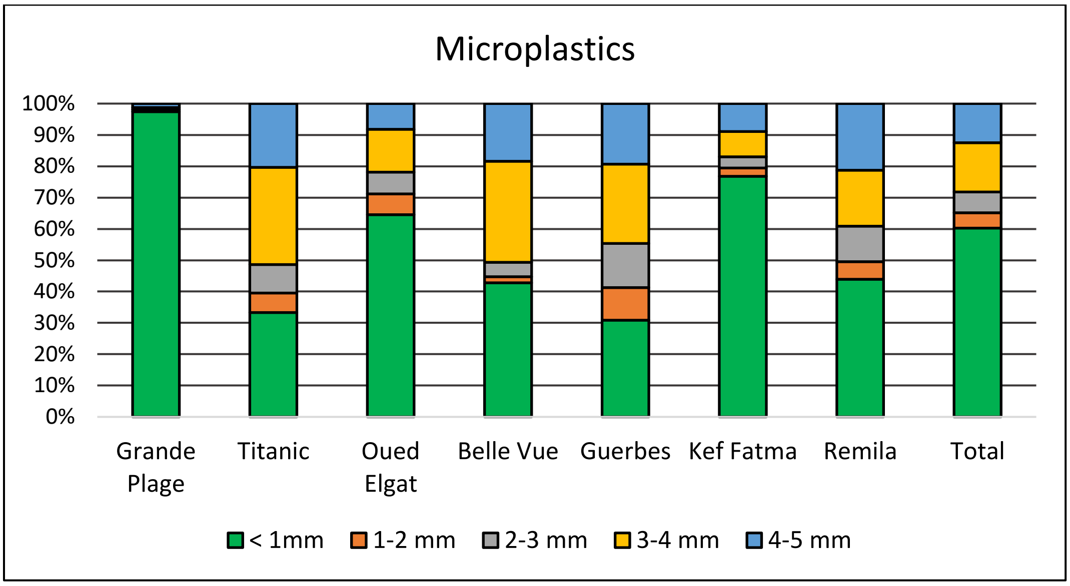


Figure 27: Size classification as percentage of total microplastic size classes.

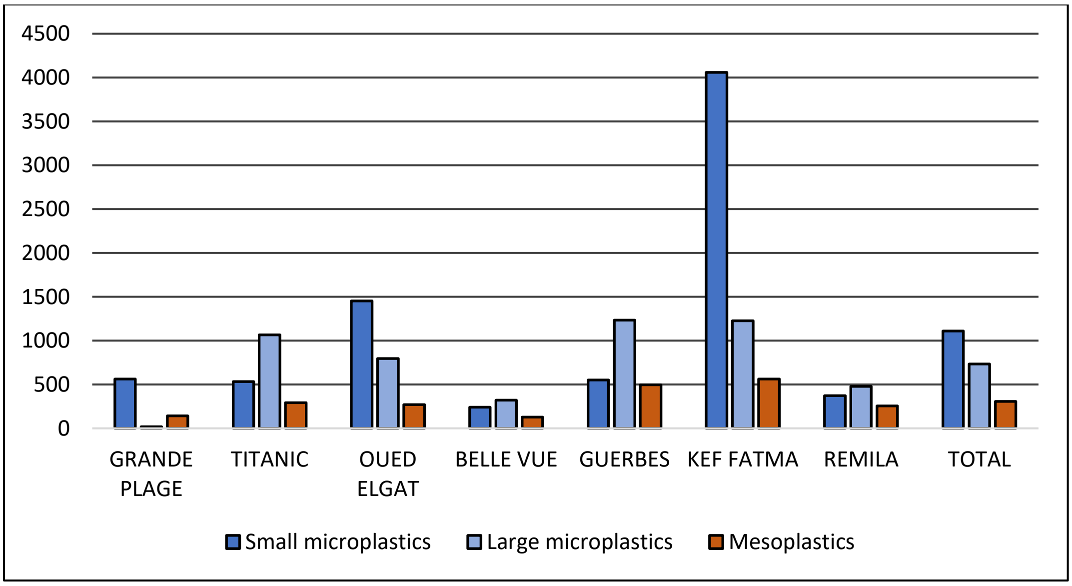


Figure 28: Size classification as abundance of Plastic (Small, large microplastics and mesoplastics)

Discussion:

Overall, small microplastic was more abundant than large microplastic. This findings are in line with several studies carried on microplastics in the Mediterranean Sea and worldwide (See Chapter 3).

Fragments were the most abundant type (74%), the identified fragments were mainly of the white/transparent color category. Similar results were reported by (De Ramos et al., 2021; Pan et al., 2019; Rapp et al., 2020; Reinold et al., 2019; Tata et al., 2020; Taïbi et al., 2021).

Hence, Fragments were very high at beaches where the highest levels of microplastics were registered, citing: Kef Fatma where 4059 item /m² small-microplastics were found (91%) of them were fragments, Oued Elgat where 1452item /m² small-microplastics were found (89%) of them were fragments, and Guerbes where 552 item /m² small-microplastics were found (58%) of them were fragments.

No relationship was found between the concentrations of small and large microplastic (R^2= 0.25), small microplastic and mesoplastics (R^2= 0.47). However, a strong correlation was found between total microplastic and mesoplastic R^2= 0.68. A similar correlation between micro and mesoplastics has been reported previously (Jeyasanta et al., 2020; Lee et al., 2015), suggesting that microplastics may be the result of fragmentation of mesoplastics. Moreover, fragments levels of different plastic sizes (mesoplastics, large microplastics, and small microplastics) picked similarly at the same beaches; e.g.: Kef Fatma, Guerbes, and Oued Elgat where the highest concentration of meso- and microplastics (small, large) were registered (Figure28). In this regard, as we mentioned previously in Chapter 3 high concentrations of mesoplastics could be an indicator of high microplastic abundance. But, for fragments only. Since fibers, the second most abundant type of small microplastics, showed a different pattern of distribution. Microfibers concentrations were significantly important in the whole study area (Kruskal-Wallis < 0.05), and were the most abundant type at 4/7 beaches. Nevertheless, the highest concentration of fibers were found at Grande Plage, which is large and open rural beach far from the anthropic pressure and where the lowest concentrations of plastic were registered (Chapter 3). In contrast, fibers were found in very low numbers for the other plastic sizes (large microplastics and mesoplastics) (Figure 17). This was explained by the limitation of the dry sieving method. The dry sieving method may not be effective in retaining fibers or filaments (Phuong et al., 2021). Though, density separation is more effective in evaluating the fibers, hence proved that the extraction method affects the recovery of microplastics (especially small sized) and the quantity of fibers.

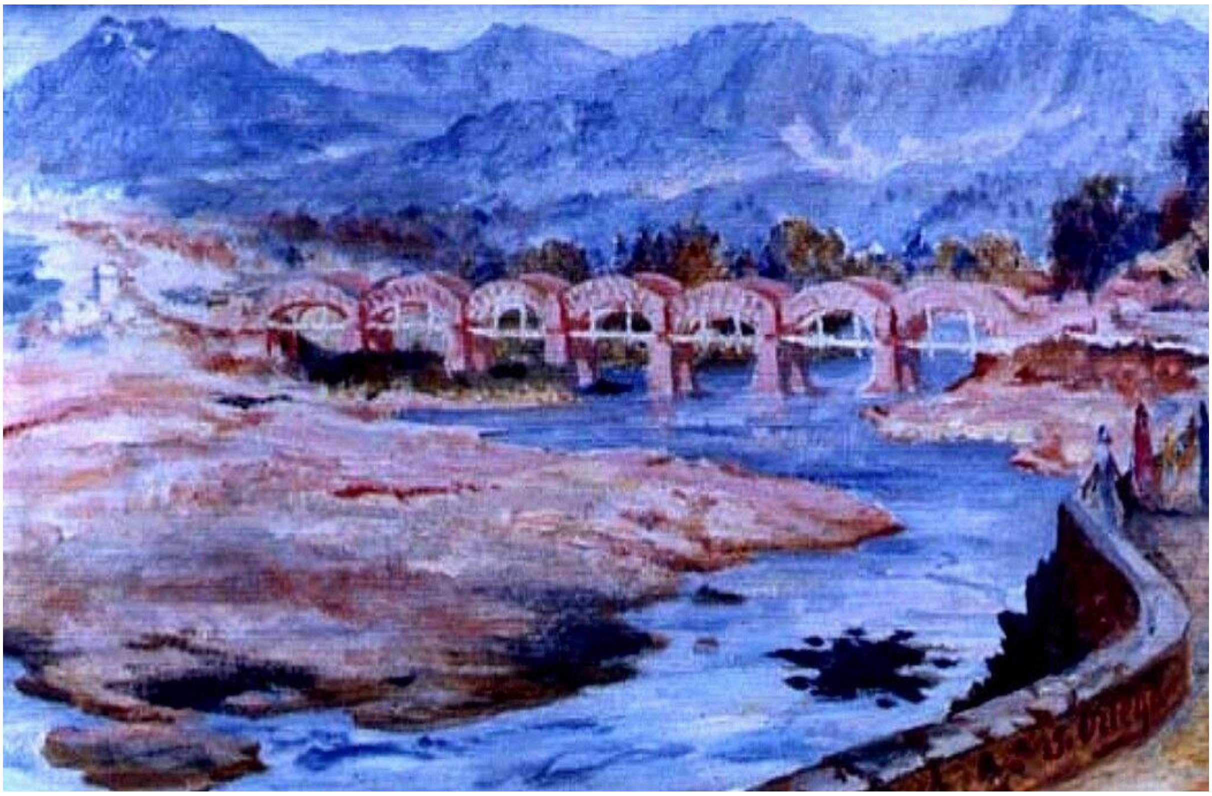
Generally fibers released from synthetic textiles, washing wastewater, sewage effluents and sludge (Acharya et al., 2021). Since these fibers are too small to be captured by the majority of water treatment systems, they may end up in waterways, and oceans.

Also fibers, have been found in atmospheric deposition and sampled air masses (Allen et al., 2020). Furthermore, Cai et al. (2017) revealed that a continuous fallout of microplastics and fibers over the three months of autumn/winter in 2016. Moreover, fibers concentration could be also influenced by season and the touristic pressure which is very high during summer. This may explain the important levels of fibers found at beaches especially at Grande Plage beach during autumn (Chapter 5) (Annex 1).

Small sized plastics are more likely to be accidently consumed by marine species (Barnes et al., 2009; Cole et al., 2011; Derraik, 2002). Microfibers are abundant in microplastic forms extracted from the bodies of various organisms. Ingestion of smaller plastics, such as microfibers, by marine organisms causes physical problems such as gut blockage, disturb the physiological processes, disruption of the endocrine system, reproductive impairment, oxidative stress, and disruption in body functions such as respiration, segregation of digestive enzymes, nutrient absorption, and energy reserve storage (Acharya et al., 2021).

Chapter V:

Seasonal variation of mesoplastics and microplastics in the Skikda Coast



The seven bridges of Wed Saf-Saf Skikda **– José Ortéga**

http://skikda.boussaboua.free.fr

Chapter V: Seasonal variations of mesoplastics and microplastics in the Skikda Coast

Research on marine litter on the Skikda coast limited on one research conducted by AND, (2020) which was limited on two beaches (Grande Plage and Kef Fatma). Research on plastic pollution in Skikda beaches is still limited on our first survey of plastic pollution in the area (Grini et al., 2022). Hence, there is no detailed study of microplastics (<5mm) and mesoplastics (5-25mm) magnitudes and spatial-temporal distribution in this coastal area to date.

Although, this region is subjected to significant pressure from several activities including industry, fishing, urbanization and tourism. This study aims to fill these existing gaps concerning plastic pollution magnitudes on the Skikda coast. This chapter presents the microplastics and mesoplastics problem along five beaches located on Skikda (central and eastern coast of Skikda), defining MPs magnitudes, spatial-temporal distribution, shapes, polymer types, impacts, and possible sources. The impetus for this study comes from the alarming situation of omnipresent plastic in this coastal environment of Skikda.

Data presented in this study were collected in two field surveys carried out in May (spring) and September (autumn/fall) 2019. Five sandy beaches were explored along the 30 km coastline of Skikda. An overview of the surveyed beaches: Titanic (S1), Oued Elgat (S2), Belle Vue (S3), Guerbes (S4) and Kef Fatma (S5) is given in (Table 1) and (Figure 6).

The presented in this chapter is subject to a publication entitled:

Seasonal variations of mesoplastics and microplastics in the Skikda Coast

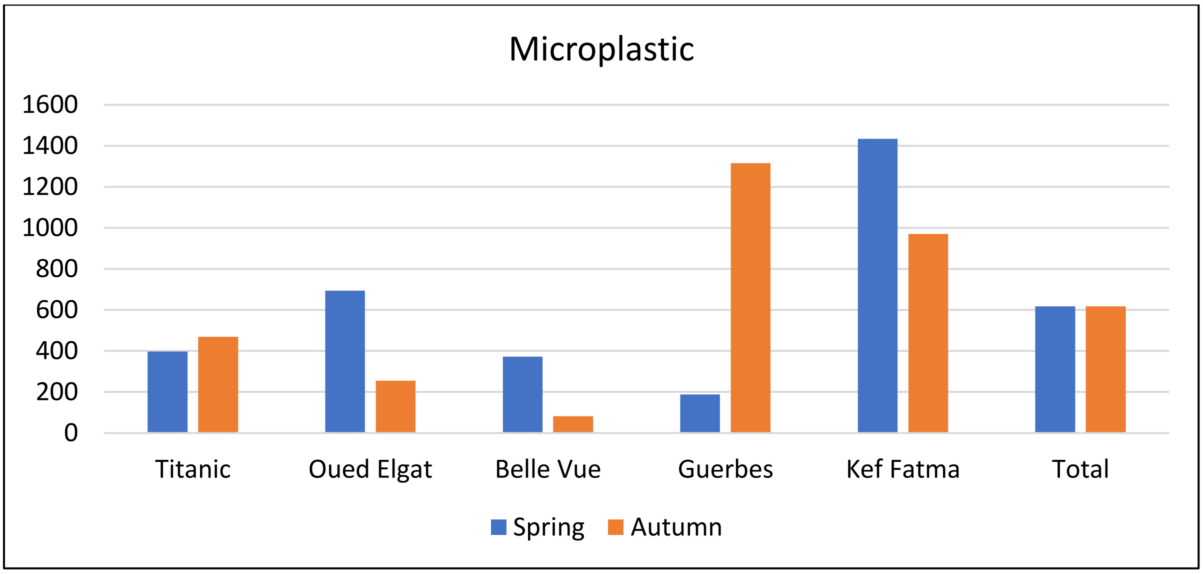
Halima Grini*, Sophia Metallaoui, Daniel Gonzalez-Fernandez, Nelson Rangel-Buitrago, Hadef Azzedine, Mourad Bensouilah

Results:

1. Seasonal variation of micro and mesoplastics abundance

Overall, the average abundance of microplastics of all beaches showed no obvious variation between seasons (6174 item/m² during spring and 6183 item/m² during autumn). However, the concentrations of MPs changed among beaches and between seasons. The highest concentration of MPs was recorded in Kef Fatma14337 item/m² and the lowest concentration was observed in Guerbes 1889 item/m² during spring. Conversely, during autumn MPs levels peaked in Guerbes while the lowest MPs level was observed in Belle Vue.

The number of MPs collected during Spring was higher than Autumn in 3/5 of sampling sites. However, the level of MPs was higher during autumn than spring in 2/3 especially Guerbes where the registered number of MPs was 7 times higher.



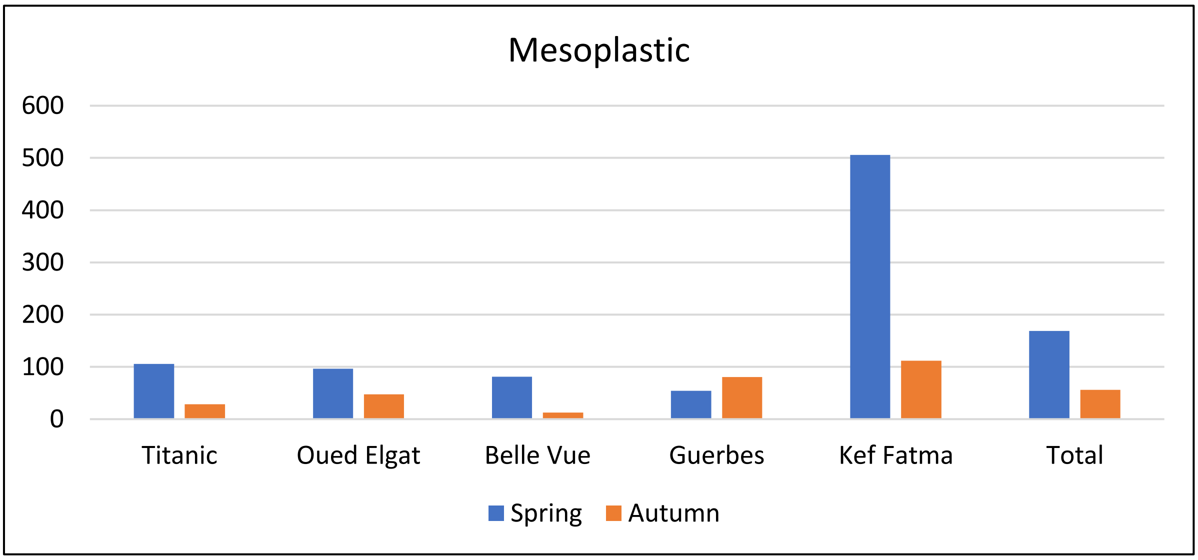


Figure 29: Microplastic and mesoplastics abundance between beaches

Table 11: microplastics and mesoplastics densities

Site/type	Microplastic				Mesoplastic			
	Item/m²		Item/kg		Item/m²		Item/kg	
	Spring	**Autumn**	**Spring**	**Autumn**	**Spring**	**Autumn**	**Spring**	**Autumn**
Titanic	3974.07	4696.30	397.41	469.63	1055.56	285.19	105.56	28.52
Oued Elgat	6940.74	2548.15	694.07	254.81	962.96	474.07	96.30	47.41
Belle Vue	3729.63	814.81	372.96	81.48	814.81	125.93	81.48	12.59
Guerbes	1888.89	13148.15	188.89	1314.81	540.74	803.70	54.07	80.37
Kef Fatma	14337.04	9707.41	1433.70	970.74	5059.26	1118.52	505.93	111.85
Total	6174.07	6182.96	617.41	618.30	1686.67	561.48	168.67	56.15

Table 12: Microplastics types densities along Skikda beaches

Saison	Spring								
Beach name	MPs/kg								
	Pellet	Fragment	Fiber	Film	Microbead	Foam	Filament	Rubber	Total
Titanic	84.81	209.63	28.15	1.85	14.81	58.15	0.00	0.00	397.41
Oued Elgat	145.93	399.26	24.07	0.37	14.81	109.63	0.00	0.00	694.07
Belle Vue	87.41	175.56	5.19	1.48	7.04	95.93	0.00	0.37	372.96
Guerbes	17.41	108.15	15.19	4.07	1.48	42.22	0.00	0.37	188.89
Kef Fatma	669.26	695.19	23.33	0.74	5.56	38.52	0.74	0.37	1433.70
Total	1004.81	1587.78	95.93	8.52	43.70	344.44	0.74	1.11	3087.04
Saison	Autumn								
Beach name	MPs/kg								
	Pellet	Fragment	Fiber	Film	Microbead	Foam	Filament	Rubber	Total
Titanic	328.52	53.70	78.52	0.00	0.00	8.89	0.00	0.00	469.63
Oued Elgat	117.78	33.33	51.85	1.11	0.37	50.37	0.00	0.00	254.81
Belle Vue	12.59	18.15	45.93	0.37	0.00	4.44	0.00	0.00	81.48
Guerbes	211.85	925.56	51.11	11.85	5.56	107.04	1.85	0.00	1314.81
Kef Fatma	505.56	336.67	54.07	3.33	9.63	61.11	0.37	0.00	970.74
Total	1176.30	1367.41	281.48	16.67	15.56	231.85	2.22	0.00	3091.48

2. Microplastics types:

2.1. Shape:

The most common microplastic types were fragments>pellets>foams>fibers during spring and fragments> pellet>fibers>foams during autumn (fall) respectively, reaching more than 98% of microplastics shapes collected in the present study.

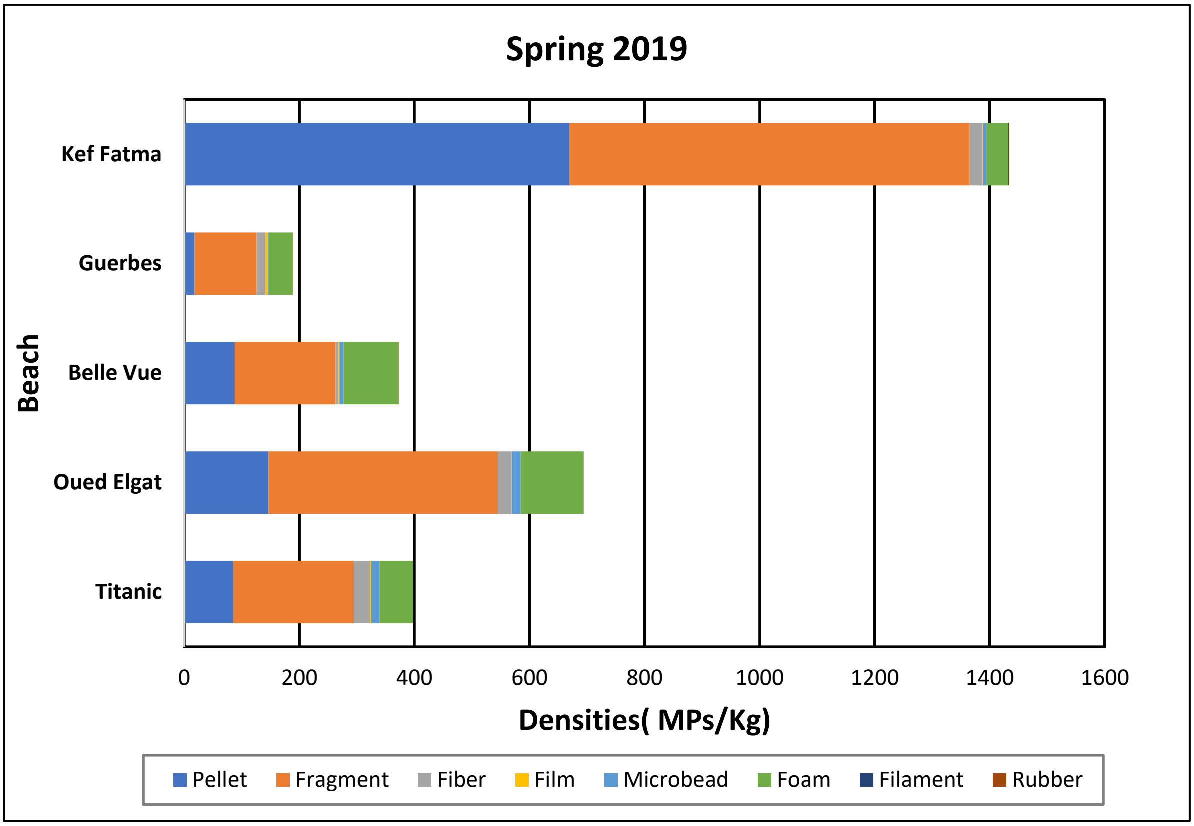
Fragments were the most abundant shape during the two seasons, accounting for 51% with an average of 318 MPs/kg during spring and with 33% of the total MPs and an average of 273 MPs/kg during autumn. The highest fragment densities were recorded in Kef Fatma (695 MPs/kg) during Spring and Guerbes (925 MPs/kg) during autumn. While the low fragments abundances were observed in Guerbes (108 MPs/kg) during spring and Belle Vue (18 MPs/kg) during autumn.

Pellets second most abundant MPs shape, reaching 33% during spring and 38% during autumn of total MPs, with a pellets' average of 200 MPs/kg and 235 MPs//kg respectively. The highest pellets densities were found in Kef Fatma beach (669 MPs/kg, 506 MPs/kg) during the two seasons. While the low pellets abundances values were recorded at Guerbes (87 MPs/kg) during spring and at Belle Vue (13 MPs/kg) during autumn.

Foams represent in the five surveyed beaches 11% (69 MPs/kg) during spring and 7.5% (46 MPs/kg) during autumn. The high foam densities of were registered at Oued El-Gat (110 MPs/kg) in the spring season and at Guerbes (107 MPs/kg) in the autumn season.

Fibers were observed in both season with an average of 19 MPs/kg (3%) in spring and 56 MPs/kg (9%) in autumn. The highest fibers abundances were 28 MPs/kg (spring) and 78 MPs/kg (autumn) found at Titanic. However, the low densities were 5 MPs/kg (spring) and 46 MPs/kg (autumn) observed at Belle Vue.

The remaining 1-2% of MPs were divided between (microbeads, films, filaments and rubbers) for the two seasons.



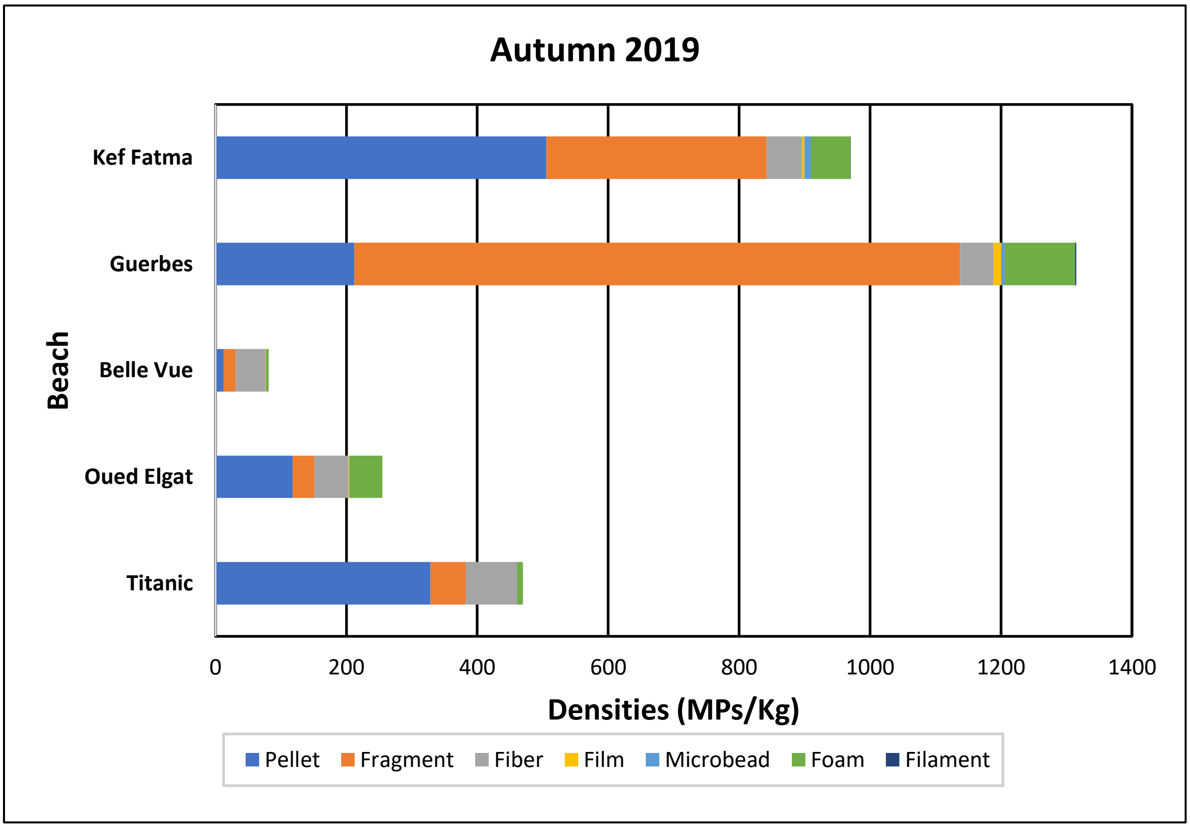


Figure 30: Microplastic types densities.

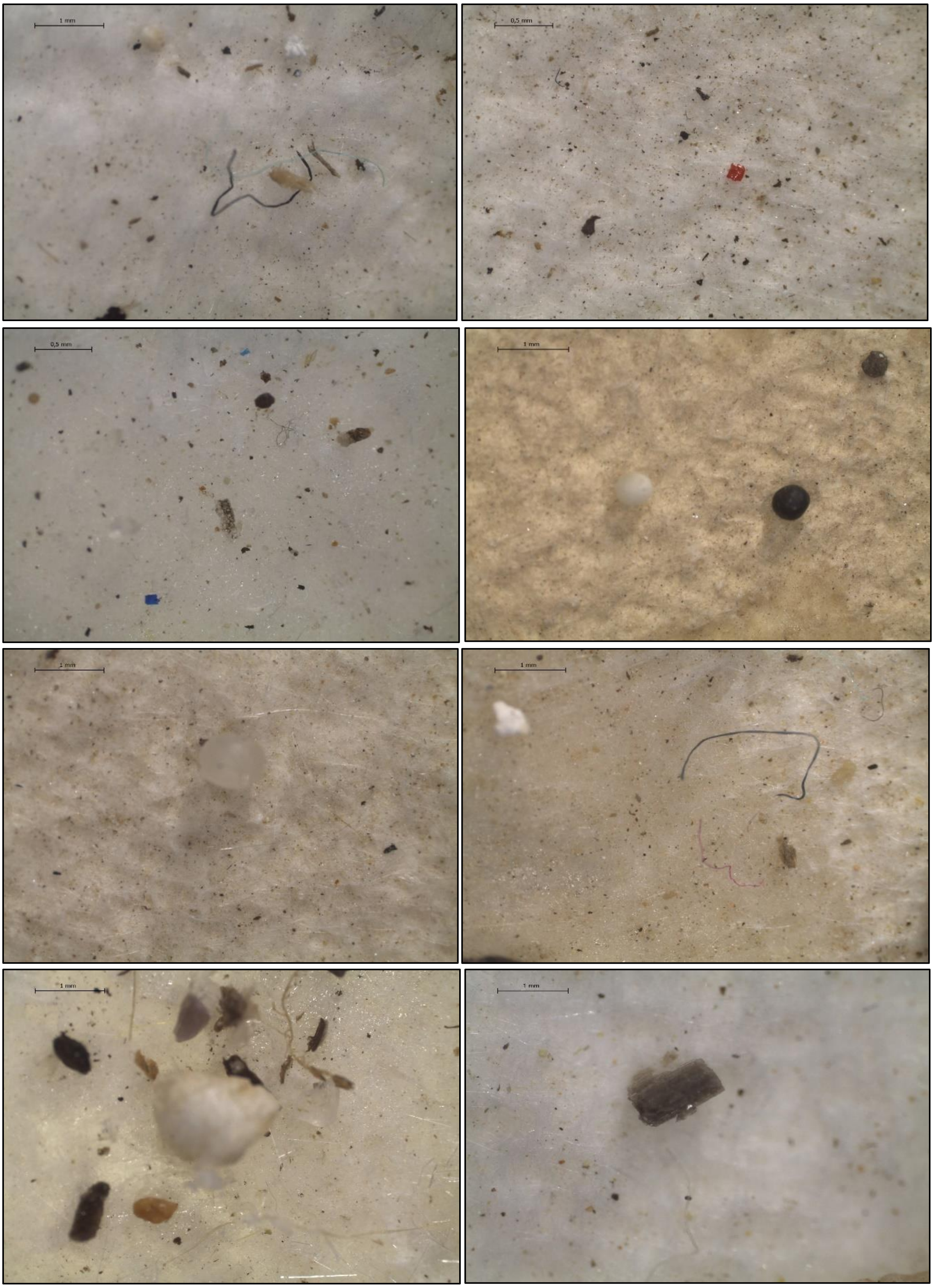


Figure 31: Microscopic photos of different types of microplastics: fibers, fragments, foams, microbeads.

2.2. Polymer types:

For the 130 analyzed potential plastic particles, Fragments (n=94) were identified as Polyvinyl Alcohol PVA (n=20), Polyamides PA (n=26), Polyethylene PE (n=29), Polypropylene PP (n=3), Polystyrene PS (n=10), Polyvinylchlorides PVC (n=6); Pellets (n=13) were identified as PE (n=8), PVA (n=4), PP (n=1); and foams (n=23) were identified as PS (Table.13, Figure32).

Table 13: Polymer types

Polymers types	**Fragments**	**Pellets**	**Foams**	**Total**
PE	29	8	/	37
PP	3	1	/	4
PS	10	/	23	33
PA	26	/	/	26
PVA	20	4	/	24
PVC	6	/	/	6

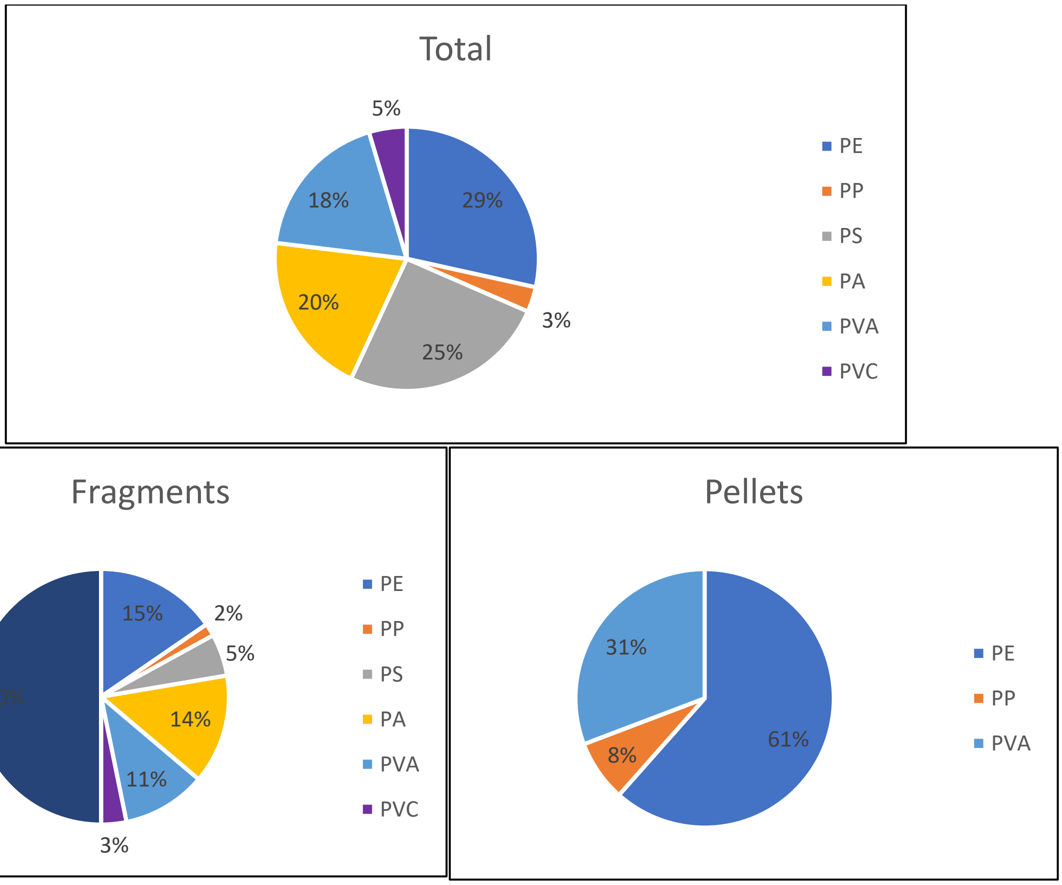


Figure 32: polymer types of microplastics.

3. Microplastics size class:

Size fraction small MPs were higher in autumn 58% than spring the small fraction is represented mostly by fragments, fibers and foams, small MPs were dominating in 3/5 beaches. Conversely, almost 80% (fragments + pellets) of MPs figure in the large fraction, which was the dominant fraction in all sampling beaches during spring

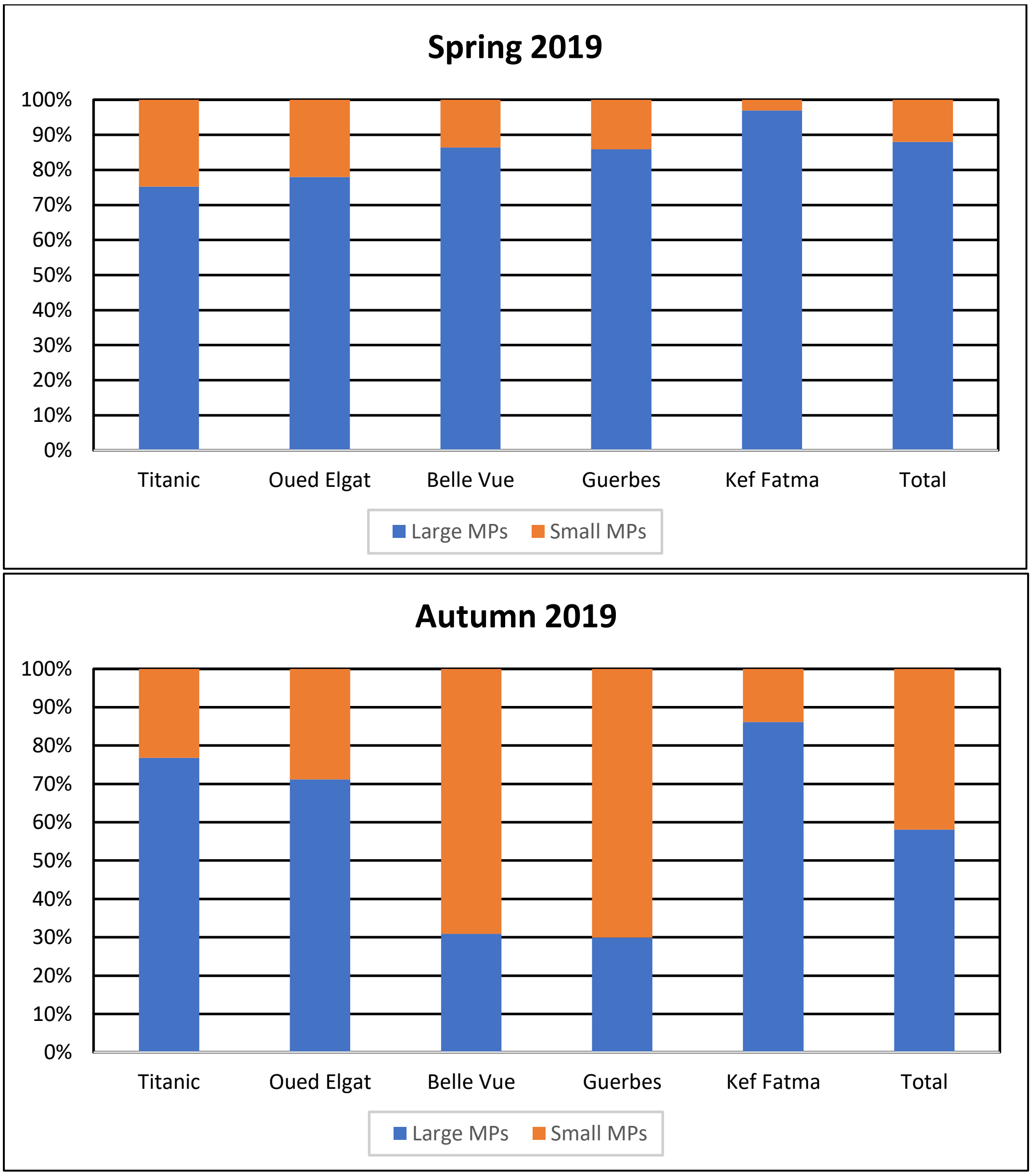


Figure 33: Size class of microplastics.

4. Environmental Indexes:

The assessed beaches were classified using the following indexes: MPPI, CMPI, ESI (Figure 34, 35, 36, 37, 38, 39), (Table.14, 15) and (Appendix 2, 3, 4, 5).

4.1. The Environmental Status Index ESI

The ESI classification showed 4 beaches as “Mediocre” presence of MPs and one beach as “Unsatisfactory” during spring, while during autumn, two beaches were classified as “Mediocre” and two as “Unsatisfactory” and one as “Good”. “Bad” category was not observed on surveyed beaches.

During spring, three beaches (Titanic, Belle Vue and Guerbes) (3/5) belong to the “Moderate” category, while Oued El-Gat and Kef Fatma showed “High” and “Very high” presence MPs respectively (Figure 34), (Table. 14).

Table 14: The Environmental Status Index values

Season	**Spring**			**Autumn**		
Site	**Wi*Xi**	**Final**	**Status**	**Wi*xi**	**Final**	**Status**
Titanic	16	2	Mediocre	15	1,875	Mediocre
Oued Elgat	18	2	Mediocre	14	1,75	Mediocre
Belle Vue	18	2	Mediocre	8	1	Good
Guerbes	16	2	Mediocre	23	2,875	Unsatisfactory
Kef Fatma	21	3	Unsatisfactory	22	2,75	Unsatisfactory

4.2. The Microplastic Pollution Index and the Coefficient of Microplastics impact:

The general microplastic pollution index:

The general MPPI of the five surveyed beaches classified as a High MPs presence. During fall, two beaches (Titanic and Kef Fatma) showed moderate presence of MPs and two beaches showed Very high presence of MPs (Belle Vue and Guerbes). While, Oued El-Gat showed low presence of MPs (Figure 35), (Table. 15).

Table 15: General microplastic pollution index

Season	**Spring**		**Autumn**	
Site	**Pollution Index**	**Pollution Index-Type**	**Pollution Index**	**Pollution Index-Type**
Titanic	10,73	Moderate	12,68	Moderate
Oued Elgat	18,74	High	2,2	Low
Belle Vue	10,07	Moderate	26,21	Very High
Guerbes	5,1	Moderate	35,5	Very High
Kef Fatma	38,71	Very High	6,88	Moderate

Fragments Pollution Index:

The general fragments pollution index for the whole study area was 8.57 during spring and 7.38 during autumn, which allows classifying Skikda beaches as Moderate presence of MPs. While by beach, the fragments pollution index highlights 2 beaches as Low presence of MPs, 2 beaches as Moderate and one with high presence of MPs during spring. There are no beaches within “very low” and “very high” categories of MPs presence. However, during autumn 3 beaches had “very low” presence of MPs, one beach had “moderate” and one beach had “high” presence of MPs. There are no beaches within “low” and “very high” categories of MPs presence.

Coefficient of fragments impact:

Taking the whole study area into account, the general fragments coefficient impact was 0.53 with a maximum impact of fragments during spring. While during autumn, the general fragments coefficient impact was 0.30 with an average impact of fragments. By beach, three beaches can be considered with maximum fragments impact and two beaches with average fragments impact, during spring. While, one beach can be considered with maximum fragments impact and four beaches with average fragments impact during autumn.

Pellets Pollution Index:

The general pellets pollution index was 5.43 during spring and 6.35 during autumn (moderate presence of MPs). In details, the pellets pollution index highlights one beach (Guerbes) with very low presence, three beaches with low and one beach with high presence of pellets during spring. There are no beaches within “Moderate” and “very high” categories in terms of pellets presence. Conversely, during autumn three beaches showed moderate presence of pellets, one beach low and one beach very low presence. There are no beaches within “high” and “very high” categories of pellets presence on Skikda beaches.

Pellets coefficient impact:

The pellets coefficient impact of the whole studied beaches was 0.24 and 0.40 during the two seasons with Average impact. In detail, four beaches had Average impact and one beach had minimum pellets impact during spring. While, two beaches had maximum impact and three beaches had Average pellet impact during autumn.

Foams Pollution Index:

The foams pollution index for the whole study area was very low foams presence during the two seasons (1.86 and 1.25). By beach, three beaches had very low presence and two beaches had low presence of foams during spring. While in the autumn, four beaches had very low presence and one beach had low presence of foams. There are no beaches within “Moderate”, “High” and “very high” categories in terms of foams presence.

Foams coefficient impact

The general foams coefficient impact was 0.16 with average impact in the spring and 0.08 with minimum impact in the autumn. While by beach, four beaches had average impact and one beach had minimum impact during spring. Conversely, four beaches had minimum impact and one beach had average impact during autumn.

Fibers Pollution Index:

The general fibers pollution index was 0.52 (spring) and 1.52 (autumn) with very low presence. By beach, the fibers pollution index highlights the whole five beaches with very low presence during spring. While during autumn, one beach had low presence and four beaches had very low fibers presence. There are no beaches within “Moderate”, “High” and “very high” categories in terms of fibers presence.

Fibers’ coefficient impact

Fibers’ coefficient impact of the whole surveyed beaches was 0.04 with minimum impact (spring) and 0.21 with average impact (autumn). In detail, the whole five beaches had minimum impact during spring. However, one beach had maximum impact, two beaches had average impact and two beaches had minimum impact during autumn.

The remaining 1-2% of MPs were divided between (microbeads, films, filaments and rubbers) for the two seasons. Since these types were less present in the study area the MPPI and CMPI of these shapes, which were all very low presence and minimum impact, were not taking in to account.

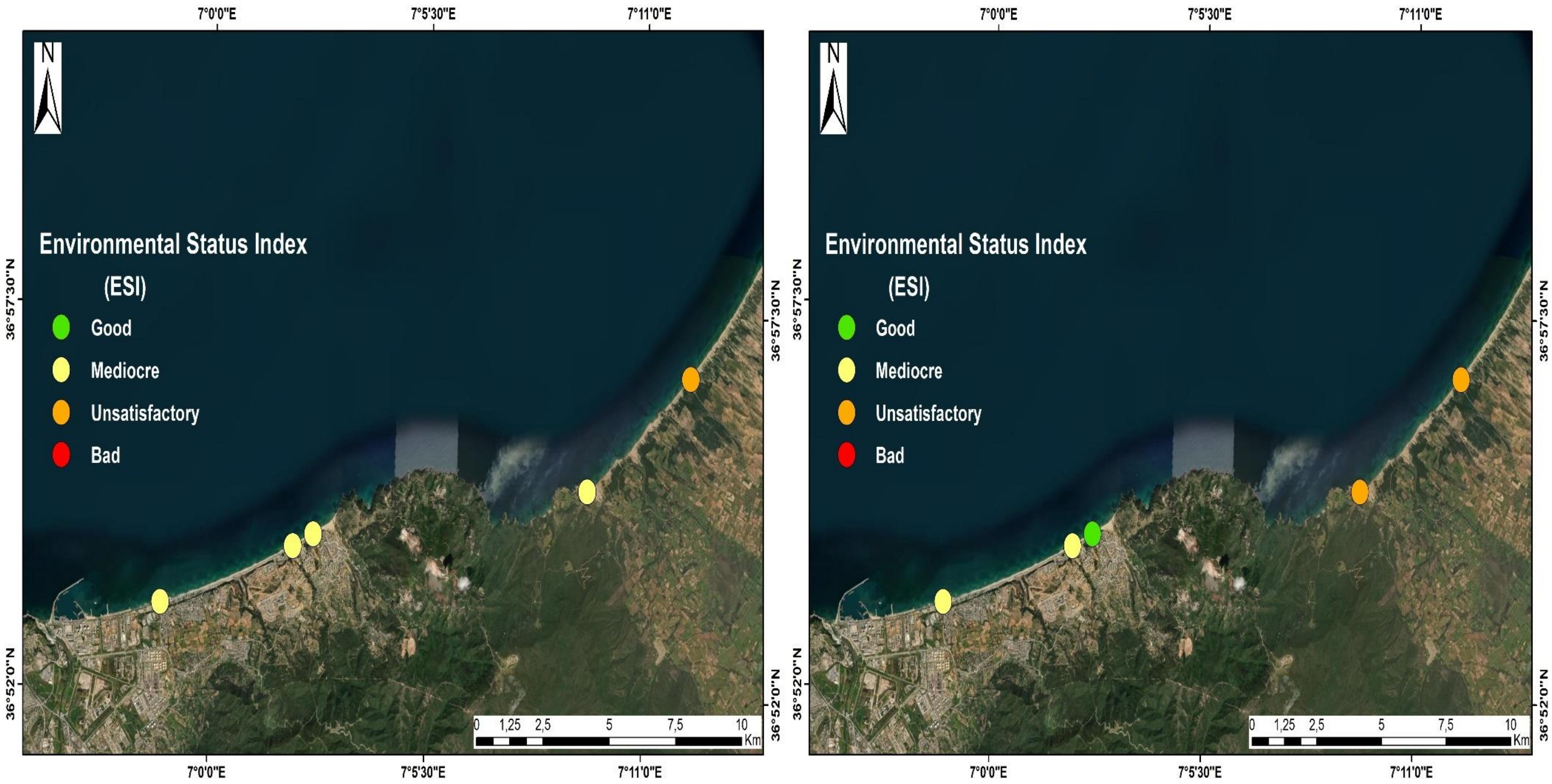


Figure 34: Geographical distribution of Environmental Status Index (ESI) (Spring /autumn).

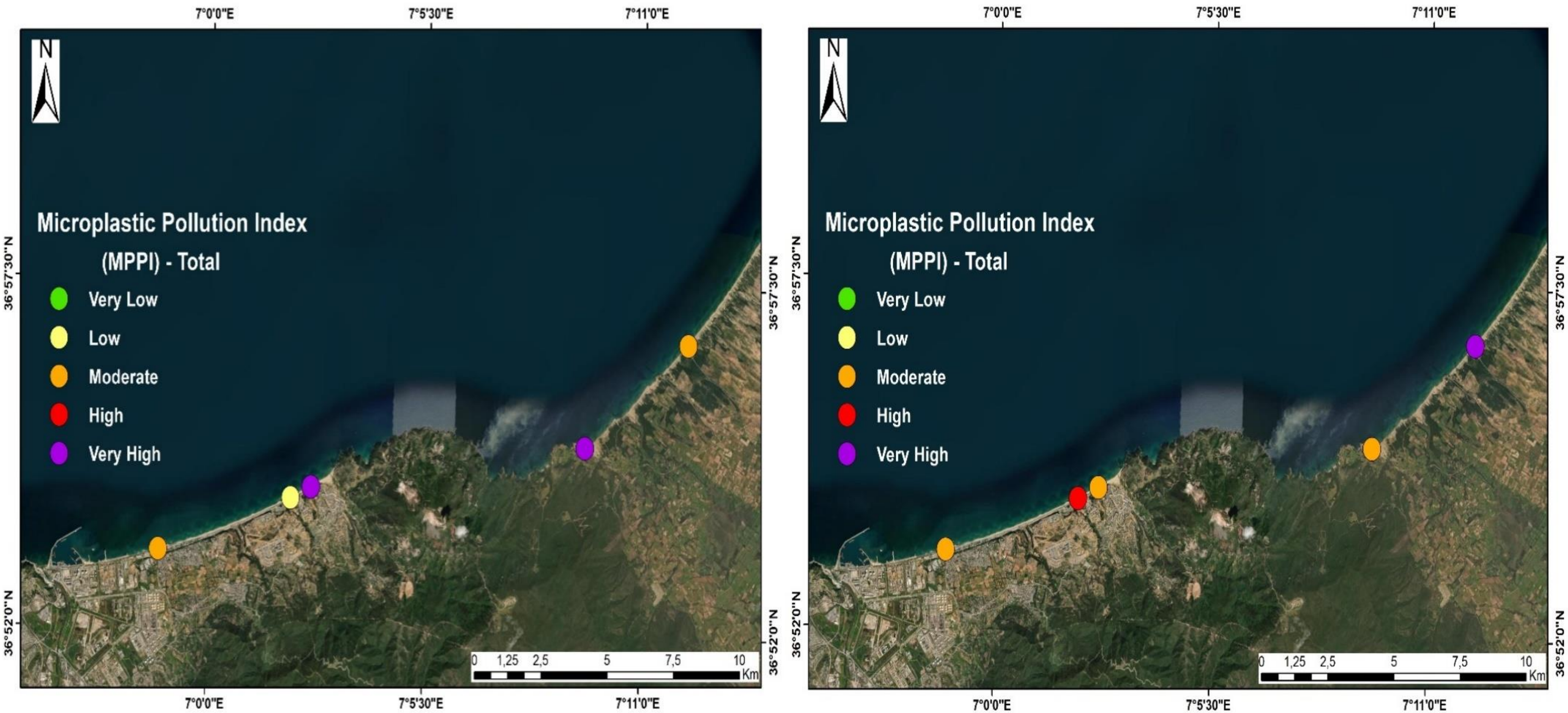


Figure 35: Geographical distribution of Microplastic Pollution Index (MPPI) (**Spring /autumn**).

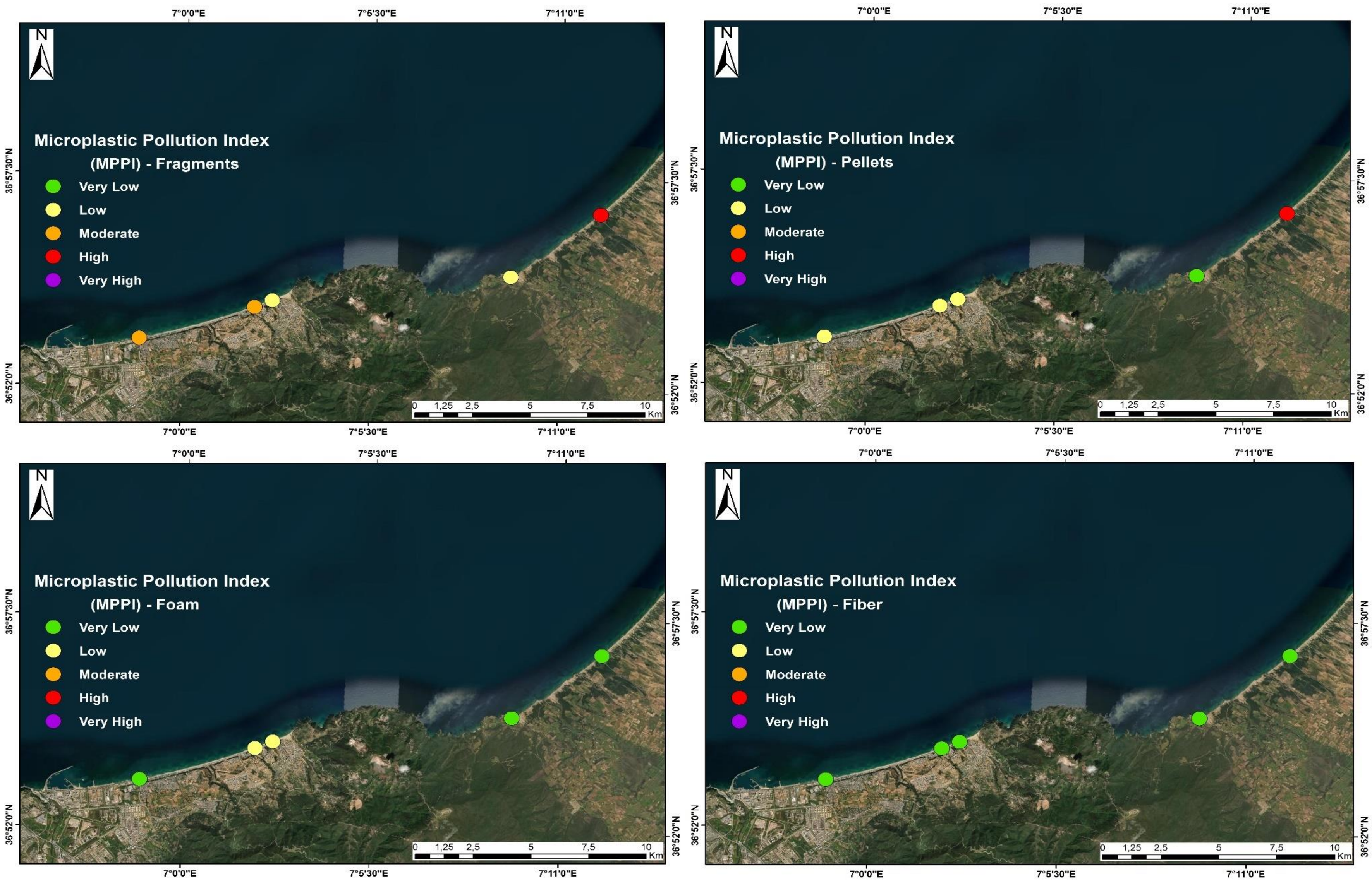


Figure 36: Geographical distribution of Microplastic Pollution Index (MPPI) by shape (**Spring**).

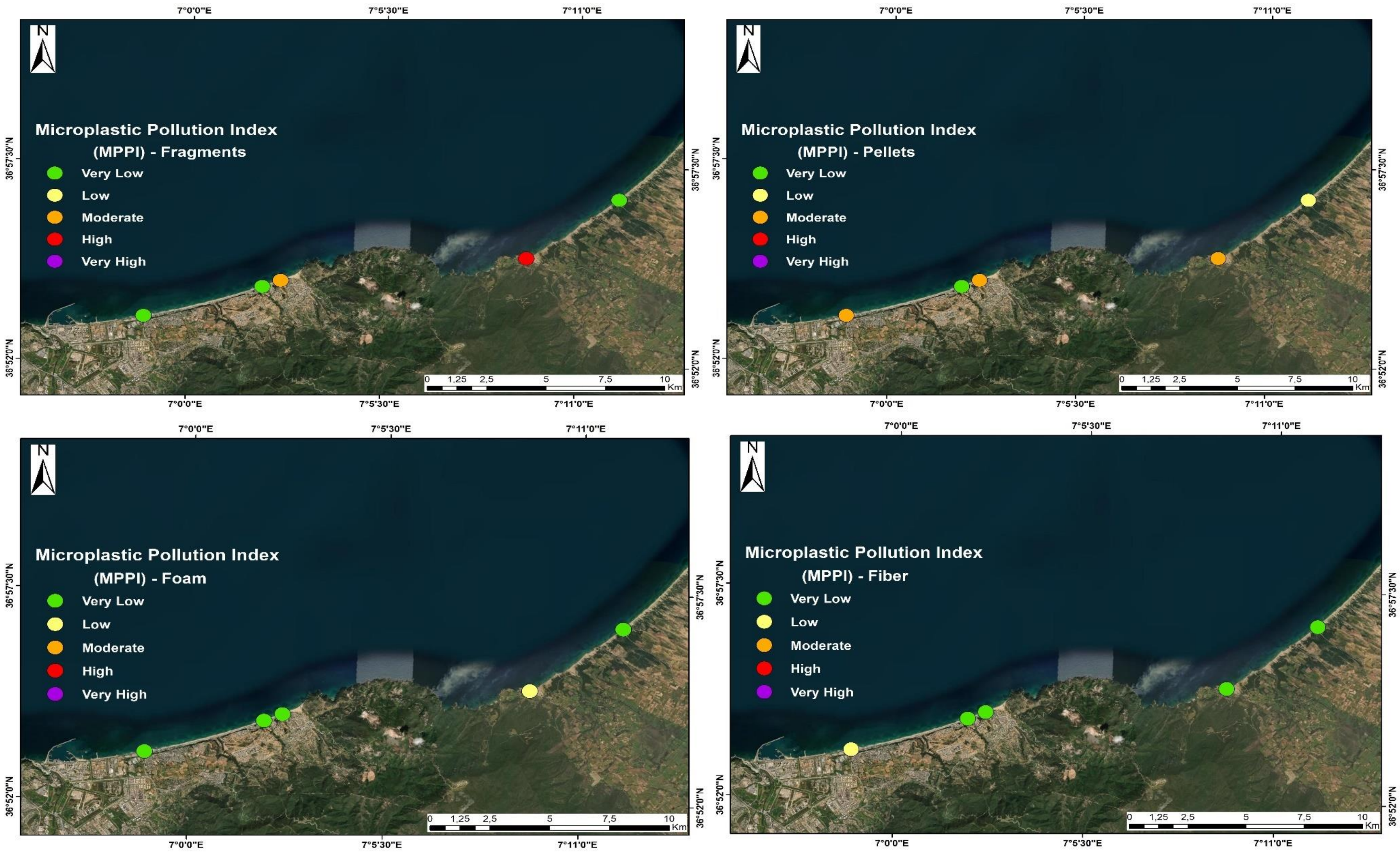


Figure37: Geographical distribution of Microplastic Pollution Index (MPPI) by shape (**Autumn**).

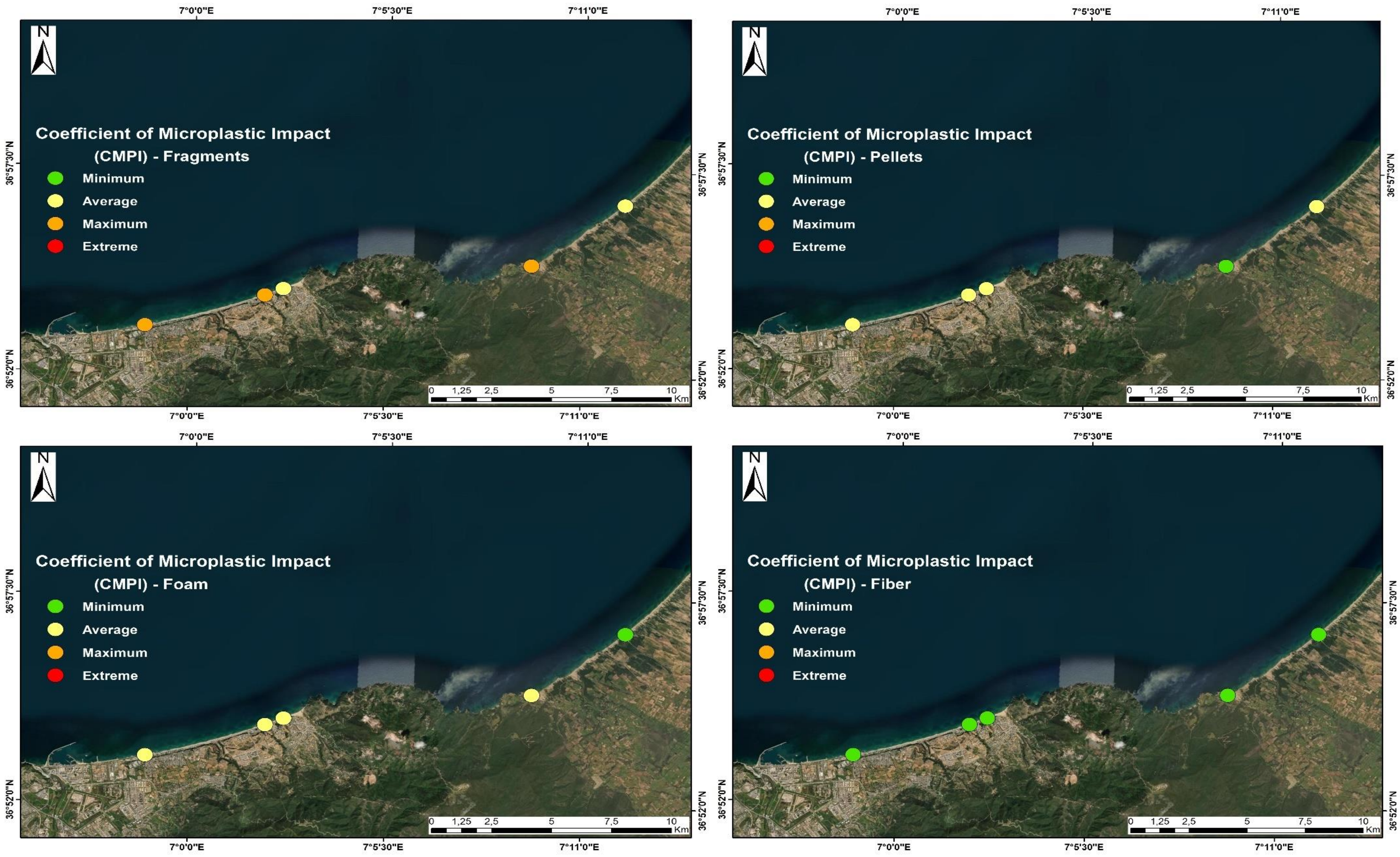


Figure38: Geographical distribution of Coefficient of Microplastic Impact (CMPI) by shape (**Spring**).

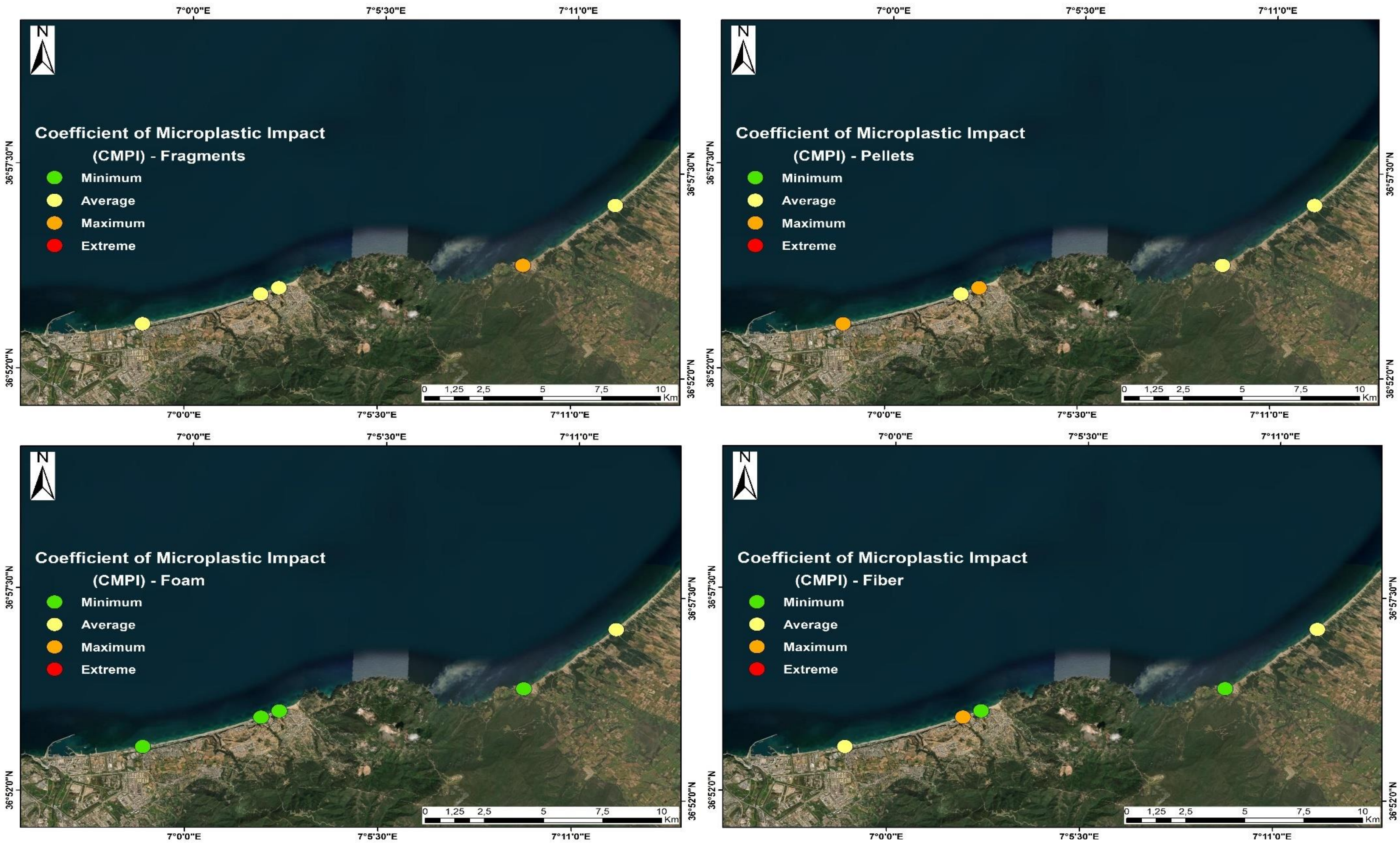


Figure39: Geographical distribution of Coefficient of Microplastic Impact (CMPI) by shape (**Autumn**).

5. Sector analysis

Sector analysis (Figure 40) combined MPPI and ESI reveals that the study area has significant MPs magnitudes that have a negative (severe) impact on the environmental quality of the beaches.

During both seasons, no beaches are found in the green zone of (Figure 36), whereas three beaches (60%) and two beaches (40%) are located in the orange and red zones, respectively. The preceding emphasizes the fact that these beaches are seriously affected by MPs, necessita ting urgent interventions (cleaning and restoration) to improve their environmental quality.

The use of density and environmental indices can provide an overall picture of how similar or unlike the Skikda beaches are in terms of MPs pollution. Using Agglomerative Hierarchical Clustering (AHC) and Multidimensional Scaling (MDS), this panorama was created by identifying natural groups and visualizing the similarities across beaches. Both statistical analyses reveal that the five beaches surveyed may be split into two categories based on MP abundance and environmental variables.

Group A:

In spring, this group is composed of four beaches encompassing 54% of all MPs found along the study area with an average density of 413 MPs/kg. Inside this group, fragments the 56% (Avg: 223 MPs/kg), pellets 33% (84 MPs/kg), fibers accounting for 73% (Avg: 18 MPs/ kg) and foam 89% (Avg: 77 MPs/kg). In terms of the MPs pollution index, 3 beaches can be classified with a “Moderate” MPs presence and one beach with high MPs presence. The environmental status shows the four beaches with a “Mediocre” status.

In autumn, this group is composed of four beaches encompassing 58% of all MPs found along the study area with an average density of 444 MPs/kg. Inside this group, fragments the 32% (Avg: 111 MPs/kg), pellets 82% (241 MPs/kg), fibers accounting for 82% (Avg: 58 MPs/ kg) and foam 54% (Avg: 31 MPs/kg). In terms of the MPs pollution index, 2 beaches can be classified with a “Very high” MPs presence, one beach with “Moderate” and one beach with “Low” MPs presence. The environmental status shows tow beaches with a “Mediocre” status, one beach with “Good” and one with “Unsatisfactory” status.

Group B:

In spring, this group is formed by one beach encompassing 46% of all MPs found along the study area with a total density of 1433 MPs/kg. Inside this group, fragments the 44% (Avg: 695 MPs/kg), pellets 67% (669 MPs/kg), fibers accounting for 27% (Avg: 23 MPs/ kg) and foam 11% (Avg: 69MPs/kg). In terms of the MPs pollution index, this beach is classified with a

“Very High” MPs presence. The environmental status shows this beach with a “Unsatisfactory” status.

In autumn, this group is formed of one beach encompassing 42% of all MPs found along the study area with a density of 1315 MPs/kg. Inside this group, fragments the 68% (Avg: 926 MPs/kg), pellets 18% (212 MPs/kg), fibers accounting for 18% (Avg: 51 MPs/ kg) and foam 46% (Avg: 107 MPs/kg). In terms of the MPs pollution index, this beach can be classified with “Very High” MPs presence. The environmental status shows this beach with an “Unsatisfactory” status.

		Microplastic Pollution Index (MPPI)					
		Very Low	Low	Moderate	High	Very High	
ESI	Good	0	0	0	0	0	0
	Mediocre	0	0	3	1		4
	Unsatisfactory	0	0	0	0	1	1
	Bad	0	0	0	0	0	0
		0	0	3	1	1	5
		Protection	Cleaning		Restoration		

Spring

		Microplastic Pollution Index (MPPI)					
		Very Low	Low	Moderate	High	Very High	
ESI	Good	0	0	0	0	1	1
	Mediocre	0	1	1	0	0	2
	Unsatisfactory	0	0	1	0	1	2
	Bad	0	0	0	0	0	0
			1	2	0	2	5
		Protection	Cleaning		Restoration		

Autumn

Figure 40: Sector Analysis Approach: Integration of Microplastic Pollution Index (MPPI) with Environmental Status Index (ESI).

6. Principal components analysis:

After defining these two types of beaches, it is useful to analyze this environmental data in terms of its principal components. The software XLSTAT 2021 provides preliminary results for a univariate descriptive univariate (minimum, maximum, mean and standard deviation) descriptive statistical analysis and bivariate (correlation matrix of the variables studied). Then, the results of the multivariate analysis (PCA) are presented in detail, focusing on the variable-factor correlations, this will enable the interpretation of the factors and fundamental result, namely, the graph of variables and observations (Figure 42, 44).

According to the PCA scatterplot, factors F1 and F2 account for over 82 % of the total variance in spring, and almost 87% of the total variance in autumn (Figure 42, 44). Furthermore, there is a definite trend along the first component (F1) from beaches with low MPs densities on the left (Group A) to that beach with the maximum densities on the right section of the X-axis (Groups B) for both seasons.

The PCA vector plot emphasizes MPs shapes that reach distinct locations on the principal axes, which establish the corresponding axis positions for the beaches (Figure 42, 44). Similarly, the presence of MPs along Skikda Coast has been linked to a high level of pollution. In this regard, the clusters created following the application of AHC, MDS, and PCA distinguish between:

- Beaches in tolerable conditions with a “Moderate” MPs presence - Group A (e.g., S1 – Titanic beach)
- Beaches in unsatisfactory conditions with a “Very High” MPs presence - Group B (Kef Fatma in spring, Guerbes in autumn)

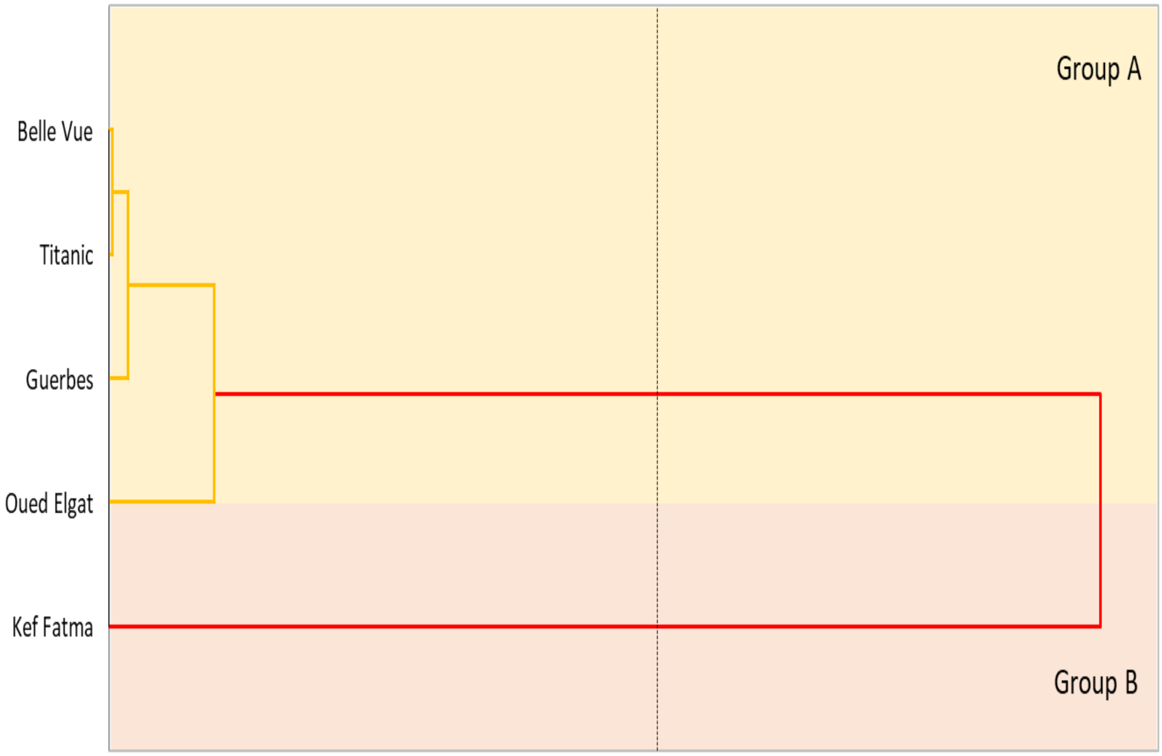


Figure 41: Groups by similarity levels between beaches and MP shapes presented by use of Agglomerative Hierarchical Clustering (AHC) (**Spring**)

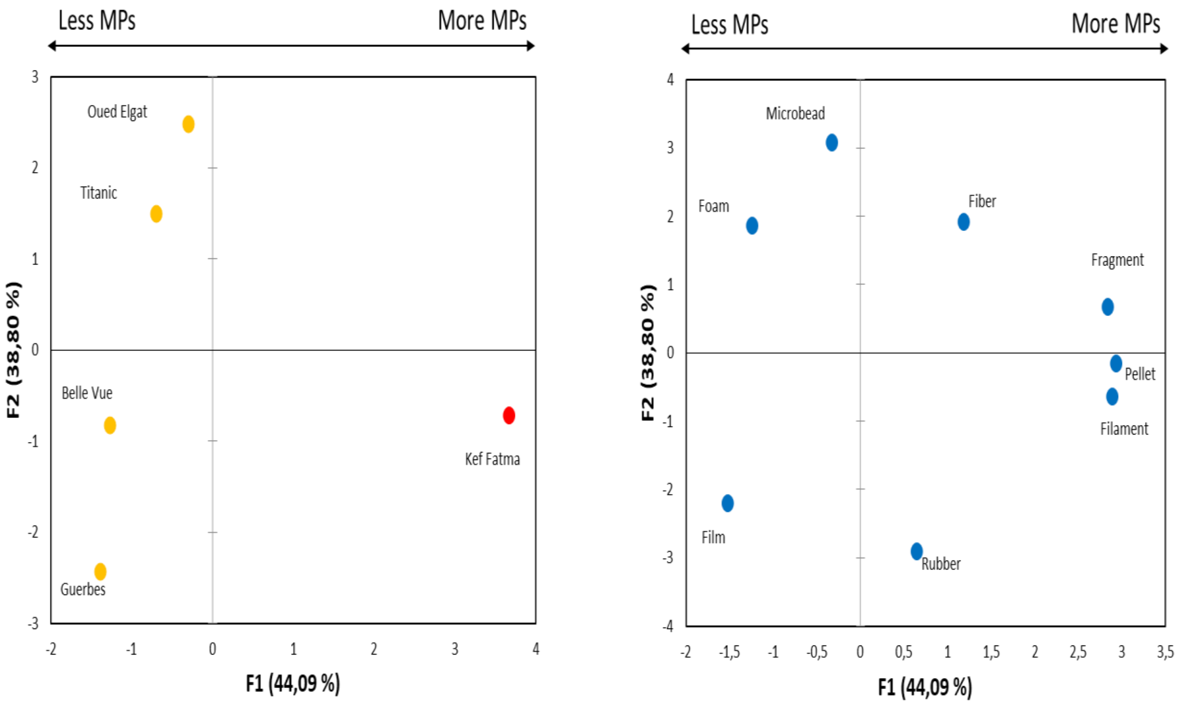


Figure 42: Principal Components Analysis (PCA scatterplot).

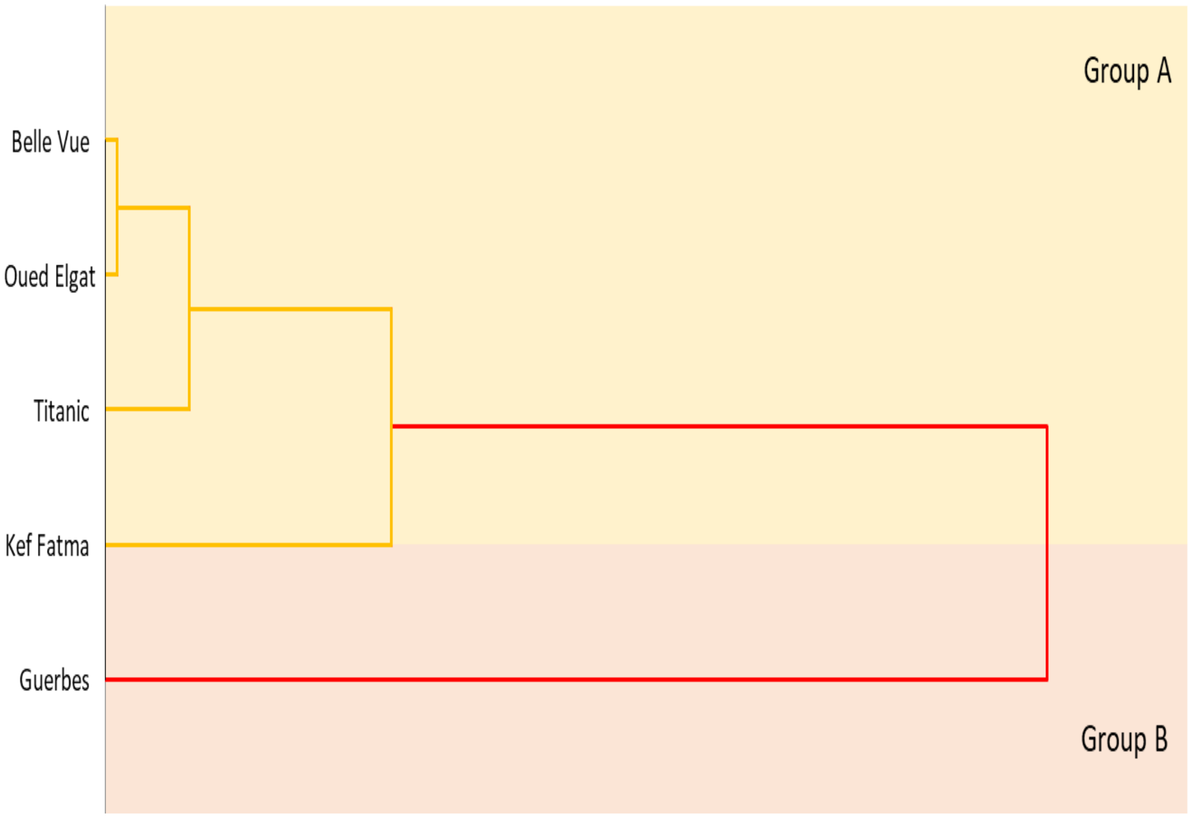


Figure 43: Groups by similarity levels between beaches and MP shapes presented by use of Agglomerative Hierarchical Clustering (AHC) (**Autumn**).

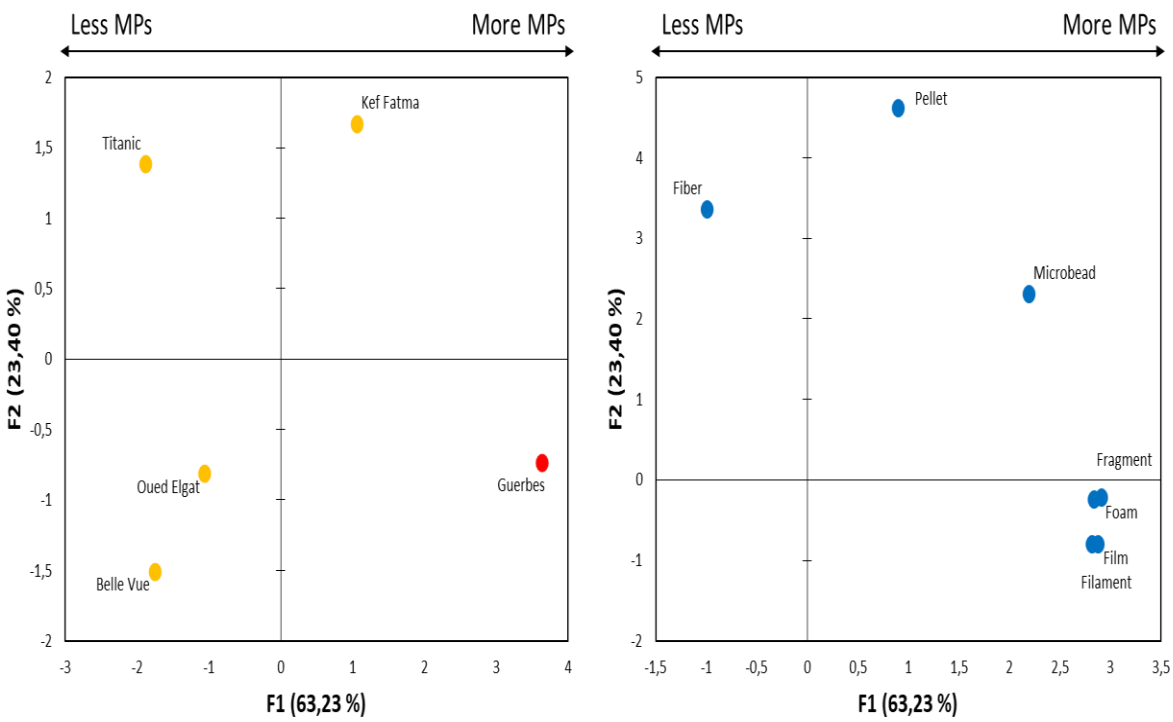


Figure 44: Principal Components Analysis (PCA scatterplot) (**Autumn**).

Discussion

The data registered in the present study showed high levels of MPs comparing to our previous data with respect of the season and size fraction (1-5mm) (Chapter 3) with similar pattern distribution of MPs densities along beaches. MPs levels observed in the present study are higher than those observed in the eastern coasts of Algeria Tata et al (2020), the north Tunisian coasts (Abidli et al., 2018), the northwestern coasts of Mediterranean Sea (Constant et al., 2019). High levels of microplastic were predicted to be released on the southwestern Mediterranean coasts Macias et al. (2019) and Mansui et al. (2015). Furthermore, this study and several researches were in line with this prediction and presents moderate to high amounts of MPs in the area (Abidli et al., 2018; Bouchentouf and Aïnad Tabet, 2013; Chouchene et al., 2019; Grini et al., 2022; Taïbi et al., 2021; Tata et al., 2020)

Spatial-temporal variation of micro- and mesoplastic densities could be related to several factors such as: high anthropic pressure, rivers inflows, waves, wind direction and main currents (Andrady, 2015; Debrot et al., 1999; Galgani, 2015). High amounts of debris were frequently found around touristic areas, urban zone with high density population and maritime routes (Suaria & Aliani., 2014)

The high concentrations presented in this study confirm this tendency. Skikda Gulf is exposed to most of these factors; main currents east-west; very high tourist pressure during summer; industry platforms and urbanization of the coasts; river outflow receiving waste water without prior treatment; proximity to ports (the 2nd most important port in Algeria). S1, S2, S3 were mostly exposed to these factors. However, S4 and S5 which presents the highest levels of microplastic and mesoplastic, during the two seasons, are wide and open rural beaches exposed to winds and main currents and far from the anthropic pressure. Beachgoers, mainly fishermen but also tourists, contributed significantly to the beach's litter deposition on rural beaches (Asensio-Montesinos et al., 2021).

After determining the magnitudes of MPs and their environmental impact along the research area, two crucial questions must be addressed: What are the potential sources and how do MPs find their way to the coastal environment?

MPs can be generated and then reach (sources/origins) the beach environment in two ways, according to NOAA (2015), Zeng (2018), and Franklin et al. (2021):

As primary MPs: manufactured raw-plastic material directly released into the environment that enters the beach via runoff from land or accidently during transport or due to the mismanagement of waste by the processing industries (Williams and Rangel-Buitrago, 2019).

Microbeads in personal care products, plastic pellets (nurdles) used in processing manufactories, and plastic fibers used in synthetic textiles, washing wastewater, sewage sludge, paint are all examples of primary MPs (Rangel-Buitrago et al., 2021).
Secondary MPs: are formed as a result of the fragmentation of mesoplastic and macroplastic objects, which gradually breakdown into smaller pieces due to biological, chemical (uv), and mechanical (waves, wind) degradation processes. The fragmentation process might occur in any area where plastics are present and continue after they are introduced into the water or washed up on beaches (Galgani et al., 2015; Gündoğdu and Çevik, 2019).

The levels of microplastics and mesoplastics found in this study indicate an increased and continuous inputs of plastics in all sizes and sorts, and suggest a wide range of sources along the study area. The observed MPs shapes (fragments, pellets, foam, fibers, microbeads, and films) show that the MPs identified along the research region had both primary and secondary sources.
Primary MPs, Pellets for example, are originated in the plastic plan located in the petrochemical platform on the coastline of Skikda, in proximity to study area. The outflow of this industry is directly discharged 1421 m^3/day in sea water through a channel at 2 km from S1 Titanic and/or towards the stream to the river mouth at 4 km from S1. Moreover, primary MPs can also originate inside the two basins and then end up along the coastline (Oued Saf-Saf, Oued Kebir). These two basins act as pathways that collect and transport various MPs toward study-area beaches.
The most important of these basins is the Saf-Saf Wadi, the most extensive river system in Constantinian Coastal basin, Occupying the central part of the Skikda area, with a drained area covering 1158 km^2 with a debit of 569 m^3/s (SCI, 1989), the Saf-Saf basin spreads on a surface of 1158 Km^2, with a population of meadows of 460 thousands inhabitants (49% of the total population of the Skikda area) discharges 23.23 million m^3/year of waste water (Khelfaoui, 2008; PAM/PNUE, 2011). The Aval part of the basin receive different types of sewage: 22 urban areas and several industries (industrial zones, petrochemical platform) with an urbanization rate reaching 98% in Skikda city (Khelfaoui, 2008). The second basin is the Kebir basin which drains an area of 1135 Km^2, with hydraulic apport estimated of 282 m^3, receive 4.6 million m^3/year of waste water (PAM/PNUE, 2011). The basin characterized by intense agriculture activity, the Aval part of the stream bordered by wetlands RAMSAR protected area (Guerbes-Sanhadja Complex).

Wondershare PDFelement

The river mouth receives industrial and urban wastewater of 12 urban areas without prior treatment (Benrabah et al.2013; ABH, 2000)

Between the principal streams (Saf-Saf and Kebir) several small Wadis (El-Gat, El-Gsab, Righa, Saboun) flow directly in the sea discharges 1.5 million m^3/year of waste water (PAM/PNUE, 2011), the area is characterized by high tourist pressure especially during the summer.

Secondary MPs are formed as a result of the degradation and fragmentation of large plastic objects. The fragmentation process might occur in any region where plastics are present and continue after they are introduced into the sea or washed up on a beach. The National Agency of Waste AND, 2020 estimated the annual consumption of plastic 25,8 kg / capita, 60% of this consumption is devoted to packaging. Plastics were 78% of the marine debris found stranded on the coast of Skikda, (AND, 2020). According to AND, 2021 and our previous data (see chapter III) fragments were 57% of plastics (microplastics 46% and mesoplastics 85%) collected on Skikda beaches (e.g. cap, cigarette butt, bottles, bags…etc.). The main sources of plastic debris were: tourism, sewage system, fishing, maritime transport and also escape from the waste collection system (AND, 2021). Mesoplastics fragments are considered as a potential source of additional secondary MPs due to degradation and fragmentation processes (Efimova et al., 2018). Some activities that lead to the generation of secondary MPs are:

Dumping activities: Dumping activities along the study area include tossing, dumping, or depositing plastic items on/or nearby streets and stream basins, as well as accumulating directly along the shore. Liubartseva et al., (2018) pointed that, more than 70% of plastic pollution in the Algerian coasts came from its own terrestrial sources. The two basins Saf-Saf and Kebir serve as channels for different wastewater to be collected and transported to study-area beaches. Such as: industrial sewage outfalls in Saf-Saf Wadi from petrochemical industrial complex (Refinery: 2162 m^3/day, 1421 m^3/day, Natural gas liquefaction 980 m^3/day, Electricity production 136 m^3/day) (PAM/PNUE, 2011), Wastewater treatment plants 229 979 PE.

Activities developed on beaches: beachgoers carry, use, and discard plastic items (single-use plastics) at the same beach during and after their beach activities. According to AND, 2021 caps, cigarette butt, polystyrene pieces, bottles, shopping bags, lolly sticks, food packaging and drinking straws are the most commonly thrown objects in the research area associated with beach activities.

Smoking-related activities: include cigarette lighters and cigarette butt brought, used, and abandoned by smokers after smoking at the same beach.

Wondershare PDFelement

Ocean and waterway activities (fisheries and shipping): 20% of the marine plastic pollution in Algeria related to shipping lanes (Liubartseva et al., 2018). The high maritime traffic due to the proximity to ports (the oil port and the mixed port: the 2nd most important port in Algeria) where transits 90% of the oil export volume of Algeria. In addition to, the proximity of two fishing ports and marinas (Stora and El-Marsa) and shrimp farm at Remila (El-Marsa) to the study area. Aquaculture, coastal and offshore fishing have also been identified as a source of marine MPs are also generated through aquaculture, coastal and offshore fishing (Allen et al., 2022). According to Asensio-Montesinos et al., 2021 plastic cap/lids of foreign origin were of a found in the SE of Spain, with Arabic inscription (Figure45). This bottle caps may be transported from their country of origin by currents or ships (Ryan, 2020; Asensio-Montesinos et al., 2021).

Figure 45: Case of Hamoud Boualem and Coca Cola lids produced in Algeria

Surface circulation play a major role in the transport, distribution and accumulation of plastics in the area (van Sebille *et al.*, 2020; Setiti et al., 2021) Formation of Anticyclonic eddies in sector from 6.5 and 8.5_ E and from 37 to 39_ N in the Algerian basin including the study area and in proximity of the Sardinia Chanel may induce the retention of litter in the mid-basin and enlighten the enormous amounts of anthropogenic debris found in the area (Figure 47, 48, 49). Eddies formed in this sector which maybe uptake energy from the Eastern Algerian Gyre and the Algerian Current, floating debris could be retained by these mesoscale features (Suaria & Aliani, 2014; Pessini et al., 2018).

In addition, the small scale and seasonal variability in the hydrodynamic pattern of the Mediterranean Sea together with the wind and waves motions affect microplastics distribution (Cozar et al., 2015; Setiti et al., 2021) Although, the lack of knowledge of the factors influencing the beaching and the release of microplastic on beaches. However, the surface currents flow towards the shore may favor the beaching of plastics debris on the coastline (Setiti et al., 2021).

According to the results of (Baudena et al., 2022), Crossroadness distributions were intense near the Algerian and Turkish coasts. Some crossroads were closer to Skikda coasts, with crossroadness value reaching 1% which means 4000 tons of plastics transiting during the simulation period (Figure 46). It appears that plastic debris transits across crossroads regions in the Mediterranean even if persistent plastic accumulation zones are not present. There is an obvious link between the locations of crossroads and the locations of anthropogenic pollution sites and the circulation features that transport debris. As most crossroads lie in coastal areas, boundary currents play an important role in determining their locations. A large volume of plastic debris can be collected by these circulation structures, which funnel and transport it over long distances. Liubartseva et al. (2018) stated that, the African coastlines from Morocco to Tunisia, including Algeria, show intermediate fluxes of 5–12.2 kg (km day)$^{-1}$. However, Baudena et al., 2022 findings show that the Egyptian coast and the Algerian coast's central part had the highest net beaching rate (43–47 kg/km/day).

The eastern coasts of Skikda (Figure 50, 51, 52) seem to have high beaching rate (7.5 kg/km/day) (Liubartseva et al., 2018); Baudena et al., 2022). Storm events are closely associated with debris deposition (beaching) on Mediterranean beaches, in addition to beach steepness <35% which represents 15% of the Mediterranean (Haarr et al., 2019; Baudena et al., 2022).

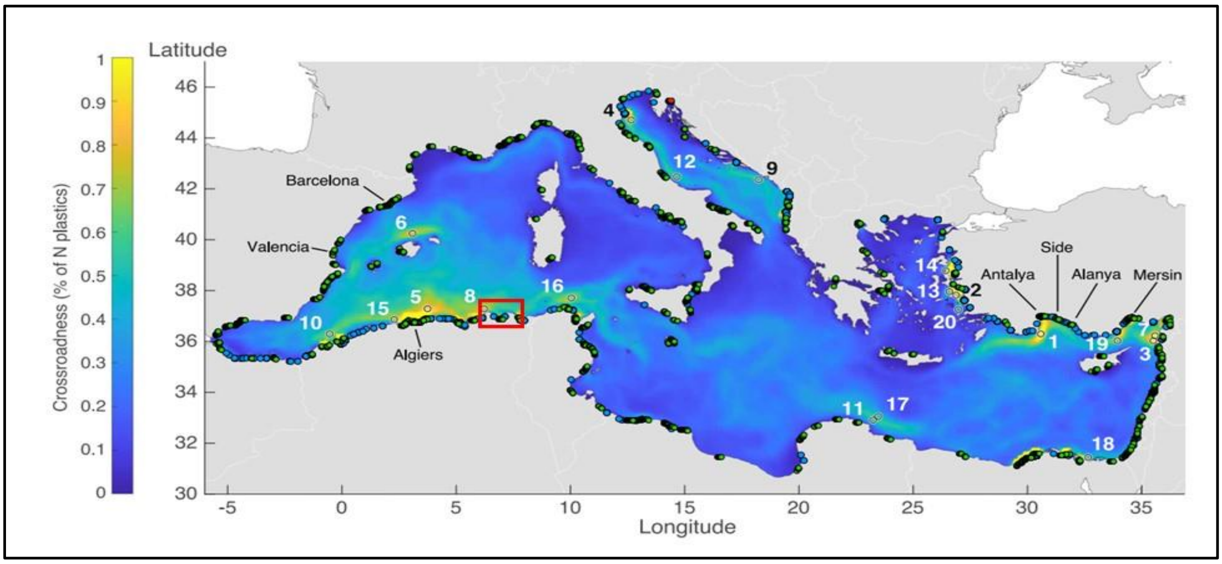


Figure 46: Crossroadness and plastic crossroads. *Crossroadness field calculated from simulated particle trajectories between 2013 and 2017. White and black circles, show the twenty most important plastic crossroads, together with their ranking* (Baudena et al., 2022)

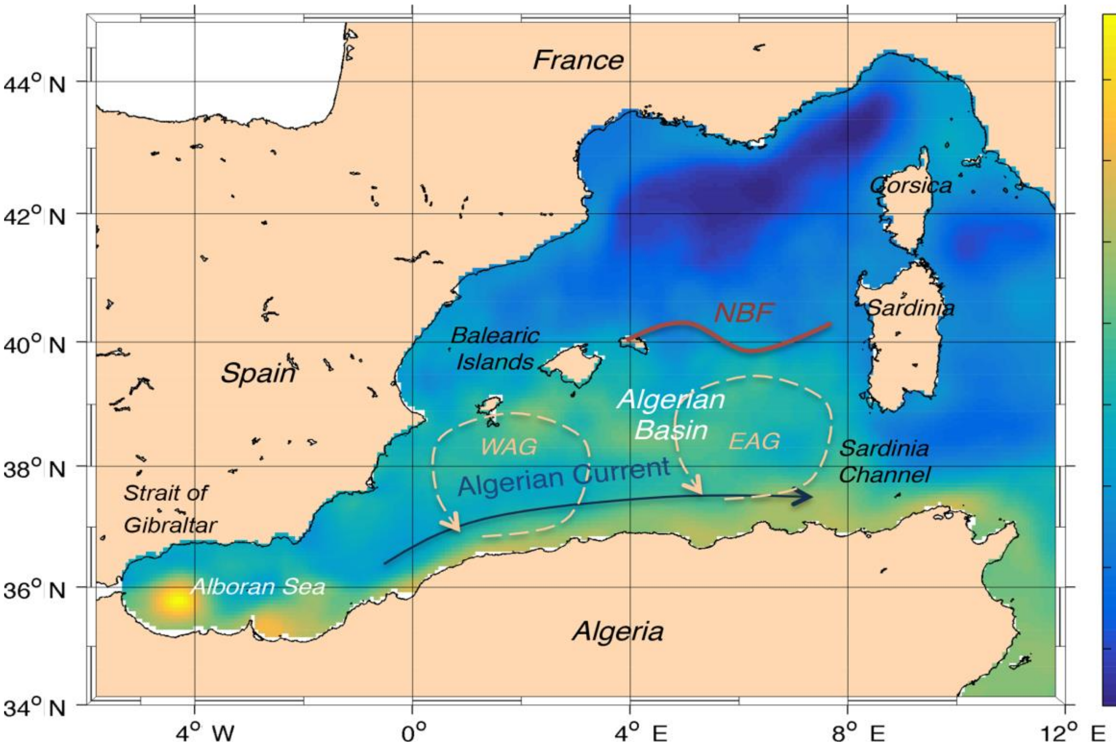


Figure 47: Mean dynamic topography (m) in the Western Mediterranean Sea (Rio et al., 2014).

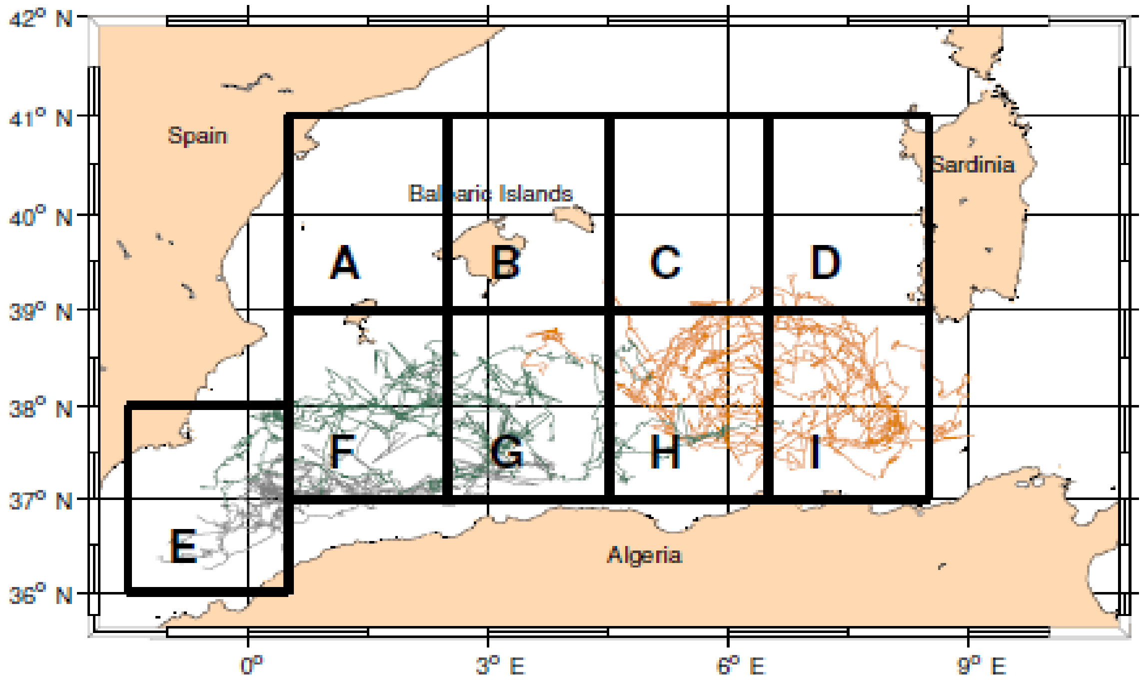


Figure 48: Tracks of the anticyclonic AEs born in sectors E (grey), G (green) and I (orange). (Pessini et al., 2018)

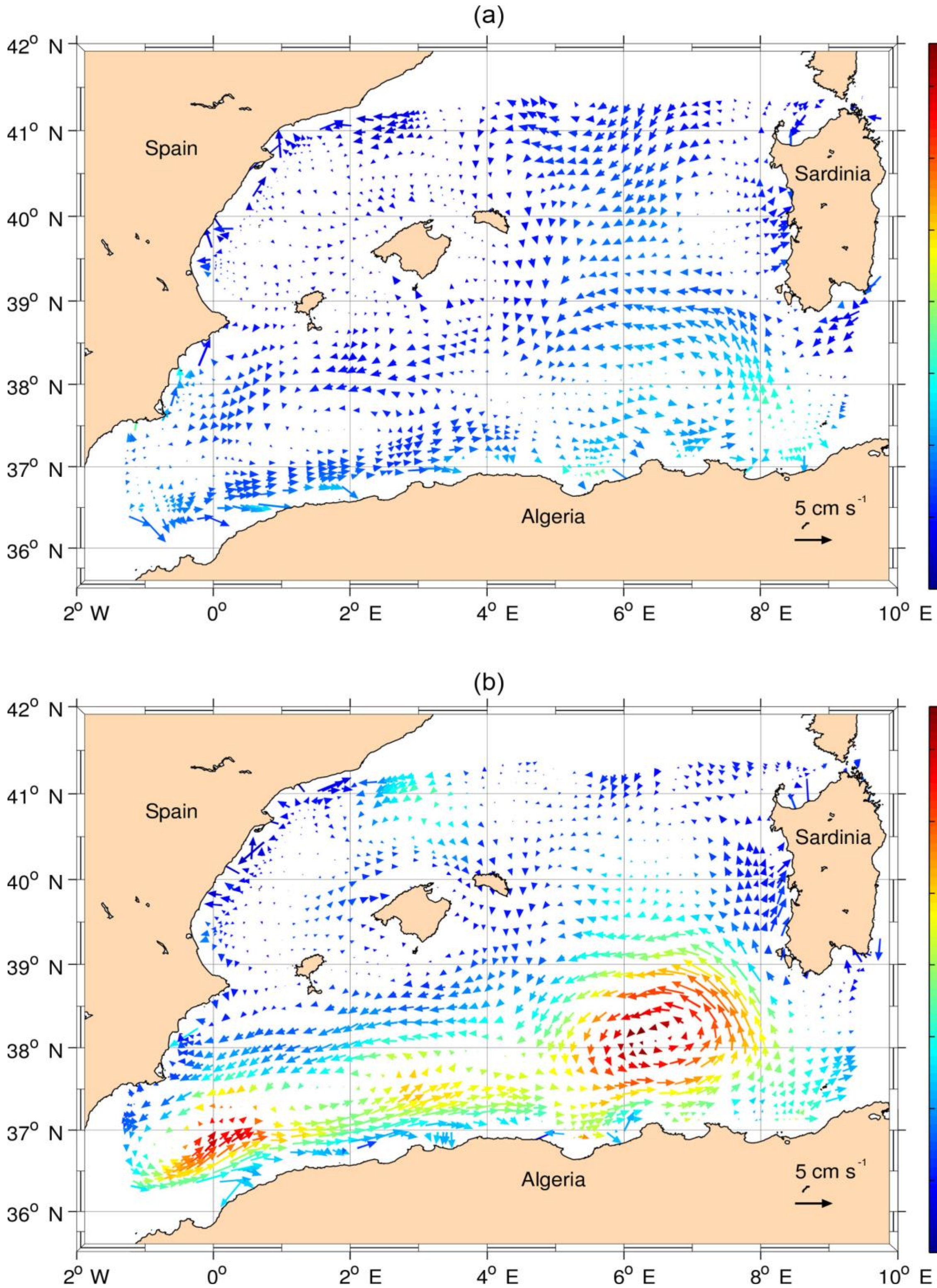


Figure 49: Average velocities in cm s^{-1} of the cyclonic (a) and anticyclonic (b) eddies in boxes of 1=5. The color indicates the average daily EKEs (cm^2 s^{-2}) in the same boxes. (Pessini et al., 2018)

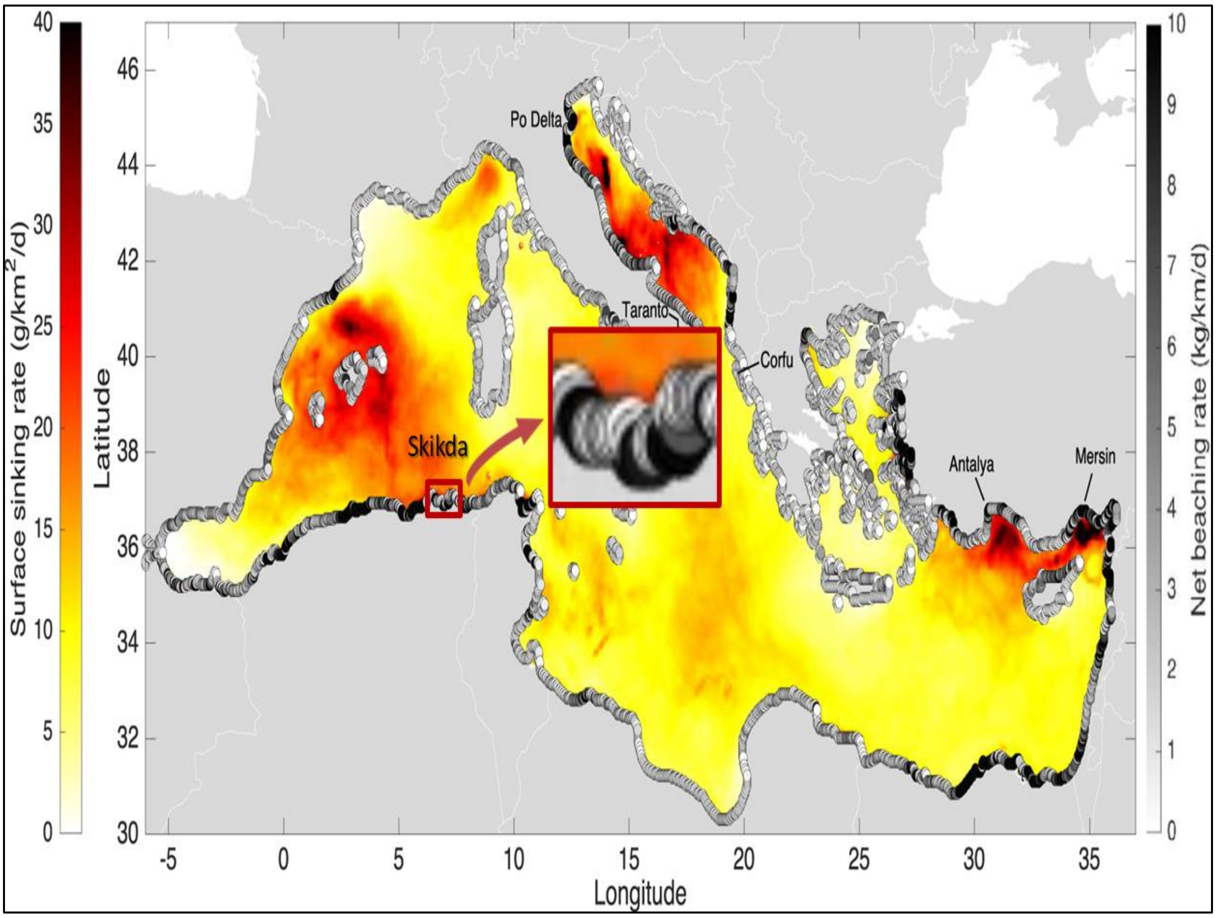


Figure 50: Mean net beaching and surface sinking rates in the Mediterranean Sea between 2014 and 2016. Adapted from Baudena et al., (2022)

Coastal gray dots show the net amount of plastic debris (kg) beached daily per kilometer of shoreline (gray scale at right). The surface sinking rates are the amounts of plastic debris (g) sinking in a square kilometer of surface each day due to biofouling (color scale at left).

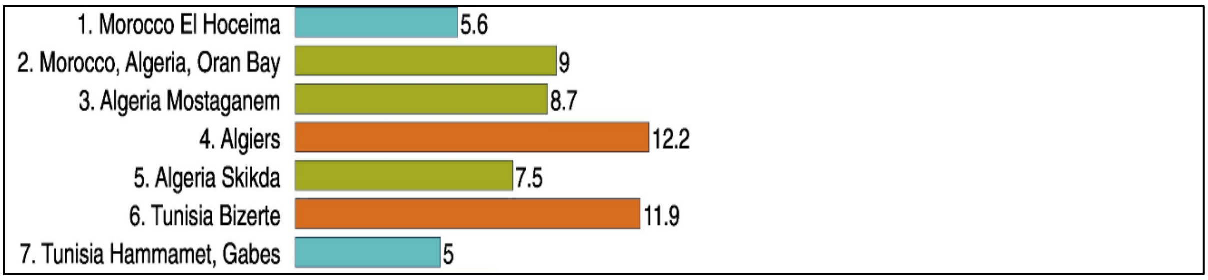


Figure 51: Bar diagram of plastic debris fluxes (kg (km day)$^{-1}$) onto the Mediterranean coastlines. Adapted from Liubartseva et al., (2018)

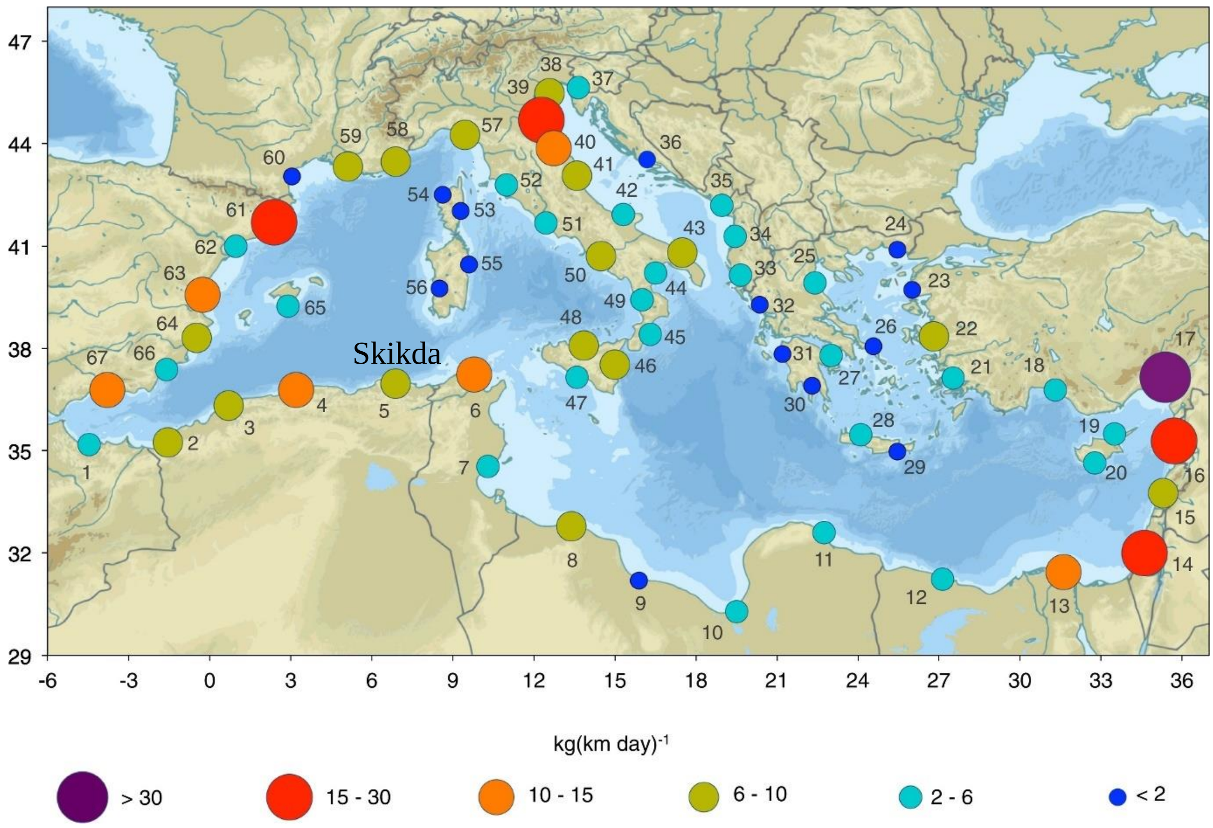


Figure 52: Map of the plastic debris fluxes (kg (km day)$^{-1}$) onto the Mediterranean coastlines. Adapted from Liubartseva et al. (2018)

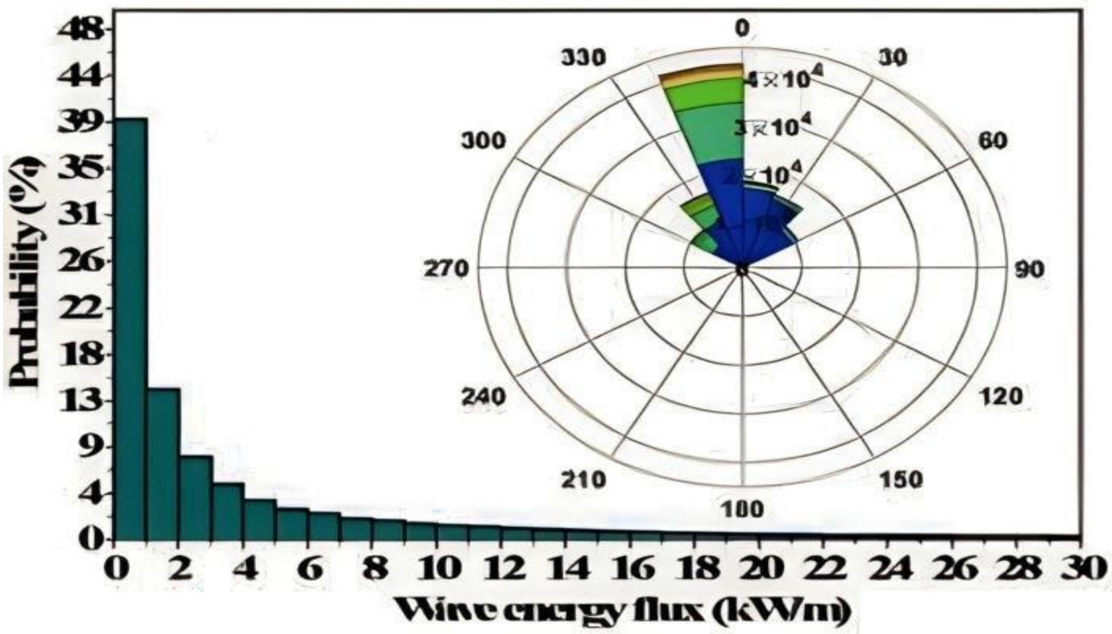


Figure 53: Probability of occurrence and the wave energy flux roses during 39 years at fourteen locations along the Algerian coast (Amarouche et al., 2020)

Eastern coast of Algeria (Annaba and Skikda province) which covers 546 km^2, the Algerian coast has the highest energy potential in the western Mediterranean basin with an availability of waves that exceed 0.5 m during 299 days of the year (Amarouche et al., 2020). Station S3 (Skikda) is characterized by a high dominance of NNE waves and a total annual wave energy of 74.9 MW/m/year (Figure49) (Amarouche et al., 2020). Wave energy generated from future cyclones and associated high energy storms could be responsible for erosion and redistribution of sediment and debris into the marine environment, increasing pollution (Lo et al., 2020).

Turner et al., (2021) and Lebreton et al., (2019) stated that microplastics formation occurs through the breakdown of legacy macroplastics. The coastal zone retains historical plastics and delays their wash-off to the ocean. Litter transport in the nearshore and subaerial beach depends on tides, waves, and currents, evidence shows that stranded litter items can contribute to the natural processes of sand dune formation and erosion (Andriolo & Gonçalves., 2022). Dunal systems plays a critical role in storage and secondary source of historic plastics (Turner et al., 2021). Plastic litter are more abundant on the foredunes due to the action of onshore winds and beach cleans (Poeta et al., 2014; Rangel-Buitrago et al., 2018; Turner et al., 2021). Wave action and foredune erosion processes can dislodge buried waste, which eventually returns to the marine environment (Andriolo & Gonçalves., 2022). Thus, modelling plastic transport and accumulation in coastal zones should also consider dunes and climate change (Critchell and Lambrechts, 2016).

Coastal erosion can be considered a secondary diffuse source of littring pollution. Buried litter can be unearthed by storm wave action and erosional foredune processes and eventually return to the marine environment. In addition to the fact that the nearshore and subaerial beach's litter transport is influenced by tide, wave, and current, evidence suggests that stranded litter items contribute to the natural processes of dunes growth/erosion throughout the year (Andriolo & Gonçalves., 2022).

Turner et al., (2021) and Lebreton et al., (2019) argument that the coastal zone traps and filters marine debris, delaying its passage to offshore oceanic seas. Furthermore, Rangel-Buitrago et al., 2018; Turner et al., 2021 stated that plastics are more common on the foredunes than on secondary dunes or the upper beach due to the action of onshore winds and beach cleans. According to the authors, the formation of microplastics is primarily caused by the degradation

of legacy macroplastics, which have been stranded, buried on beaches and settled and resurfaced (through changes in buoyancy) in coastal waters (Turner et al., 2021).
Models of plastic transport and accumulation in the coastal zone should also take into account the role of dunes (Critchell and Lambrechts, 2016).

Wind may transport microplastics on both a transcontinental and transoceanic scale (Allen et al., 2022). Wind can also influence microplastics transport processes, it has the ability to carry items from shores to backshores and dune systems (Rangel-Buitrago et al., 2021). According to the meteorological station of Skikda, winds along the study area mainly come from the W, and NW. the mean wind velocities reach more than 13 m/s during November–February. During the third trimester, (Jully- September) winds blow from the E, and the NE with a low velocity, with values that fall below 11 Km/h in August (Figure5/ Chapter 2).
The wind transports microplastics to some of the most distant locations on the planet, wind has the potential to transport MPs on both a transcontinental and transoceanic scale (Allen et al., 2022). According to a 2017 IUCN report, wind transport 15% of marine plastic debris, both primary and secondary plastics are atmospherically transported to the marine environment. It has been proved, however, that coastal air samples of wind moving from the sea to the land may contain high MP concentrations of roughly 2.9 MP m^{-3}, peaking to 19 MP m^{-3} during stormy sea conditions (Allen et al., 2020). Atmospheric transport is faster than marine transport, moving particles from origins to far sites in days to weeks. However, the concentrations of particles generally decrease with distance from cities.
Long et al., (2022) highlighted the impacts of the size and morphology on atmospheric transport of microplastics. Fibers, films, foams and fragments shapes have been found in atmospheric deposition and sampled air masses (Allen et al., 2020). Hence, the low density allows MPs to be dispersed over long distances by wind and strong currents (Ryan, 2015). MP lines, films and fragments with low density and high surface-to volume ratio, may be transported in the atmosphere over 1000 km; MP pellets (granules and microbeads) mostly deposit near their point of emission (Long et al.,2022). This may explain the important number of pellets found in the study area. Pellets have the potential to accumulate and transport organic contaminants (Teuten et al. 2009; Camacho et al. 2019) toxic and can be consumed by fauna.
The high amounts of pellets found at the studied beaches highlight a serious malfunction in the discharge of the plastic industry that may be discharged directly into the sea without prior treatment. Furthermore, the observations of some citizens and the CNL, who have reported massive amounts of pellets and small plastic particles with a powder aspect being found on

Titanic beach and beaches near the plastic platform in January 2020, could confirm this malfunction (See Appendix 6).

Given the presence of the petrochemical platform and the oil transit in the study area. Several studies found high concentration of persistent organic pollutants POPs (e.g. hydrocarbons) and metallic trace elements in the sediments of the Gulf of Skikda. (Gueddah, 2003; Rouidi, 2014; Rouidi et al., 2013). Beach monitoring could be conducted using stranded pellets (Teuten et al., 2009; IPW http://www.pelletwatch.org/)

Algeria was the second most importer of plastics in primary form in Africa and the Middle East in 2018, the plastic imports ramped from 304 Kt (Kiloton) in 2007 to 931 Kt in 2020 (http://www.plastalger.com). In addition, The National Agency of Waste estimated the annual consumption of plastic of 10 kg/capita in 2007 reached 25.8 kg/capita in 2020, where 60% of this consumption is devoted to packaging (AND., 2020). More than 2 million tons of plastic waste produced in Algeria less than 10% is the of total plastic waste (https://www.wamda.com) and only 4,000 tons of packaging are recovered (i.e. 0.0002%) (Djemaci, 2018), after the introduction public system for treatment and recovery of packaging waste to promote the recycling in 2004. According to Jambeck et al., (2015) Algeria was ranked 13th among the top 20 countries producing plastic waste in 2010, each Algerian generates 0.14 kg/day of plastic waste. Annually, Algeria generates 0.52 million metric tons of mismanaged (MMT) plastic waste and 0.08 – 0.21 MMT becomes marine plastic litter. The recent statistics of AND in 2020 stated an amelioration in recycling plastic reaching15% (PET, PEHD, films) of plastic waste.

Among 130 MPs analyzed particles, six types of polymers were identified, namely PE (29 %), PS (25%), PA (20 %), PVA (18 %), PVC (5 %) and PP (3 %). Similar results were obtained from our previous chapter of microplastics in which the same six polymer were identified but with different levels. PE has many applications, used for packaging, bottles, caps, trash bins, etc. (PlascticEurope, 2020). PVA represents 18 % of the analyzed microplastics. The low toxicity of PVA makes it suitable for use in food packaging, coatings, textiles, paper, cosmetics, and pharmaceuticals (D'Amelia and Mancuso, 2020). Moreover, as mentioned above light polymers (polyethylene, polypropylene) are more likely to be transported by wind and strong currents over long distances (Ryan, 2015)

In term of quantity, the MPs shapes quantities were variable between seasons and among beaches especially fragments which showed a low quantities during autumn than spring in 4/5 of beaches. However, the most important quantity of fragments collected during autumn was in Guerbes which was 70% small MPs. These findings support the idea that the fragmentation process may start during the summer (the long exposer of MPs to UV and mechanic by beachgoers and waves which accelerate the degradation and fragmentation of MPs and mesoplastics (fragments) influenced the amounts of MPs collected.

For fibers it was proved that the extraction method affects the quantity of fibers. Density separation is more effective in evaluating the fibers types or shapes of MPs. As we mentioned previous chapters (3, 4) fibers were found in very low numbers, which may have been influenced by the target size range (particles >1 mm) and the dry sieving method. The dry sieving method may not be effective in retaining fibers or filaments (Phuong et al., 2021). The extraction method affects the recovery of microplastics (especially small sized) and the quantity of fibers.

The total amounts of plastics (microplastics and mesoplastics) collected during spring was much higher than in autumn the shapes and size fraction distribution were all different between the two seasons

The influence of tide on the washed-up plastic particles to the sea again by waves or moved to the upper tide by winds and tide movements/ hide in deep fractions of sediments further studies are necessary to recognize the pattern of dispersal of plastic debris on the beaches (zonation) and in deep of sediments. The microtidal characteristic of the Mediterranean sea Previous studies support this suggestion, Constant et al. (2019) suggests that the spatial distribution of microplastics (quantity and type) on Mediterranean beaches, which are microtidal coasts, can exhibit high heterogeneity at small scales and can change within a short time span (one month), and that microplastic concentrations depend on the sampling strategy in addition to hydrodynamic and anthropogenic factors. Thus, further monitoring would be needed to understand the distribution pattern and temporal variability of plastics stranded along Skikda beaches, such as microplastics, which represent the most abundant size fraction (68% of items) of collected plastic samples (Chapter 3).

Mesoplastic can be useful for microplastics monitoring, high amounts of MPs were assessed usually when and where high amounts of mesoplastics were found. The present data confirms that high microplastics amounts are associated to high amounts of mesoplastics in both location and season (Guerbes beach in both seasons). These findings are in line with autumn 2018 results. Moreover, (Lee et al., 2015; Jeyasanta et al., 2020; Grini et al., 2022) have also found a correlation between microplastics and mesoplastics, suggesting that microplastics may originate from fragmentation of macro- and mesoplastics. As a screening indicator, mesoplastic results could be useful in locating hotspots of microplastic accumulation in beaches while saving monitoring and analysis efforts (Chapter 3).

Injuries, entanglements, and ingestions are all common effects of plastic on marine biota (Nelms et al., 2016; Thiel et al., 2018). Mesoplastics also can be ingested by biota (Jâms et al., 2000). Furthermore, plastic particles can transport alien species and toxic chemicals into the oceans, where they can be released and accumulated in organism tissues (Barnes et al., 2009; Mato et al., 2001) and transfer through the food web. During sampling, several intertidal species were observed of different levels of food web such as Beetles (larva, adult), Gastropods (Patella), Decapods (Crab), isopods (pill-bugs), Amphipods (sand-hopper) and Cirripeds which are exposed to microplastic available in the beach. Several studies stated that intertidal species ingest MPs: Sand-hopper (Lannilli et al., 2018); Barnacles (X.-Y. Xu, et al., 2020) which may promote the MPs transfer from a level to another of the food web and cause directly or indirectly major hazard to human life.

A debate also exists about whether the amount of plastics measured at sea has kept up with global plastic production over the past few decades (Van Sebille et al., 2020; Lebreton et al 2019; Geyer et al 2017). Plastic fluxes, pathways, and fate remain less known (Van Sebille et al., 2020) highlighting the uncertainties and discrepancy of estimations of plastic dispersion because of the complexity of relation between plastic pollution, environmental conditions and riverine transport (Roebroek et al., 2022).

Various physical processes may explain some of this discrepancy between estimates of plastic inputs and the pool of floating plastic at sea: stranding, sedimentation and fragmentation at unmeasured sizes (Van Sebille et al., 2020). Evidence suggests that large debris sizes and compositions change with distance from major land-based sources (Ryan 2015), possibly as a result of these mechanisms. Horizontal and vertical transport of plastics within the oceans may also be assisted by biological processes (e.g. ingestion and settlement). Identifying the physical, chemical, and biological processes that influence the transport of plastics on the ocean's surface is necessary for addressing the plastic pollution challenge (Van Sebille et al., 2020). Thus, environmental factors such as: Currents, wind directions, beaching, sedimentation, dunes, and fragmentation are strongly recommended in monitoring plastic litter in addition to the harmonized and adapted protocol to each size rage.

Conclusion

Plastic planet – Daniel Garcia

"How much brighter and cleaner a world [it would be] than that which preceded this plastic age"

Yarsley & Couzens.

This study represents the first investigation of plastic pollution along 50 km of the Skikda coastline. The distribution of microplastics and mesoplastics was variable between beaches and within sampling sites, revealing the extent of anthropogenic impact in the area. The average concentrations of microplastics and mesoplastics suggest moderate to high levels of plastic pollution in the area. The highest concentrations of plastic debris were recorded in the beaches of Kef Fatma and Guerbes, located in the eastern part of the Skikda coastline, where anthropogenic development is low.

The most common types of plastic were fragments and pellets. Local activities (anthropogenic pressure), industrial discharges, and coastal hydrodynamics were the most notable factors influencing plastic distribution along beaches. Further research is recommended to confirm the influence of marine currents on the transport and accumulation of plastics away from sources in order to identify their distribution pattern along the beaches of Skikda. The high concentration of pellets found along the studied beaches indicates a malfunction in the discharge of the plastic industry, which could be discharged directly into the sea without prior treatment. More precautions are recommended to control the situation and limit the leakage of pellets during the industrial process and/or transport.

The accumulation of microplastics and mesoplastics on beaches is still not accounted for in routine monitoring methods (macrowaste surveys) and beach cleanup campaigns, representing a significant large-scale knowledge gap. The mesoplastic fraction doubles the mass of microplastics present in beach sediments, revealing a notable reservoir of plastics that has hardly been reported in the literature. Future monitoring programs should implement harmonized methodologies to obtain representative and comparable data for these plastic size fractions.

Overall, the results show that MPs has regions where exposure concentrations are above the environmental hazard thresholds based on the environmental indexes tested in the present study. Microplastic input into coastal environments are anticipated to triple if we carry on as usual. Plastic inputs into the environment must be stopped or at least reduced if we are to tackle the microplastics problem.

It is complex to track the plastic in the marine environment and to understand the fate, flux, trajectory in different part of the ecosystems since plastics is ubiquitous, many factors should be taken into consideration such as: atmospheric inputs, marine circulation, wind direction, beaching, release, biofouling, sinking, ingestion by fauna during monitoring: in addition to

microplastics and mesoplastics, sampling macroplastics is also important to better understand since the major part of plastics enter the water (rivers or oceans) are macroplastics.
The mismanagement of waste, the lack of garbage cans and the seasonal cleaning of beaches could be major contributors to the accumulation of plastic waste in the surveyed beaches. However, cleaning up, waste management, and recycling still not enough to control the situation of plastic waste. Thus, controlling the plastic cycle from the production till the generation of plastic waste, mitigating the plastic consumption, raising citizens' awareness about environment, legal framework, and reducing plastic production might be crucial solutions.

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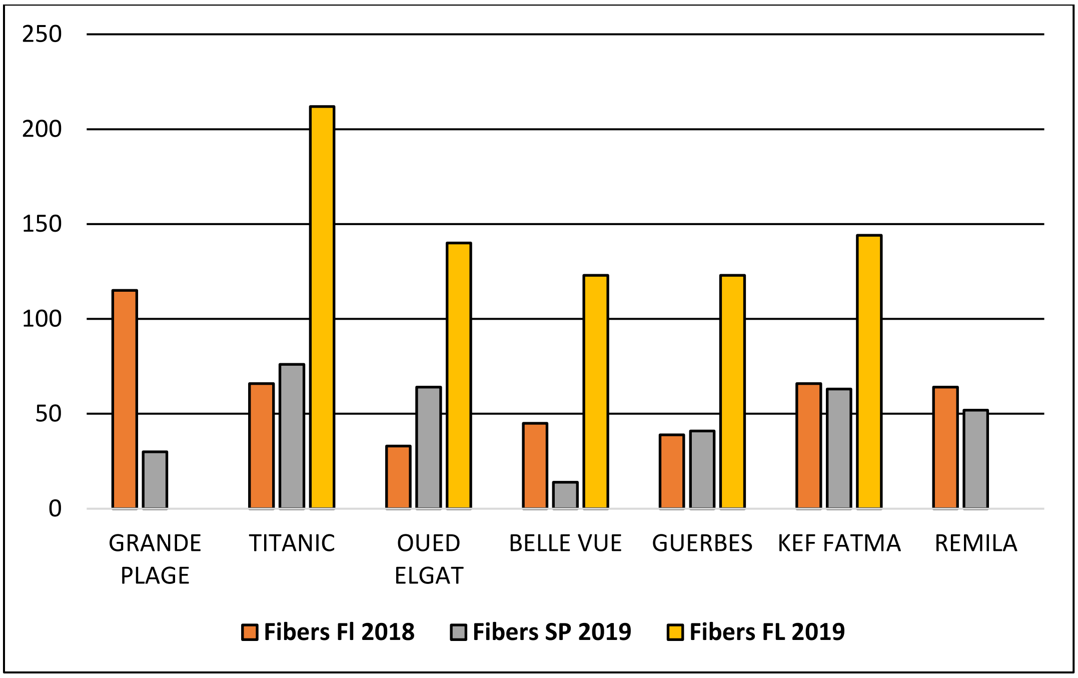
Appendices



Appendix 1: Abundance of small microplastics.

Appendix 2: Microplastic pollution index by type of Spring 2019

Site	**Titanic**	**Oued Elgat**	**Belle Vue**	**Guerbes**	**Kef Fatma**
PI- Pellets	2,29	3,94	2,36	0,47	18,07
PI - Pellets -Type	Low	Low	Low	Very Low	High
PI- Fragments	5,66	10,78	4,74	2,92	18,77
PI - Fragments -Type	Moderate	Moderate	Low	Low	High
PI- Fiber	0,76	0,65	0,14	0,41	0,63
PI - Fiber-Type	Very Low	Very Low	Very Low	Very Low	Very Low
PI- Film	0,05	0,01	0,04	0,11	0,02
PI - Film -Type	Very Low	Very Low	Very Low	Very Low	Very Low
PI- Microbeads	0,4	0,4	0,19	0,04	0,15
PI - Microbeads-Type	Very Low	Very Low	Very Low	Very Low	Very Low
PI- Foam	1,57	2,96	2,59	1,14	1,04
PI - Foam-Type	Very Low	Low	Low	Very Low	Very Low
PI- Filaments	0	0	0	0	0,02
PI - Filaments-Type	Very Low	Very Low	Very Low	Very Low	Very Low
PI- Rubber	0	0	0,01	0,01	0,01
PI - Rubber-Type	Very Low	Very Low	Very Low	Very Low	Very Low

Appendix 3: Coefficient pollution impact by type of microplastics of Spring 2019

Site	**Titanic**	**Oued Elgat**	**Belle Vue**	**Guerbes**	**Kef Fatma**
MPI Pellets	0,21	0,21	0,23	0,09	0,47
MPI Pellets - Type	Average	Average	Average	Minimum	Average
MPI Fragment	0,53	0,58	0,47	0,57	0,48
MPI Fragments - Type	Maximum	Maximum	Average	Maximum	Average
MPI Fiber	0,07	0,03	0,01	0,08	0,02
MPI Fiber - Type	Minimum	Minimum	Minimum	Minimum	Minimum
MPI Film	0,00	0,00	0,00	0,02	0,00
MPI Film - Type	Minimum	Minimum	Minimum	Minimum	Minimum
MPI Microbeads	0,04	0,02	0,02	0,01	0,00
MPI Microbeads- Type	Minimum	Minimum	Minimum	Minimum	Minimum
MPI Foam	0,15	0,16	0,26	0,22	0,03
MPI Foam - Type	Average	Average	Average	Average	Minimum
MPI Filaments	0,00	0,00	0,00	0,00	0,00
MPI Filaments- Type	Minimum	Minimum	Minimum	Minimum	Minimum
MPI Rubber	0,00	0,00	0,00	0,00	0,00
MPI Rubber- Type	Minimum	Minimum	Minimum	Minimum	Minimum

Appendix 4: Microplastic pollution index by type of Autumn 2019

Site	**Titanic**	**Oued Elgat**	**Belle Vue**	**Guerbes**	**Kef Fatma**
PI- Pellets	8,87	0,34	13,65	5,72	3,18
PI - Pellets -Type	Moderate	Very Low	Moderate	Moderate	Low
PI- Fragments	1,45	0,49	9,09	24,99	0,90
PI - Fragments -Type	Very Low	Very Low	Moderate	High	Very Low
PI- Fiber	2,12	1,24	1,46	1,38	1,40
PI - Fiber-Type	Low	Very Low	Very Low	Very Low	Very Low
PI- Film	0,00	0,01	0,09	0,32	0,03
PI - Film -Type	Very Low	Very Low	Very Low	Very Low	Very Low
PI- Microbeads	0,00	0,00	0,26	0,15	0,01
PI - Microbeads-Type	Very Low	Very Low	Very Low	Very Low	Very Low
PI- Foam	0,24	0,12	1,65	2,89	1,36
PI - Foam-Type	Very Low	Very Low	Very Low	Low	Very Low
PI- Filaments	0,00	0,00	0,01	0,05	0,00
PI - Filaments-Type	Very Low	Very Low	Very Low	Very Low	Very Low
PI- Rubber	0,00	0,00	0,00	0,00	0,00
PI - Rubber-Type	Very Low	Very Low	Very Low	Very Low	Very Low

Appendix 5: Coefficient pollution impact by type of microplastics of Autumn 2019

Site	**Titanic**	**Oued Elgat**	**Belle Vue**	**Guerbes**	**Kef Fatma**
MPI Pellets	0,70	0,15	0,52	0,16	0,46
MPI Pellets - Type	Maximum	Average	Maximum	Average	Average
MPI Fragment	0,11	0,22	0,35	0,70	0,13
MPI Fragments - Type	Average	Average	Average	Maximum	Average
MPI Fiber	0,17	0,56	0,06	0,04	0,20
MPI Fiber - Type	Average	Maximum	Minimum	Minimum	Average
MPI Film	0,00	0,00	0,00	0,01	0,00
MPI Film - Type	Minimum	Minimum	Minimum	Minimum	Minimum
MPI Microbeads	0,00	0,00	0,01	0,00	0,00
MPI Microbeads- Type	Minimum	Minimum	Minimum	Minimum	Minimum
MPI Foam	0,02	0,05	0,06	0,08	0,20
MPI Foam - Type	Minimum	Minimum	Minimum	Minimum	Average
MPI Filaments	0,00	0,00	0,00	0,00	0,00
MPI Filaments- Type	Minimum	Minimum	Minimum	Minimum	Minimum
MPI Rubber	0,00	0,00	0,00	0,00	0,00
MPI Rubber- Type	Minimum	Minimum	Minimum	Minimum	Minimum

Appendix 6: Plastic pellets and powder stranded on L’rbi Ben M’hidi (January 2020, Photos taken by Ammar Laroum).