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Assessment of Marine Litter in a Polluted Area of the Mediterranean: The Coast of Annaba (North-East Algeria): Sources, Abundance and Composition

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KEYWORDS

Annaba, coastal waste, pollution, management, environment

ABSTRACT:

Introduction: Marine litter (ML) poses a significant threat to global marine ecosystems, impacting biodiversity, coastal economies, and public health. Most of this waste, especially plastics, originates from land-based activities and accumulates along coastlines, degrading slowly and causing long-term damage. Algeria's rich coastal biodiversity has been impacted despite national efforts to manage this issue. Previous clean-up efforts in Annaba highlight the need for sustained action to protect these areas.

Objectives: This study aimed to assess the spatial distribution, sources, and composition of ML on 13 beaches in Annaba (North-Eastern Algeria) during the first quarter of 2024. By identifying the types and amounts of waste, with a focus on plastics, the study seeks to raise awareness and guide local waste management strategies, essential for future environmental policies in the region.

Methods: The research covered 13 beaches, divided into three zones, based on their proximity to pollution sources. Solid waste, including plastics, wood, glass, metals, textiles, and paper/cardboard, was collected and analysed following protocols adapted to local conditions. The total study area spanned 13,000 m², with waste density calculated using standard formulas. Beach cleanliness was also assessed using the Coastal Cleanliness Index (CCI).

Results: The study showed significant variation in ML types and quantities across the beaches. Joannonville and Sidi Salem were the most polluted, primarily due to human activities and poor waste management, while Plage des Juifs and Belvédère were relatively clean. Plastics, mostly bottles and cigarette butts, were the most prevalent type of waste, accounting for 31%, followed by glass (23%) and unidentified waste (11%). A pollution gradient was observed, with zone Z3, near industrial areas, being the most polluted, while Z1, further from pollution sources, was the cleanest.

Conclusions: The CCI classified Plage des Juifs as very clean (CCI of 1.4), while Joannonville and Sidi Salem were classified as dirty (CCI of 12.2 and 19.8, respectively). Overall, the ML density in Annaba (0.3 items/m²) was lower than the global average but highlighted the urgent need for tailored environmental measures to improve beach quality. The findings will support the development of a waste management plan for the region.

1. Introduction

Approximately 80% of coastal marine litter (ML) (items > 2.5 cm) originates from land-based activities, while the remainder has a marine origin [2]. This litter accumulates along the coasts, gradually fragmenting, which depends on its composition and density [3]. Among them, plastics are the most harmful and abundant, representing between 61% and 87% of the waste [4].

ML poses a major threat to the safety and health of global marine ecosystems [1]. This term refers to any solid material manufactured or processed that has been discarded or transported into the marine environment [5], [2]. Since the 1970s, oceans have faced severe threats, including climate change, acidification, habitat destruction, biodiversity loss, overfishing, and pollution, primarily from terrestrial sources. These abandoned or washed-up wastes on coasts pose serious ecological threats with social and economic repercussions [6], [7].

Algeria, with its 1,622 km of coastline, 32 islands, 208 islets, and 71 marine and coastal areas of ecological

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interest, boasts a coastline rich in natural heritage, offering significant potential for socio-economic development. In 2015, the first National Integrated Coastal Zone Management Strategy was implemented, and it was updated in 2021. Despite these efforts, nearly 4 tons of wastes were recovered during the 2021 coastal waters cleanup campaign in Algiers, highlighting the need to continue protection and sustainable management actions for coastal areas.

In Annaba, several studies have analyzed the distribution of marine litter along the coast [8], [9]. However, gaps remain regarding the understanding of the sources, quantities, compositions, and trends of this waste. To fill these gaps, in 2024, we conducted an assessment of the spatial distribution, sources, and characteristics of seven types of marine litter (plastics, wood, glass, metals, textiles, cardboard/paper, and other unidentified materials) on 13 beaches in Annaba, Northeastern Algeria. Therefore, the variations in the types and quantities of waste collected, highlighting the importance of waste management and the need for increased awareness of coastal environmental protection in Annaba were investigated.

2. Methods

Description of the Study Area

Located on the eastern coast of Algeria, with a coastal strip about 80 km long, the wilaya of Annaba covers an area of 1,439 km², representing 0.06% of the national territory. It is bordered to the north by the Mediterranean Sea, to the south by the wilaya of Guelma, to the west by Skikda, and to the east by El Tarf (Fig. 1). Covering 51 km², its population grew from 170,000 inhabitants in 1966 [10] to ≈ 680,000 in 2024 [11]. Its coastline was chosen for the study due to its environmental and economic significance: major coastal developments (petrochemical industries, desalination plants, fishing and ports, metallurgy, tourism hosting up to 1,4 million visitors annually) [11], marine and coastal protected areas (Marine Protected Area of Edough Mountains Natural Park), and diverse ecosystems (forests, coral reefs, and seagrass meadows).

We selected 13 beaches, grouped into 3 zones: Z1 in the Northwest with 3 stations: (S1) Sables d'Or 3, (S2) Chétaibi City Beach and (S3) Oued Boukrat (Djnen El Bey); Z2 (North) with 8 beaches: (S4) Ain Achir, (S5) Belvédère, (S6) Refes Zahouane (formerly Toche), (S7) La Caroube, (S8) Rizi Amor (formerly Chapuis), (S9) Rezgui Rachid (formerly Saint-Cloud), (S10) Plage des Juifs, and (S11) Lever de l'Aurore; and Z3 in the Northeast of Annaba with Joannonville (S12) and Sidi Salem (S13) (Tab. 1). Various factors were considered, such as proximity to wastewater outlets, river mouths, residential areas, and other industrial and economic activities, including the April 2024 commencement of works to convert Joannonville Beach (S12) into a mineral quay for phosphate and phosphate products export.

Identification and Quantification of Solid Waste

To identify and quantify solid waste, we used a camera, a GPS, a scale, trash bags, as well as stakes and string to delineate the study areas. Between January and March 2024, we analyzed the spatial distribution, sources, and characteristics of seven categories of marine litter, in accordance with the recommendations of the TGML/JRC reference guide [12]: plastics, wood, glass, metals, textiles, cardboard/paper, and other unidentified materials. These wastes, of varying sizes and volumes, required the application of rigorous rules for measurement and counting, following a protocol inspired by OSPAR guidelines [13], adapted to local specifics. This protocol includes methods for collecting, sorting, and counting waste, in accordance with the recommendations of the Marine Environment Action Plan of the Marine Strategy Framework Directive [14].

The protocol involves marking lines on the beaches where waste was recorded, classified, weighed, counted, and assigned a probable source. The sampling covered 13 beach transects of 1,000 m² each (10 x 100 m) set back from the coastline. This operation allowed coverage of an area of 3,000 m² in Z1, 8,000 m² in Z2, and 2,000 m² in Z3. Quantification was carried out along the beach front line, separated by at least 0.5 m [15]. The density of macro-litter (items > 2.5 cm) was calculated according to Lippat et al. [16]: $CM = n/(w*l)$, where n is the number of ML recorded, w is the width, and l is the length of the sampling unit, expressed in ML/m².

Clean Coast Index

To assess the cleanliness status of the beaches along the Annaba coast, the Clean Coast Index (CCI) was calculated as follows: $CCI = CM \times K$, where CM is the density of items ML/m² and K is a constant equal to 20 [17]. The CCI scale provides the degree of cleanliness of the beach as follows: 0 to 2: very clean; 2 to 5: clean; 5

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to 10: moderately clean; 10 to 20: dirty; and >20: extremely dirty.

3. Results

Typology of waste on Annaba beaches

The solid waste collected was classified into seven categories, 33 types and five probable sources. Plastics, glass waste, metals and cardboard/paper come mainly from tourist activities, while textiles are often associated with sanitation. Some product sources are specific, such as healthcare or fishing activities, while others remain unidentified (Tab. 2).

Distribution of Different Categories of ML (Kg/m²) on the Beaches of Annaba

Our results show that the abundance, types, and weights of ML vary considerably from beach to beach. Joannonville (0.146 kg/m²) and Sidi Salem (0.103 kg/m²) exhibit significantly higher levels of plastic pollution than the other beaches, suggesting poor waste management and more intense human activity. In contrast, Plage des Juifs and Belvédère show relatively low amounts of plastic, possibly reflecting better maintenance or less usage of this material.

Regarding wood waste, the most affected beaches are Joannonville (0.112 kg/m²) and Sidi Salem (0.059 kg/m²), followed by Ain Achir (0.024 kg/m²) and Oued Boukrat (0.007 kg/m²). These levels are associated with fishing activities for the first two beaches and proximity to forested areas for the latter two.

Glass is particularly present on Joannonville (0.0837 kg/m²), Sidi Salem (0.053 kg/m²), and Ain Achir (0.008 kg/m²), which could indicate significant consumption of beverages in glass containers and a lack of recycling systems for this material.

As for metal waste, Joannonville (0.007 kg/m²) and Sidi Salem (0.008 kg/m²) remain the most affected. The beaches of Rizi Amor (0.010 kg/m²) and Rezgui Rachid (0.009 kg/m²) also show notable concentrations of metals, primarily consisting of beverage cans and proximity to commercial activities.

Rezgui Rachid and Rizi Amor (0.009 kg/m²) exhibit significant amounts of textiles, often linked to human activities (abandoned clothing, towels). Joannonville (0.007 kg/m²) and Sidi Salem (0.008 kg/m²) also continue to show high pollution levels in this category.

Paper and cardboard waste are particularly concentrated on Joannonville (0.039 kg/m²) and Sidi Salem (0.016 kg/m²), a consequence of inadequate management and intense urbanization in this area (Z3). La Caroube also shows a relatively high concentration (0.011 kg/m²).

Finally, unidentified waste, consisting of fragments of composite materials or advanced decomposition, is notably present on Joannonville (0.020 kg/m²) and Sidi Salem (0.024 kg/m²) (Fig. 4).

Distribution of ML in the three zones

In zone 1 (Z1), pollution is moderate, with wood and cardboard/paper predominating. Plastics are not very prevalent (0.006 kg/m²), as a result of very active informal recovery for recycling since 2020 in this zone, and unidentified waste amounts to 0.006 kg/m². Wood (0.028kg/m²), glass (0.01kg/m²), metals (0.011kg/m²), textiles (0.006kg/m²) and cardboard/paper (0.012kg/m²) are present at moderate levels (Tab. Zone 2 (Z2) is more polluted than Z1, with a high concentration of wood (0.074kg/m²), glass (0.007kg/m²), metals (0.047kg/m²) and cardboard/paper (0.035kg/m²). Plastics (0.014 kg/m²) and textiles (0.05 kg/m²) are also present in greater quantities. Finally, zone 3 (Z3) is the most polluted of the three, dominated by wood (0.249kg/m²), glass (0.171kg/m²) and metals (0.137kg/m²). It also has high quantities of cardboard/paper (0.055kg/m²) and unidentified waste (0.044kg/m²) (Tab. 3).

Distribution of the different categories of ML/m²/beach.

The beaches at Sable d'or 3, Chétaibi Ville and Oued Boukrat show moderate levels of pollution. Sable d'or 3 has 0.11ML of plastics/m², with notable quantities of wood (0.07ML/m²) and textiles (0.06ML/m²), indicating mixed pollution (Tab. 4).Oued Boukrat is particularly marked by the presence of wood (0.09ML/m²) and glass (0.07ML/m²), suggesting a possible influence of natural or marine debris. In contrast, Plage des Juifs, Belvédère and Lever de l'Aurore are among the cleanest beaches. Plage des Juifs has only one ML in each category of waste, suggesting a low level of pollution. Belvédère and Lever de l'Aurore also show low levels of litter, with a predominance of plastics but very few other types of litter, indicating that they are better cleaned and less exposed to pollution (Tab. 4).

In general, plastics are the most common type of waste, particularly at Sidi Salem (0.22ML/ m²) and Joannonville (0.19ML/ m²), followed closely by glass. Beaches such as Oued Boukrat and Sable d'or 3 show a significant accumulation of wood, while Joannonville stands out for its exceptional quantity of cardboard/paper and

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unidentified waste, due to its proximity to urban and industrial areas (Tab. 4).

Distribution of different categories of ML/m^2/zone

In general, there is a spatial gradient of ML with higher densities on the beaches of Z3 (N-E), average densities in Z2 (N) and the lowest in Z1 (N-W) (Tab. 3) with respectively 1.60 (43%), 1.22 (33%) and 0.87 (24%) ML/m^2 (Tab. 5).

The order of abundance of ML along the coast is as follows: plastics (31%) > glass (23%) > unidentified (11%) > paper/cardboard (11%) > wood and metals (7%) and textiles (7%) (Fig. 5).

The plastics found consist mainly of bottles (42%), cigarette butts (39%), single-use bags (7%), corks (3%) and other plastics (9%). According to their labels, over 71% of the polyethylene teraphthalate (PET) bottles washed up were produced between 2021 and 2024.

Classification of Beaches by Clean Coast Index

We collected a total of 51480 ML along the Annaba coast, corresponding to densities ranging from 0.08 to 1.23 ML/m^2, corresponding respectively to the Plage des Juifs and Joannonville. Assessment of the cleanliness of the beaches based on the density of ML/m^2 shows that the Plage des Juifs is classified as very clean with a CCI of 1.4. The majority of beaches are classified as clean or moderately clean, with indices ranging from 2.8 (Belvédère) to 7.6 (Sables d'or 3) (Tab. 6).

Conversely, Sidi Salem and Joannonville have the highest indices, respectively 12.2 and 19.8, classifying them as dirty.

Overall, Z1 is considered moderately clean, Z2 clean and Z3 dirty, with higher levels of pollution (Tab. 6).

Table 1. Location of the zones and beaches selected for the study.

Zone	Station	Appellation	Position
1 North West	S1	Sables d'or 3	37°06'509"N, 07°33'964"E
	S2	Chétaibi ville	37°06'609"N, 07°38'148"E
	S3	Oued Boukrat (Djnen El Bey)	36°94'943"N, 07°70'468"E
2 North	S4	Ain Achir	36°95'684"N, 07°78'025"E
	S5	Belvédère	36°94'669"N, 07°77'065"E
	S6	Zahouane (Toche)	36°94'327"N, 07°76'753"E
	S7	La Caroube	36°93'391"N, 07°76'357"E
	S8	Rizi Amor (ex. Chapuis)	36°92'748"N, 07°76'104"E
	S9	Rezgui Rachid (Saint-Cloud)	36°91'969"N, 07°76'525"E
	S10	Plage des Juifs	36°91'644"N, 07°76'861"E
3 North East	S11	Lever de l'aurore	36°90'948"N, 07°77'225"E
	S12	Joannonville	36°88'185"N, 07°76'178"E
	S13	Sidi Salem	36°85'527"N, 07°79'488"E

Table 2. Characteristics and probable sources of the waste collected.

Categories	Type (composition)	Probable sources
Plastics	**Healthcare-related plastic articles**	**Healthcare activities**
	Plastic articles related to fishing	**Fishing activities**
	Ice cream sticks	**Sanitation**
	Plastic caps	**Tourism/ Residents**
	Lighters	**Unidentified**
	Rubber	**Unidentified**
	Shoes / sandals	**Tourism/ Residents**
	Fast food containers	**Tourism/ Residents**
	Cotton buds	**Tourism/ Residents**
	Plastic film	**Tourism/ Residents**
	Cigarette butts	**Tourism/ Residents**
	Plastic parts < 50cm	**Tourism/ Residents**
	Polymers	**Tourism/ Residents**

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	Plastic bags	**Tourism/ Residents**
	Worked wood	**Sanitation**
Wood	**Toothpick**	**Tourism/ Residents**
	Bottles	**Tourism/ Residents**
Glass	**Coloured glass**	**Tourism/ Residents**
	Flat glass	**Unidentified**
	Clear glass	**Tourism/ Residents**
Metals	**Cans**	**Tourism/ Residents**
	Candy/chocolate packaging etc	**Tourism/ Residents**
	Aluminium foil / chip paper	**Tourism/ Residents**
	Metals	**Unidentified**
Cardboard / paper	**Cardboard/paper**	**Tourism/ Residents**
	Tetra pack cardboard	**Tourism/ Residents**
	Food packaging	**Tourism/ Residents**
	Fabrics / textiles	**Sanitation**
	Fragmented paper	**Sanitation**
	Cigarette pack	**Tourism/ Residents**
Textiles	**Fabrics**	**Sanitation**
Others	**Construction products, ceramics, bricks etc.**	**Sanitation**
	Unidentified products	**Unidentified**

Table 3. Abundance categories (Kg/m2) of different of ML by zone.

Zone	Plastics	Woods	Glasses	Metals	Textiles	Carboards/ Papers	Unidentified
Z1	0,006	0,028	0,010	0,011	0,006	0,012	0,006
Z2	0,014	0,074	0,074	0,047	0,050	0,035	0,010
Z3	0,013	0,249	0,171	0,137	0,015	0,055	0,044

Table 4. Breakdown of ML categories/m^2/beach.

Plage	Plastics	Woods	Glasses	Metals	Textiles	Carboards/ Papers	Unidentified
Sable d'or 3	0,11	0,07	0,05	0,04	0,06	0,03	0,02
Chétaibi Ville	0,12	0,02	0,04	0,02	0,03	0,02	0,02
Oued Boukrat	0,03	0,09	0,07	0,06	0,01	0,03	0,02
Ain Achir	0,09	0,01	0,05	0,03	0,02	0,01	0,01
Belvédère	0,05	0,01	0,04	0,01	0,01	0,01	0,01
RefesZahouane	0,08	0,02	0,07	0,01	0,01	0,03	0,01
La Caroube	0,07	0,01	0,06	0,03	0,03	0,01	0,02
Rizi Amor	0,10	0,01	0,02	0,02	0,01	0,01	0,01
Rezgui Rachid	0,09	0,02	0,03	0,01	0,03	0,01	0,01
Plage des Juifs	0,01	0,01	0,01	0,01	0,01	0,01	0,01

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Lever de l'Aurore	0,06	0,01	0,01	0,02	0,01	0,01	0,01
Joannonville	0,19	0,04	0,27	0,01	0,03	0,22	0,23
Sidi Salem	0,22	0,07	0,20	0,02	0,01	0,05	0,04

Table 5. Distribution of ML categories/ m^2/ zone.

Zone	Plastics	Woods	Glasses	Metals	Textiles	Carboards/ Papers	Unidentified	Total
Z1	0,26	0,18	0,16	0,12	0,01	0,08	0,06	0,87
Z2	0,55	0,01	0,29	0,14	0,13	0,01	0,09	1,22
Z3	0,41	0,11	0,47	0,03	0,04	0,27	0,27	1,60

Table 6. Classification of beaches by their Clean Coast Indexes

			Classement	
Beaches	**ML/m^2**	**CCI**	**Per beach**	**Per zone**
Sable d'or 3	0,38	7,6	moderately clean	Z1 moderately clean
Chétaibi Ville	0,27	5,4	moderately clean	
Oued Boukrat	0,31	6,2	clean	
Ain Achir	0,22	4,4	clean	
Belvédère	0,14	2,8	clean	
Refes Zahouane	0,23	4,6	clean	
La Caroube	0,23	4,6	clean	Z2 clean
Rizi Amor	0,18	3,6	clean	
Rezgui Rachid	0,20	4,0	clean	
Plage des Juifs	0,07	1,4	very clean	
Lever de l'Aurore	0,13	2,6	clean	
Joannonville	0,99	19,8	dirty	Z3 dirty
Sidi Salem	0,61	12,2	dirty	

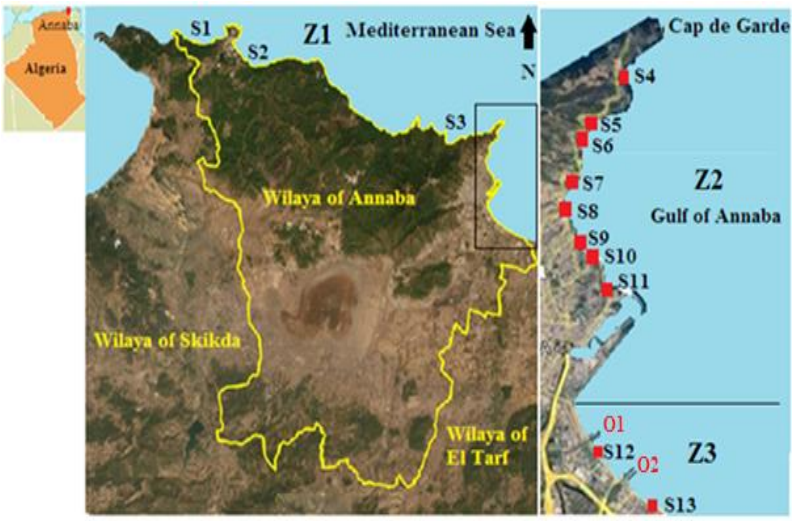

Figure 1. Map showing the geographical location of the wilaya of Annaba, the studied zones (Z) and beaches (S). Outfalls of the Meboudja (O1) and Seybouse (O2) rivers.

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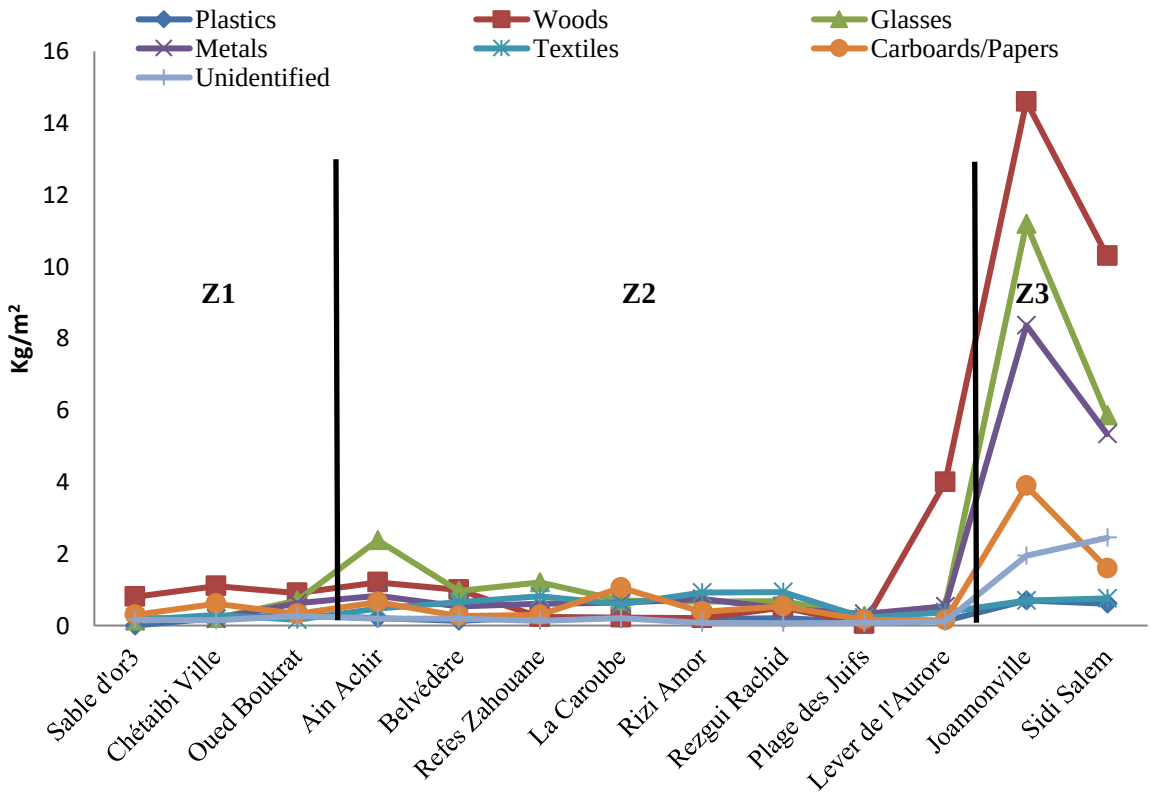

Figure 2. Distribution of ML groups (Kg/m^2) on the 13 beaches.

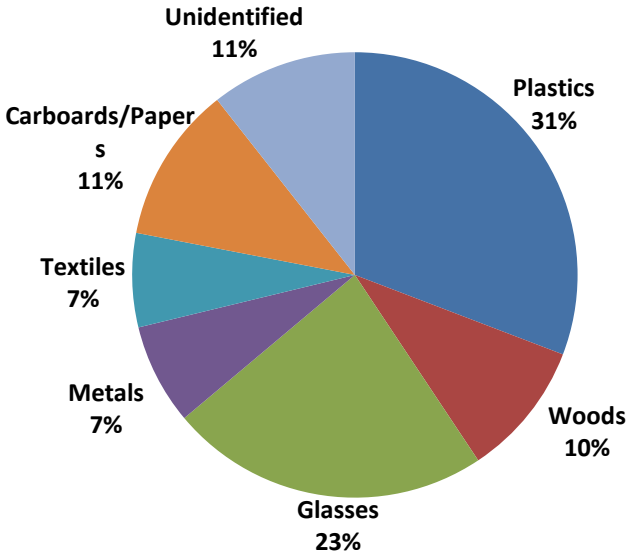

Figure 3. Abundance of plastics on the Annaba coastline.

4. Discussion

Marine litter monitoring in the Mediterranean focuses mainly on ML, although comparison and interpretation of results remain limited. In Annaba, despite previous studies on the distribution of marine litter along beaches [8], [9], gaps persist regarding the sources, quantities, composition and trends of this litter. This study therefore aims to fill these gaps by analysing the spatial

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distribution, abundance and composition of ML, while classifying beaches according to their level of cleanliness.

The ML found along the Annaba coastline comes from three origins: land, sea or uncertain, and from five probable sources: tourist activities, sanitation, specific activities, healthcare or fishing, as well as other unidentified sources. Our results show that the majority of waste comes from land-based sources.

Over a total surface area of 13,000 m² spread over 13 beaches in Annaba, including 6 natural beaches, 1 village beach and 6 urban beaches, we collected, classified, weighed and counted 51,480 pieces of macro-waste divided into seven different categories.

In terms of weight, an average of 0.081 kg/m² was recorded (varying between 0.001 and 0.146 kg/m²), consisting mainly of glass bottles. This figure is almost twice as high as the average observed in Slovenia (0.005 kg/m²) according to Laglbauer et al., [18].

The average density of waste was 0.30 ML/m², which is lower than the world average of 1 element/m² [19], with variations ranging from 0.01 ML/m² (Plage des Juifs) to 0.27 ML/m² (Joannonville). These values are low compared with those observed elsewhere in the Mediterranean, for example in Italy, where the density varies between 1.05 and 1.5 ML/m² [20] and in the Red Sea (0.66 ML/m²) [21].

Plastics accounted for 33% of the waste, a dominant category also observed on beaches around the world. In Annaba, plastics consisted mainly of PET bottles dating from 2021 to 2024 and single-use bags. Only 1% of the bottles were of foreign origin, 97% were manufactured in Algeria and the remaining 2% could not be identified. Plastics also included bags, corks, cosmetic packaging and miscellaneous fragments. This dominance of plastics is confirmed by numerous studies. Chaouch et al., [9] reported that 29% of waste on the Annaba coast was plastic. Elsewhere, for example in Spain (82.6% of marine waste is plastic), Qatar (71.4%) and Turkey (54.05%), similar proportions are observed [22], [23].

Paper and cardboard accounted for 10% of waste in Annaba, up from 6% in 2018. This rate is comparable to that observed in Turkey (10.45%), but remains higher than that of Moroccan (4%) and Spanish (5.6%) beaches [24].

Metals represented up to 8% of waste, a significant drop from the 23% reported in 2018 (Chaouch et al., (2018), probably due to efforts to recover and recycle metals. Glass accounted for 25% of waste, a rate similar to that reported in 2018 in Annaba [9], but much higher than in other Mediterranean regions, such as Spain (1.5%) or Qatar (5.1%) [22].

Wood also recorded a decline, from 15% in 2018 to 8% in this study, while textiles represented 5% of waste, a similar rate to 2018 [9]. Finally, unidentified waste accounted for 11%, well above the rate of 0.3% observed in Spain [25].

A spatial gradient in ML density was observed, with higher concentrations in zone Z3 (1.6 ML/m²), average densities in zone Z2 (1.22 ML/m²) and the lowest in zone Z1 (0.87 ML/m²), which is certainly related to human activities. This phenomenon has been observed in other regions such as Qatar [22].

The assessment of beach cleanliness showed that the Plage des Juifs is classified as very clean with a Clean Coast Index (CCI) of 1.4. The majority of beaches are considered clean or moderately clean, while Sidi Salem and Joannonville have the highest pollution indices, at 12.2 and 19.8, respectively. These results indicate an urgent need for local intervention to improve the cleanliness of these 2 beaches, which are mainly polluted by residents, bathers, sewage and fishing activities. The short-term objective is to classify the majority of beaches as very clean.

5. Conclusion

This study provides detailed information on the spatial distribution, characterisation, likely sources and quality index of marine litter along the west coast of Annaba. The density of marine litter (0.3 items/m²) is lower than the world average of 01 item/m². We observed a spatial gradient in waste density, with higher concentrations in zone Z3 (urbanised area, close to chemical industries and the mouths of two rivers), intermediate densities in zone Z2 (City centre), and the lowest in zone Z1 (area away from pollution sources). Urgent measures, tailored to the specific characteristics of each zone, are needed to improve the environmental quality of Annaba province beaches and ensure their preservation for future generations. Plastics are the dominant category of waste, a phenomenon similar to that seen on beaches worldwide. Almost all the plastic bottles collected have been produced in Algeria over the last four years. This underscores the need to limit single-use products and

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adopt stricter local regulations, while closing the recycling gap, which remains below 10% in Algeria.

The protection of Annaba's coastal zone, although complex, is achievable. The results of this study will contribute to the development of the master plan for the management of household and similar waste in Annaba, currently under preparation [26].

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