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Evaluation of sediment contamination by macro and microplastics in coastal waters of Southern Mediterranean: a case study of Annaba, Algeria, before and after the COVID-19 pandemic

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Abstract: Plastic pollution in the hydrosphere ranks among the most pervasive environmental issues since the inception of the plastic industry and its widespread use in our daily lives. Nowadays, numerous countries worldwide suffer from this pollution not only along coastlines but also in deep-sea ecosystems. Our study carried out in the Gulf of Annaba aims to assess the prevalence and spatial distribution of plastic waste. Sampling was conducted at four coastal sites: El Battah, Seybousse, Rizzi Amor, and Ain Achir, both before and after the Covid-19 pandemic. The results reveal varying rates of macro and microplastic contamination, influenced by geographical differences, urban activities, and hydrodynamic factors. Moreover, the proportions of contamination depend on the types of waste. Furthermore, our study showed a clear divergence, particularly in two periods before and after the pandemic. Due to the lockdown, implemented in 2020, there was a marked decrease in the percentage of sediment plastic pollution, attributed to reduced human activity and partial cessation of industrial operations in these areas.

Introduction

Ecosystems, and in particular animal and plant species, are threatened by plastic pollution, which hampers their ability to provide vital services to humanity. While the leakage of plastics into the ocean and its subsequent impacts on marine life has been most studied, plastic pollution also affects freshwater and terrestrial ecosystems, yet little is known about the potential risks plastics have on human health (Yang et al. 2023). Plastics are present in all marine habitats, on beaches and coasts, on the ocean surface, and on the seabed. They can be found in both the most urbanized areas as well as in the most remote parts of the planet. Densities vary with marked influences from human activities, but also from transport mechanisms and geomorphological factors such as the conformation of bottoms and bays. Estimates of the quantities present are limited and often restricted to beaches and the surface, due to the diversity of mechanisms governing their distribution. On beaches, densities can reach several thousand objects per kilometer, depending on adjacent sources and the currents causing their accumulation (Galgani et al. 2020).

The presence of plastic waste, including microplastics (MP), in the world's oceans and seas is widely documented. MP are observed in sediments, at the ocean surface, in the water column, and deep environments. Even regions remote from all human activity, such as the Arctic and Antarctica (Waller et al. 2017), are contaminated by MP.

The Mediterranean Sea is also an area where microplastics and plastics in general accumulate. The density of plastic in this sea is of the same order of magnitude (423 g/km² on average) as that found in oceanic gyres (281 to 639 g/km² of plastic) (Cózar et al. 2015). However, the Algerian coastline has been little referenced, and it seems necessary to determine the level of pollution by microplastics. Given that fishing and human activity are significant there, plastic is ubiquitous in our daily lives and demand is constantly increasing, following major changes due to the growing global demand for plastic production and consumption. As part of the Algerian coastline, Annaba is not protected against anthropic aggression (tourist, port, agricultural activities, etc.), receiving huge quantities of wastes of all kinds each year, marked by a plastic prevalence, This situation raises alarma for the aquatic ecosystem.

In the wake of these events, another incident occurred on earth: the discovery of a virus at the end of 2019, which led to the ongoing Covid-19 pandemic, an infectious disease caused by a coronavirus. To cope with the spread of this pandemic, a

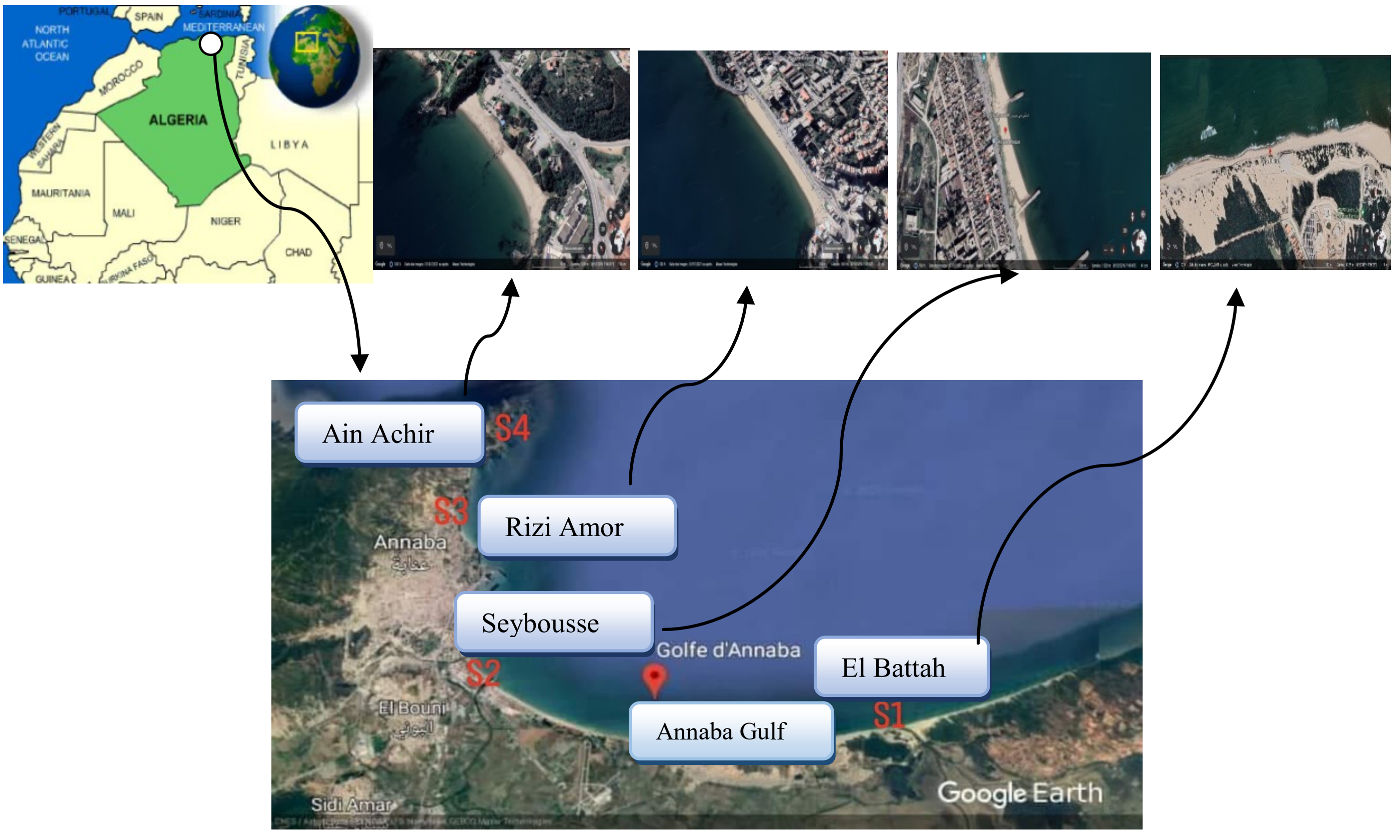

Figure 1. Location of study sites in the Gulf of Annaba (Google Earth).

restriction on the use of beaches and a lockdown was instituted by the government for almost six months. During this time, people were forced to wear masks, visors, gloves and other protective equipment in hospitals to ensure the safety of health personnel, Consequently, the use of plastic increased. In addition to its widespread effect on jobs, economies and countries, the global economic downturn caused by this pandemic has also significantly affected terrestrial and marine ecosystems. In the short term, there are positive impacts , such as the reduction in pollution, overfishing, loss of marine habitats, introduction of invasive species, and the impact of climate change on the oceans (Ang et al. 2023). There is already evidence of this slowdown in the fishing, shipping, tourism and coastal development sectors, as well as in oil and gas extraction. A recent survey conducted by The Economist (2021) found that participants ranked the following ocean-related sectors as the most affected by Covid-19: tourism (70.7%), fishing (10.4%), offshore oil and gas (7.2%), shipping (6.2%), offshore renewable energies (2.9%), and aquaculture (2.6%) (Hudson, 2020). Nevertheless, facemasks play an essential role in preventing the spread of Covid-19. Facemasks such as N95 and surgical masks contain a considerable proportion of non-recyclable plastic. Marine plastic pollution is likely to increase due to the rapid use and inappropriate distribution of facemasks. It is estimated that around 0.15 to 0.39 million tons of plastic debris could end up in the world's oceans within a year (Chowdhury et al. 2021).

The main objective of our research is to assess the abundance and distribution of plastic debris on the Annaba coast, while taking into consideration the effect of certain factors such as season, hydrodynamics and the Covid-19 pandemic.

Material and methods

General information of Study Area

The Gulf of Annaba occupies a large continental shelf in the Mediterranean Sea and plays an important role in tourism and the economy on the east coast. The Bay of Annaba is bounded to the east by Cap Rosa (8° 15" E 36° 58 "N), and to the west by Cap de Garde (57° 16 "E and 36° 58 "N), a distance of 40km, with a maximum water depth of 65m.

Almost all of the North of Algeria is Mediterranean, characterized by a mild and wet climate in winter and hot and dry one in summer. Generally, rainfall is irregular and sometimes unequally distributed not only in time but also in space. Precipitation is very scanty in summer , reaching its maximum abundance in winter. During the sampling periods (December 19- February 20 and September 20- February 21), the region experienced two periods of severe weather, in January 2020 and November 2020.

The areas studied were determined on the basis of their location in relation to the sources of pollutant discharges (rivers, discharges, industrial zones and urban areas). Four specific areas were selected (Table 1; Fig.1)

Sample collection and preparation

For the sampling protocol, we used the method described by Lippiatt et al. (2013).

Macro-debris >2.5cm sampling

Four 5m-long transects were selected in the section of shoreline to be sampled. This number corresponds to 20% shoreline coverage. The transects extend perpendicular to the section of shoreline, starting from the water's edge and

Table 1. Site distribution criteria.

Beaches	Streams rivers	Tourist attendance	Residential Zone	Industriel Zone	Type of waste	Municipality
Ain Achir (S4)	/	Yes	Yes	No	/	Annaba
Rizi Amor (S3)	/	Yes	Yes	No	urbains and domestics	Annaba
Seybouse (S2)	Oued Seybouse	No	No	No	urbains, domestics, industriels.	El Bouni
El Battah (S1)	Oued Bou Namoussa	Yes	Yes	No	/	Ben Mehidi

continuing to the back of the bank. The back of the bank is defined as the location of the first barrier (primary substrate change) (Fig.2). Ancillary data are recorded prior to the debris survey, including the length of each transect from the water's edge to the first barrier, time, season and date of last survey, description of recent storm activity, and current weather conditions. Once everything is in place, each transect is walked, and debris items are counted according to material type and subcategory. Debris should only be recorded if it measures at least 2.5 cm in its longest dimension. The concentration of macro-debris elements (number of debris elements/m²) per transect is calculated as follows:

$$C = n / (w \times L)$$

C: Macro-debris concentration
n: number of macro-debris
w: transect width = 5m
L= transect length = each transect has a length

Note that the shoreline width measured at each transect is essential for calculating debris concentrations.

Meso (2.5cm-5mm) and micro-debris (≤5mm) sampling

Random samples can be taken from sandy beaches for meso- and micro-debris analysis. For random sampling within a shoreline segment, a random number table is used to select the location of a 1m² quadrat (Fig.3).

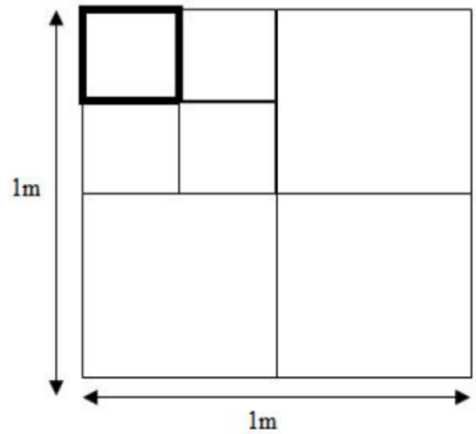

Figure 3. Randomly placed 1m² quadra and collection of the top 3 cm of sand on 1/16 of the bold quadra (0.25m X 0.25m = 0.0625m²).

Once the quadrat placement has been chosen, all debris larger than 2.5 cm (which should have been counted in the macro-debris survey) is removed from the surface. This is done using a small stainless steel shovel to collect the top 3 cm of sand from 1/16 of the quadrat (0.0625 m²). The quadrat is divided into quarters, and one of the quarters is further divided into quarters. The collected sand is sieved through a 5 mm stainless steel mesh sieve over a bucket. The sieved

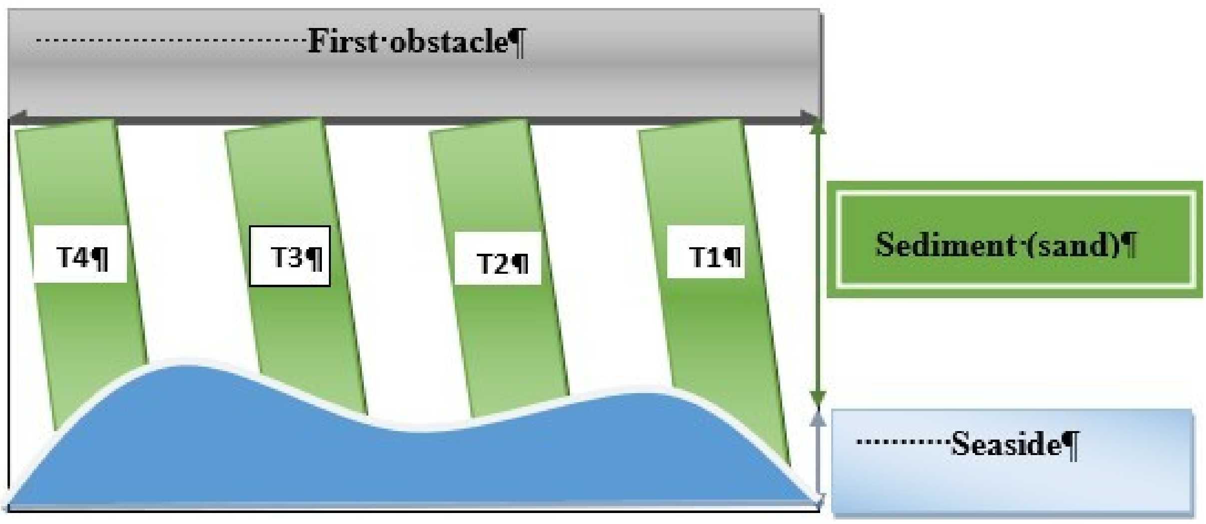

Figure 2. Cross-section of shoreline (100 m) with perpendicular transacts (T) from the water's edge at low tide to the first barrier behind the shoreline section.

Table 2. Determination of the number of macro-plastics at the four sites during winter (December 2019, January and February 2020).

	December 2019		January 2020		February 2020	
	MAP	MD	MAP	MD	MAP	MD
Battah	63.75±32.42	70.25±34.04	153.5±69.93	164.75±72.52	138.75±65.75	151.25± 68.5
Seybousse	30.75±10.37	42±14.35	54.5±11.62	71.25±11.90	53.25±13.65	69.75±13.30
Rizzi amor	10±7.75	13.25±9.25	86.25±39.60	106.5±41.41	49.5±26.03	63.25±26.73
Ain achir	29±7.44	38.25±11.15	34.25±5.85	53±6.06	30.25±8.77	43.5±9.47

micro-debris samples are then transferred to labeled amber glass bottles for further analysis in the laboratory. If meso-debris elements (> 5 mm) cannot be correctly identified in the field, they must be collected and re-analyzed in the laboratory. This process is repeated for each of the four transects sampled for macro-debris. The concentration of meso- and micro-debris elements (number of debris elements/m^3) is calculated as follows:

$$C = n / (a \times h)$$

C: meso/micro-debris concentration
n: number of meso- or micro-debris
a: area sampled = 0.0625 m^2.
h: sample depth = 0.03m

Sampling analysis

In the laboratory, macro-debris samples were deposited on flat surface receptacles. Organic and non-plastic debris samples were removed. The remaining substrate was sorted into several categories: hard plastics representing breakable plastics, soft plastics representing twistable plastics, and other easily recognizable categories . The sorted debris was then counted. For meso- and micro-debris samples, the sand contained in each glass sample bottle was sieved using a 5 mm mesh sieve. This can be done in the laboratory or at the sampling site. Particles larger than 5 mm, retained by the sieve, were retained; those smaller than 5 mm were poured into a bucket filled with seawater. Plastic debris was then recovered by flotation, thanks to the difference in density between seawater and plastic. The contents of the container were poured into a sieve with a mesh size of 0.33 mm and stopped when the sand level was reached. Next, the sieve is washed with distilled water to remove the foam. Plastic debris is counted visually or under the microscope. Using tweezers and needles, meso- and microplastics are sorted into different categories: fragments (hard, soft) and filaments.

Data analysis

Statistical processing was carried out to understand the distribution of debris in the Gulf of Annaba. The results were analyzed statistically using the one- and two-factor ANOVA 1 and 2 tests, followed by the Tukey multiple comparison test. Graphpad Prism 7.0 software is used for statistical analysis, where $p<0.05$ is considered significant. Additionally, the FactoMineR package was used to conduct a principal component analysis (PCA) on standardized data with the objective of characterizing the structuring of spatiotemporal fluctuations of microplastic pollution in the Algerian coastline using a multivariate approach.

Multiple Factor Analysis (MFA) is a k-table method (organized in blocks). Its aim is to describe the typology of individuals (or periods) based on plastic variables (Micro, Meso and Macro). The analysis also generates comparisons between tables (stations).

Results

Determination of macro-plastic waste

All the macro-debris collected at the four sampling sites was classified according to several categories: macro-plastic, rubber, metal, glass, clothing, etc., over a nine-month period (before the pandemic: December 2019 – January, February 2020, and after the pandemic: September, October, November, December 2020 – January, February 2021). We then determined the percentage of macro-plastics (MAP) in relation to the total number of macro-debris (MD). Our investigation showed both intra- and inter-site differences in the number of wastes collected.

a – *Pre-pandemic*: According to our results, the highest number of macro-debris pollution was recorded at El Battah beach during the three months (December 2019 – January, February 2020) followed by Rizzi Amor. The percentage of macro-plastic (MAP) in relation to total macro-debris (MD) shows dominance at all four beaches during the three months, with the highest rates recorded at El Battah (93%), followed by Rizzi Amor (80%), and Seybousse (76%), while the lowest percentage (64%) is at Ain Achir (Table 2). Evaluation of macroplastic pollution over the three months showed that the highest value was recorded in January for El Battah beach, followed by Rizzi Amor. This pollution is probably due to the heavy rainfall experienced by the region during this period.

b – *After the pandemic:* During the autumn and winter seasons (September 2020 - February 2021), our results showed that the highest numbers of MD and MAP were recorded in November and December 2020, respectively, at Rizzi amor beach, followed by El Battah. The percentage of MAP also shows dominance over MD for both variants: beaches and months. Generally speaking, no Covid-19-related waste was encountered (Table 3 and 4). The macro-plastic pollution recorded in November 2020 also was induced by heavy weather in the region.

Table 3. Determination of the number of macro-plastics for the four sites during autumn 2020 (September, October and November).

	September 2020		October 2020		November 2020	
	MAP	MD	MAP	MD	MAP	MD
Battah	35.75±25.69	59.75±34.58	48.25±17.46	76.25±24.70	122.25±40.43	182.75±49.37
Seybousse	37.5±36.68	60±37.27	37.5±14.27	52±18.20	61.5±16.134	112±16.99
Rizzi amor	13.5±3	14.75±4.27	24.5±11.35	32±14.46	154.25±55.48	224.25±57.66
Ain achir	23.75±9.70	33.75±14.95	25±13.26	37.75±16.64	58±17.66	94.5±18.21

Table 4. Determination of the number of macro-plastics for the four sites during Winter (December 2020, January and February 2021).

	December 2020		January 2021		February 2021	
	MAP	MD	MAP	MD	MAP	MD
Battah	32.75±10.05	46.5±7.85	22.25±4.79	27±2.5	18.5±14.20	28.75±16.80
Seybousse	21.25±4.99	32±5.72	10.5±2.89	13.5±4.20	28.25±6.70	33.75±8.26
Rizi Amor	57.25±74.31	78.25±90.72	27±12.03	35±9.20	15.75±6.99	23.25±10.44
Ain Achir	24.25±7.09	35.25±11.53	27±10.30	41±12.70	24.75±13.02	31.75±15.97

Quantifying plastic debris (macro, meso and micro)

To standardize our results and bring them into line with international standards for comparison with other research, we adopted one of the most popular assessment methods currently available: calculating concentration based on the formula mentioned above. The concentrations of plastic waste collected over the nine months were categorized by size (macro, meso, micro) (Fig.4).

The graph shows variations in macro-plastic concentrations across four beaches during three seasons (Fig.4A). In the first season, characterized as the pre-pandemic period, there was an increase in macro-plastic concentrations at El-Battah and Rizzi Amor beaches. In January 2020, we observed a significant ($p<0.05$) and highly significant difference ($p<0.01$) in macroplastic concentration at El Battah beach (0.9 n/m^2) compared to Seybousse and Ain Achir, respectively. There was also a significant difference at Rizi Amor beach (0.8 n/m^2) compared to Ain Achir. In February 2020, there was a significant difference at El Battah beach (0.81 n/m^2) compared tp Ain Achir. During the second season, spanning from September to November 2020 and considered as the period of recovery from lockdown, contamination levels were low across all four beaches, with no significant difference noted for the months of September and October. However, in November, there was a highly significant increase at Rizi Amor beach compared to El Battah, Seybousse and Ain Achir.

In the third season, spanning from December 2020 to February 2021, macroplastic concentrations decreased at all four beaches, with no significant differences observed among them.

Figure 4B shows the varying concentrations of meso-plastics at the four sampling sites over a nine-month period. The highest concentrations of meso-plastic debris were recorded in the winter prior to the pandemic. Subsequent months from September and November 2020 showed consistently low values, which began increasing from December onwards, with no significant differences between them. In December 2019, our results revealed a significant and highly significant fluctuation at El Battah (13333.33n/m^3) compared with Seybousse, Rizzi Amor and Ain Achir, respectively. In January 2020, a significant increase was recorded at El Battah beach (20933.33n/m^3), compared with Seybousse and Ain Achir. In February 2020, a significant difference was noted only between El Battah and Ain Achir.

The graph (Fig.4C) shows the variance of microplastic waste concentrations on the same beaches over the same period. In December 2019, there was a highly significant increase in microplastic debris at El Battah beach (54933.33 n/m^3) compared with Seybousse, Ain Achir and, also Rizzi Amor, respectively. In January 2020, there was a significant increase at El Battah (71866.67 n/m^3) compared with Ain Achir, Rizzi Amor and Seybousse. In February 2020, there was a significant difference in El Battah (54933.33 n/m^3) compared with Seybousse, Rizi Amor and Ain Achir, respectively. Similar to meso-plastics, microplastics exhibited very low values from September to November, increasing from January onwards, with no significant differences.

Characterization of microplastics

Microplastics were classified according to their type, nature and color, including fragments (hard, soft) and filament,

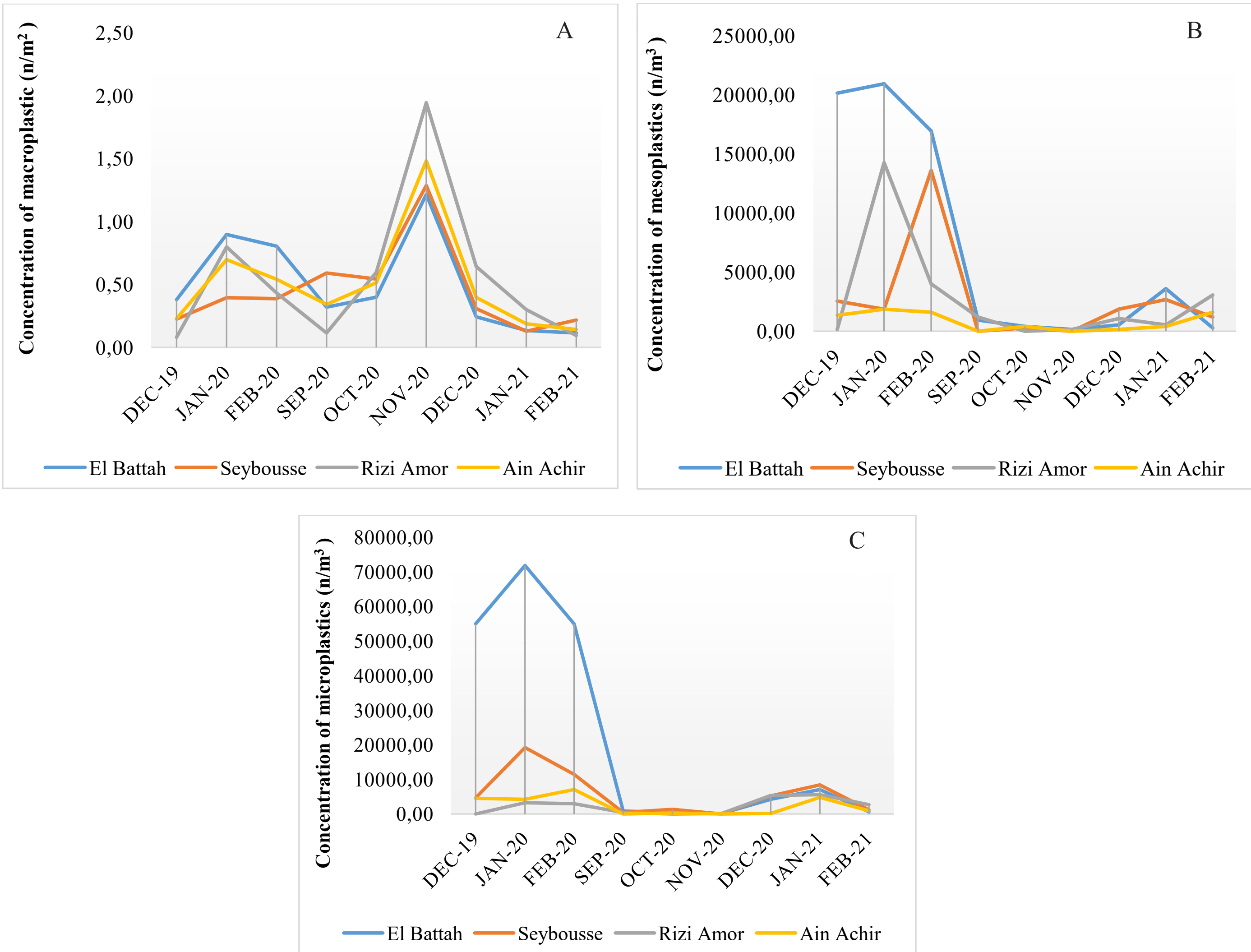

Figure 4. Variation in the concentration of macroplastics (A) (n/m^2), mesoplastics (B) and microplastics (C) (n/m^3) before and after the pandemic (n=4, $p<0,05$).

in order to assess their distribution at shoreline level before and after the pandemic. Figure 5A shows that, before the pandemic, filament-type microplastics predominated in El Battah during the months of January, February and December. In contrast, fragment types (hard, soft) were present in very small quantities at all four sites. However, after the pandemic, during the autumn months, the presence of MP was almost non-existent, starting in December. Filament type continued to dominate in both months (December-January 2021) for all four beaches (Fig.5B). The colors recorded for the fragments included transparent, white, black, red, green, blue, yellow, orange and brown, while for the filaments, the colors were transparent, black, blue, green and yellow.

The first plane (Dim1xDim2) of the Multiple factor analysis (MFA) captures ghe maximum amount of information, accounting for 72% of the total information in the global cloud. The first component explains 45.12% of the variance, while the second component explains 26.84%. The correlation circle (Fig 6 A) reveals the structure of the variables defining the expression of the first two components. The first component delineates a gradient combining the meso and microplastic variables, while the second component forms a gradient

Table 5. Percentage (%) of macroplastics (MAP) relative to total number of macro-debris (MD).

	Dec19	Jan20	Feb20	Sep20	Oct20	Nov20	Dec20	Jan21	Feb21
Battah	90	93	91	59	63	67	70	80	64
Seybousse	73	76	76	62	72	54	66	77	83
Rizi Amor	75	80	78	91	76	68	73	77	67
Ain Achir	75	64	69	70	66	61	68	65	77

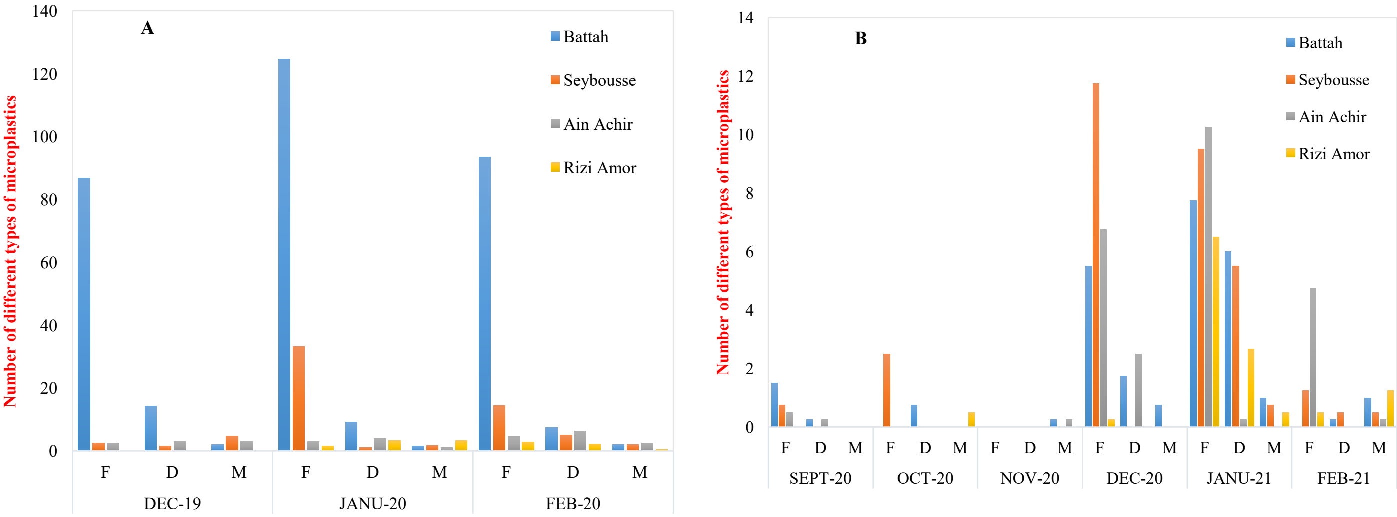

Figure 5. Determination of the different types of microplastics (Filament, Hard, Mud) in the four sites before the pandemic (December 2019, January- February 2020) (A) and after the pandemic (September 2020- February 2021) (B).

combining the expression of macro-plastic variables. The typology of periods results from a combined analysis process involving PCA-type ordination and Ward-type hierarchical classification (Fig 6 B). The first cluster represents the Nov20 period (in black), with variables characterizing this group selected using the V-test method, retaining only the most significant variables. The second cluster encompasses the periods Dec19 - Sep20- Oct20- Dec20- Jan21- Feb21. The third cluster covers the periods Jan20-Feb20. We can confirm that the positioning of the AinAchir and Seybous stations is linked to the Dim1 gradient (Micro and Mesoplastic gradient), while the RiziAmor station is associated with the expression of Dim2 (Macroplastic gradient).

Discussion

In order to study the impact of the Covid-19 pandemic on the extent of plastic pollution in bodies of water at the level of the Gulf of Annaba, we tried to compare the results obtained from the investigation carried out during the winter of 2019/2020 with those of the two seasons autumn 2020 and winter 2020/2021 at the level of the four sites: El Battah, Seybousse, Rizzi Amor and Ain Achir.

The persistence of the pandemic worldwide has shifted the focus to human health, with little attention to the impact of the virus on the environment. Early studies highlighted the indirect impact on the environment, namely reduced concentrations of particulate matter ($PM_{2.5}$) and NO_2 in China (Yuan et al. 2020); lower greenhouse gas (GHG) emissions in France, Germany, Spain and Italy (Global Carbon Project 2020) and cleaner beaches due to reduced waste production by tourist activities on the beaches of Acapulco, Barcelona and Salinas as well as those in Kenya. Ormaza-Gonzalez and Castro-Rodas (2020) also reported cleaner beaches in a study conducted in Ecuador, attributed to the lockdown and social distancing measures implemented by the government during the Covid-19 pandemic season. This positive observation was made despite the reported increase in the use and availability of PPE such as face masks and gloves in over 50 countries, including Ecuador, Austria, Venezuela, Morocco, Argentina, Spain, and Portugal (Ormaza-Gonzalez and Castro-Rodas 2020, Zambrano-Monserrate et al. 2020, Okuku et al. 2021). Our results showed that the highest number of macro-debris was recorded at El Battah beach, followed by Rizzi Amor, during the three months before the pandemic. During the autumn and winter seasons after the pandemic (September 2020- February 2021), the highest numbers were recorded in November and December, this time at Rizzi Amor beach, followed by El Battah.

The percentage of macro-plastic shows a dominance over macro-waste across both beach types and months during the two study periods. This fluctuation in pollution at these precise times is due to the heavy rainfall experienced by the region. Numerous publications have studied the presence of plastic particles on beaches (Van Cauwenberghe et al. 2015b). It is thus possible to observe the presence of pollution by these particles on beaches on all continents: Africa, North America, South America, Asia and Europe (Baztan et al. 2014).

PM concentrations in sediments are often expressed as elements per mass (g, kg), per surface area (m^2) or per volume (mL, L). Highly variable results have been reported, ranging from 0 to 50,000 MPs per kg of sediment (dry weight), 30 to 8,000 MPs per L, and 0 to 3,300 MPs per m^2. This variation arises from the multitude of studied localities, as well as the diverse protocols, sampling techniques, and identification methods used.

In our work, the concentrations of plastic waste collected over the nine months were calculated according to size (macro, meso, micro). Over the course of three seasons, each of the four beaches experienced a marked fluctuation in the distribution of plastic waste, under the influence of a number of factors which are discussed below.

In winter 2019/2020, considered as the pre-pandemic period, increased macro-plastic pollution was recorded at both Rizi Amor and El Battah beaches. However, in winter 2020-2021, during the Covid-19pandemic, pollution levels significantly decreased. This reduction is likely attributable to beach restrictions and lockdown measures implemented during the summer season.

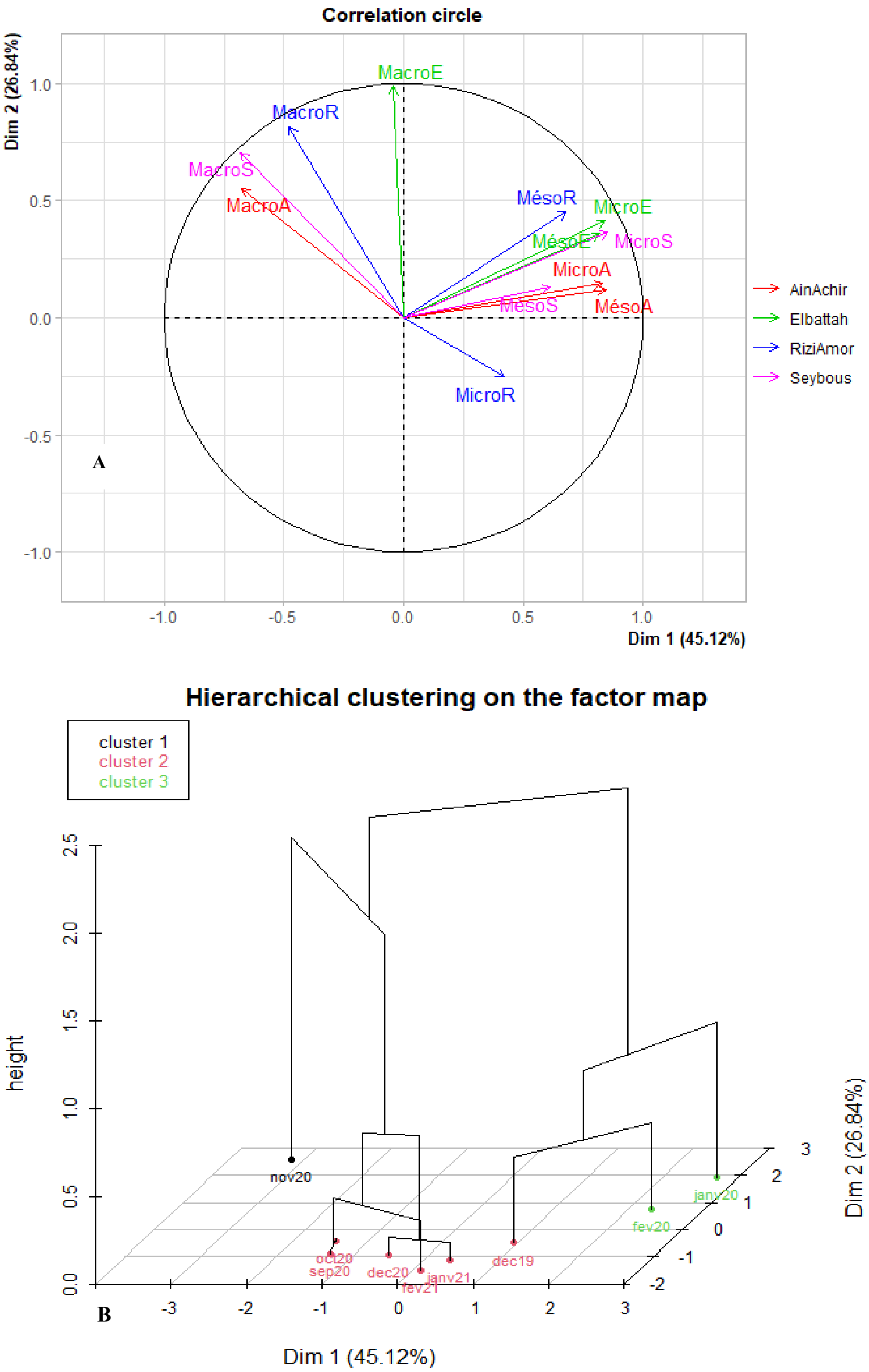

Figure 6. Correlation circle for the Dim1 plan (45.12%) and the Dim2 plan (26.84%) (A) and representation of the typology of periods resulting from the dual analysis process (B).

From September to November 2020, considered the post-contaminated recovery period, we observed low contamination levels at the four beaches, with no significant difference between September and October. However, exceptionally high levels of macro-plastics were recorded in November 2020 for all four beaches, with a significant increase noted at Rizi Amor compared to El Battah, Seybousse and Ain Achir. This increase can be attributed to bad weather the region experienced during this period, which confirms the role of hydrodynamic factors such as wind and rain, which carry waste away from the seabed, in the distribution of plastic pollution. Regarding meso- and microplastic debris, the highest concentrations were recorded in the winter before the pandemic. Subsequent months saw very low values between September and November 2020, increasing from December onwards, with no significant differences among them. This significant reduction in microplastic pollution after the pandemic is viewed as a beneficial side-effect of these circumstances, contributing to the purification of the environment from the impacts of human activities such as plastic pollution.

We also noticed that the most affected sites are Rizi Amor and El Battah. The former, classified as a tourist beach, is situated near a densely populated area and receives a high number of daily visitors, leading to multiple sources of urban waste. Similarly, El Battah is a popular tourist destination, particularly during the summer when it attracts families from neighboring towns such as Guelma, El Taref, and Annaba. The beach is also known for fishing activities, which contribute to the accumulation of waste, including discarded equipment from fishermen that often finds its way into the sea.

Tourism is a significant contributor to beach pollution (Galgani et al. 2020). In addition, the lack of hygiene culture and public awareness campaigns by citizens and associations exacerbates the problem. It should also be noted that there are parameters that influence the distribution of plastic debris along shores. This could be explained by topography, hydrodynamics and environmental factors. The concentration of microplastics varies according to climatic conditions. For instance, wind patterns influence the surface distribution of plastics, while environment hydrodynamics, including swell and currents, control suspension/sedimentation phenomena. In areas like the Venice lagoon, microplastics tend to accumulate mainly in regions with low hydrodynamics. Longshore drift currents also play a key role in transporting plastics to beaches, while tides contribute to the deposition of sea flotsam along foreshores with significant tidal ranges (Imhof et al. 2017).

On a smaller spatial scale, plastic distribution is influenced by various factors such as surface turbulence (wind, waves), distance from the coast, and proximity to pollution sources, (Pedrotti et al. 2016) found a positive correlation between floating plastic waste density and coastal population density, as well as with distance from the coast, within a range of a few tens of kilometers. Frère et al. (2017) confirmed microplastic contamination of surface water and sediment in the Brest roadstead. This contamination was attributed to the distribution of microplastics, which appears strongly influenced by proximity to the port area and the city of Brest, where anthropogenic activity is intense. Additionally, the strong hydrodynamics generated by tidal currents in the area play a significant role in plastic dispersion.

In the same context, Klein et al. (2015) measured levels of several hundred to several thousand particles/kg (or between 10 mg/kg and 1 g/kg) in Rhine sediments. Data of the same order of magnitude have been reported for the River Thames (Horton et al. 2017a). Sediment samples taken from the River Kelvin in Glasgow showed a total abundance of 161-432 particles/kg dry sediment (Blair et al. 2019). In the marine environments, a recent study conducted in the Great Australian Bight reported an average concentration of 1.26 micropartic /g dry sediment from 51 samples taken (Barrett et al. 2020), comparable to levels found in Rhine and Thames River sediments (Horton et al. 2017a, Klein et al. 2015). Based on these results, the authors estimated global microplastic amounts in marine sediments at 14 million tonnes, a small fractionof 8 million tonnes of plastics that reach the seas and oceans every year, leaving much of the "missing plastic" unaccounted for. (Vermeiren et al. 2020) found the highest mass concentration on German beaches (East Frisian Island, North Sea), the highest volume concentration on the Japanese coast, and the highest surface concentrations on the South African coast. Conversely, the lowest values were found in the southern Baltic Sea (mass concentration), the southwestern Indian Ocean (sediment volume), and the Adriatic Sea (sediment surface) (Graca et al. 2017). The highest values were found in beach and coastal sediments, while the lowest values were reported in sediments from open ocean areas.

Characterization represents the final step in the MP analysis procedure and plays a crucial role in understanding the nature of the particles. This step typically involves two stages: observation and identification. During the observation stage, researchers visually or microscopically examine the particles to determine their size, color, and shape. This visual inspection provides initial insights into the physical characteristics of microplastics. Secondly, in the identification stage, researchers employ spectral or chromatographic chemical analysis techniques to characterize the composition of the particle. This analytical approach enables the precise determination of the chemical composition of microplastics. It is worth noting that some studies have relied on macro- or microscopic visual observation for the analysis of microplastics (Vandermeersch et al. 2015).

Most works have identified fibers, filaments, and fragments as the three most commonly reported categories of microplastic shapes. These shapes can be observed and recorded either with the naked eye or under a microscope. Other forms such as granules, foams, films, pellets, and spheres exist, all of which can offer valuable insights into microplastic sources (Phuong et al. 2021). Most contamination occurring during sample processing comes from fibers, due to their ubiquitous presence in outdoor and indoor atmospheres. Consequently, some studies opt to exclude fibers from their reports, as they can be challenging to identify when they are too fine. Filament-type microplastics predominated in El Battah beach during the three months prior to the pandemic. On the other hand, the other two types of fragments (hard, soft) were present in very small quantities at all four sites. During the autumn months, microplastic presence was nearly non-existent, with an increase observed from December onwards. Filament-type microplastics dominated during the subsequent two months (December-January 2021) across all four beaches. This prevalence is likely attributed to various factors, including activities of beach users, as well as wind, precipitation, or marine currents. The exact origin of hard types of microplastics can be linked to tourist activities.

The work of Blair et al. (2019) showed that the dominant type of MP was fibers, accounting for over 88% of total counts. Nevertheless, fibers in blanks suggest potential contributions from atmospheric contamination. A comprehensive study on Danjiangkou Reservoir Lake (DJK) (Di et al. 2019) confirms the dominant presence of fibers in sediments (80%), and that of particles smaller than 2 mm, confirming multiple previous studies. The microplastics represented in river sediments correspond to those present in the water column, with a proportionally greater representation for the densest polymers (Bordós et al. 2019).

Studies on the Canadian Great Lakes region highlight a continuity in their composition between tributaries, lakes and estuaries (Anderson et al. 2016). As with the DJK reservoir, plastic particle size decreases away from populated areas. On the other hand, as this is an open system, the microplastics collected in the St. Lawrence estuary have been reduced in size by the mechanical effect of the tides, while those in the DJK dam area have the largest particles. Concerning colors, Galgani e•• al. (2013) proposed 12 different categories of MP. These are determined by direct observation. We recorded the following colors: transparent, white, black, red, green, blue, yellow, orange and brown for fragments and transparent, black, blue, green and yellow for filaments.

According to several studies, numerous colors have been reported for MP found in marine sediments, including black, white, red, blue, transparent and brown. However, color designation should be treated with caution. Apparently transparent MP may have undergone long environmental weathering resulting in color loss, or lost their color during sample processing or they appear transparent due to light density during measurement, or simply be intrinsically transparent (Blumenroder et al. 2017).

Conclusions

The results of our study on the pollution of Annaba's Gulf beaches (Al-Battah, Seybousse, Rizzi Amor, Ain Achir) showed the existence of plastic debris contamination of the entire coast, with inter- and intra-site differences in concentrations, which depend on certain factors such as tourist activities, population density and proximity to a waterway or port. After the pandemic, high levels of macroplastics were recorded exceptionally in November 2020 for all four beaches, with a significant increase at Rizi Amor compared with El Battah, Seybousse and Ain Achir.

Author statement

Kheireddine Ouali: Conceptualization, Methodology and presentation of the published work.
Chanez Lakbar: Conducting a research and investigation process.
Rania Djennane: specifically performing the experiments and sample, Data collection.
Fouzia Trea: Writing and review editing Faouzi Samar: Application of statistical and reviewing

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Declaration of competing interest

The authors declare that there are no conflicts of interest.

• Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

• Ethics approval
All the protocols used in this study were conducted according to the International Guidelines for Laboratory Animal Care and Use (Council of European Communities) (JO86/609/CEE) and approved by the Ethical Committee of Directorate General for Scientific Research and Technological Development at Algerian Ministry of Higher Education and Scientific Research, permit no PRFU/SF 08/2021

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