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Cotton buds: The new villain of the marine litter story in the coastal lagoon

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Abstract

Plastic bags, bottles, packing tapes, and fishing lines are at the forefront of the discussion on plastic pollution in the oceans. However, scientific interest on the role of cotton buds in such context is rapidly increasing, as these objects continue to be widely used and discarded improperly. Therefore, this study aimed to determine the abundance and fate of cotton buds as a case study in the Küçükçekmece Lagoon. At two sampling stations, the pebbly beach and the rocky beach, a total of 854 cotton buds were found over the course of six months with an average value of 71.16 litters m^{-2} per month. The similarity of months of occurrence in summer and autumn was statistically significant. However, in November and December, when meteorological conditions were more severe, significant similarity was observed. Furthermore, the results of the potential environmental hazard, risk assessment, and carbonyl index were used to provide answers to the main problems of cotton bud pollution. Consequently, the hazard level was classified as either III or IV and the risk level was determined unfriendly. In total, 44.5% of the samples had a high level of oxidation. EDX analysis also confirmed that the biofilm influenced the accumulation of metals on the plastic surface. Overall, the results have addressed the issues that should be considered in improving the management strategies for plastics, which can be implemented to reduce the environmental impact of plastics and achieved the main objective of raising awareness on the accumulation of plastic waste generated by anthropogenic activities in coastal areas.

Keywords: Marine pollution, Waste management, Plastic, Carbonyl index, Ecological risk

Introduction

In 2020, almost 400 million tons of plastic were used in countless industries (Çevik et al., 2021). Thus, plastic pollution has become inevitable on a global scale. The detection of plastic at any point in the ocean, from the deepest point to the poles, and its impact on biota is of great interest (Bergmann et al., 2019; Barrett et al., 2020; Markic et al., 2020).

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Pollution of the marine environment by microplastics is a global phenomenon that is widespread and persists in the natural environment for long periods of time (Hale et al., 2020; Zhou et al., 2020). Microplastics are known as plastic particles in the size range between 1 μm and 5 mm (Fan et al., 2022), and their sources are divided into primary and secondary (González-Fernández et al., 2021). Primary microplastics are small pellets produced for industrial use (Cole et al., 2011). Secondary microplastics, on the other hand, are often found in the marine and ocean environment and form when macroplastics are exposed to UV radiation and hydrolysis (Lee et al., 2013).

Studies on microplastics and their possible origins have increased significantly, mainly due to the growing concerns about the negative impacts they may have on filter feeders at the bottom of the food chain (Zarfl and Matthies, 2010; Andrady, 2011; Cole et al., 2011). Although there have been many recent reports on determining the extent, consequences, and control mechanisms of microplastic pollution, there are very few studies that focus on identifying a specific source of microplastics in the ecosystem and developing a management plan (Aragaw, 2020). Furthermore, since the COVID-19 pandemic, the amount of plastic waste worldwide has been increasing rapidly every day (Aragaw, 2020). Studies have been conducted to identify the source of these pollutants, and in this context, the need for research to identify the current situation of pollutants transported from land to sea has been emphasized (Auta et al., 2017; Fan et al., 2022; Gallitelli and Scalici, 2022).

One of the most commonly encountered plastic litter in marine litter studies is cotton buds (Poeta et al., 2016; Williams et al., 2017; Bruge et al., 2018; Fortibuoni et al., 2021; Cesarini et al., 2022). Similarly, coastal studies have been conducted to detect many plastic products that can be a source of microplastics, including bottles (Poeta et al., 2014), single-use plastics (Schnurr et al., 2018), plastic bags (Sobhani et al., 2020), fishing nets (Montarsolo et al., 2018; Battisti et al., 2019), and other pollutants (Dunlop et al., 2020; Schmid et al., 2021). Recently, many similar studies have described the abundance and spatial distribution of cotton bud sticks in coastal areas and wastewater treatment plants (WWTPs). For example, Mourgkogianni et al. (2018) found that cotton buds were by far the most common plastic waste in WWTPs, followed by plastic caps and pieces of plastic bags. Similarly, Poeta et al. (2016) reported that cotton buds accounted for more than 30% of total beach litter on the Tyrrhenian coast of central Italy. According to both studies, cotton buds were often thrown into domestic sewage and thus entered the coastal environment, as wastewater treatment plants have a low retention capacity. Some non-profit organizations have found that cotton buds are the most common source of pollution during beach clean-ups in the UK and Australia (CleanOcean, 2021; Marine Conservation Society, 2021). Cotton bud is a widespread pollution, but on beaches around the world they are threat to wildlife and the environment (Plastic Soup Foundation, 2018). As cotton buds decompose, they not only contribute to microplastic pollution, but continue to threaten wildlife throughout the food chain by ingesting or releasing toxins (Fidra, 2023). Therefore, it is essential for researchers to prioritize detecting and managing the presence of cotton buds and other similar pollutants, as their impact can be mitigated by actions taken by the public, industry, and government.

This study aimed to present the results of a six-month sampling (July-December 2021) of cotton buds in the Küçükçekmece Lagoon (Istanbul, Turkey), using the monitoring method of beach litter surveys (Wenneker et al., 2010). Furthermore, the study aimed to provide information for public action to reduce plastic consumption, waste, and pollution. Specifically, this study will assessed (I) the current status of cotton bud pollution, (II) the monthly variation in the frequency of cotton buds, (III) the degradation rate of plastics using the carbonyl index (CI), (IV) the potential ecological risks from cotton buds, and (V) provided information to national authorities and policy makers to develop a more robust waste management plan.

Materials and Methods

Study Area

Istanbul has a population of over 16 million people, which will significantly increase due to the daytime working population and tourists (Demir et al., 2021). Studies emphasize that the amount of pollutants is increasing at the same rate as the population density (Barnes et al., 2009). Moreover, the large amount of marine litter, especially plastic, is likely to pose a threat to freshwater, marine, and coastal systems due to the population density in Istanbul (Kopuz et al., 2018; Erkan et al., 2021; Çevik et al., 2021). The Küçükçekmece Lagoon on the southwest coast of Istanbul is a special wetland with an area of 15.22 km^2, a maximum depth of 20 m, and a volume of 145 million m^3, located in the west of Istanbul and connected to the Sea of Marmara by a narrow channel (Sönmez and Sivri, 2022). The water resources of Küçükçekmece Lake includes underground springs as well as the Ispartakule (10,017 m), Nakkaşdere (35,564 m), and Sazlıdere (10,017 m) streams (Gürevin et al., 2017). Although water renewal rates are low during the summer season due to the lack of freshwater inflows, the lagoon has a better chance of recovering in autumn for the aquatic ecosystem and water quality, and its profile becomes relatively homogeneous (Taner et al., 2011).

According to the EU Water Framework Directive specified in the EU Coastal Union (EUCC), the coasts where the Küçükçekmece Lagoon is located have a microtidal level, as the tidal range is less than 2 m. Changes can also occur depending on different meteorological and climatic conditions. In areas with nano-tides, wind is the main driver of water renewal in coastal lagoons (Albay et al., 2005; Sönmez and Sivri, 2022). The predominant wind directions in Küçükçekmece were determined to be north (16.67%), northeast (45%), and southwest (16.77%). The study area is influenced by the effective winds from the southwest, however, differences in the connections of the transitional waters can change this water renewal mechanism. Küçükçekmece Lagoon has only one connection to the sea, and the water exchange originating from this connection is relatively weak. Considering the hydrological-morphometric parameters for the Küçükçekmece Lagoon, it is concluded that it is a weakly connected lagoon with high freshwater influence, and the freshwater content tends to increase with time (Şenduran, 2007). The sampling area is one of the least disturbed parts of Küçükçekmece Lake, and access is prohibited to the public. As the shore is regularly cleaned once a week by the local authorities, the amount of regularly accumulated pollutants can be clearly determined.

Figure 1 shows that the recent migration of the basin has led to an increase in domestic and industrial pollution and a degradation of the natural structure. Pollution from these inadequately treated effluents has been demonstrated by many studies (Sivri, 2014; Çullu et al., 2021; Yilmaz et al., 2021; Sönmez and Sivri, 2022).

Figure 1. Study area with the two different sampling sites.

Sampling points and analysis

Two sampling sites were established since the beach's ability to retain litter might change regardless of the lagoon's current. Few studies have examined plastic litter on rocky beaches, while most studies have examined sandy beaches (Browne et al., 2015). These studies have shown that rocky areas retain a different number and type of plastic compared to sandy beaches (Thiel et al., 2013; Willis et al., 2017; Weideman et al., 2020). They also point out that the profiles of litter on rocky and sandy beaches differ. Since both types of beaches are found in Küçükçekmece Lagoon, it was necessary to include both rocky and sandy shore areas in this study. Therefore, two different sampling stations were investigated depending on the beach type. The "transect sampling" method was used to identify the stations (Martins and Sobral, 2011; Blettler et al., 2017). The outermost corner of the lagoon's coastal area is divided into eight equal zones. More polluted, less polluted, and least polluted areas were selected throughout the sampling area. Within these equal squares, equally selected sampling areas were created. In the more and less polluted areas, transects were selected randomly, taking care that they only covered more than 50% of the coastline. In the selected areas, the areas 1, 2, and 3, which have similar coastal and dune characteristics, were compared. Area 3, marked in red, where cotton buds were most numerous, was the first study area. A similar comparison was made between areas 4, 5, and 6. Of these stations, which had similar rocky features, area 4 was as the second study area. Figure 2 shows that point A is a beach with smaller pebbles, also classified as a pebble beach, while point B is an exact rocky beach.

The monitoring method was chosen based on studies on beach litter (Wenneker et al., 2010). Cotton bud sampling was carried out at two stations at monthly intervals for six months (July to December 2021). In each sampling area, all anthropogenic litter larger than 2 cm on the surface of each transect (2×2 m^2) was classified according to its composition and photographed. Among these mixed structures, only cotton buds were selected as they have the same sampling design and match the pattern of this study. Moreover, working with collection tools (glass cups and metal forceps) was preferred for sampling. All sampled particles were then measured and weighed (Araújo et al., 2018). Litter abundance was calculated as the number of sticks per square meter. For accurate comparison, each cotton bud stick was marked and carefully examined to avoid damage during measurements. After counting and weighing the analyses, the ecological risk of the cotton buds was assessed (Smith and Turrell, 2021).

Moreover, the metal adsorption rates of sediment and cotton buds were investigated according to the protocol of Lippiatt et al. (2013). For this purpose, sediment samples (from 1 to 5 cm depth) were collected once a month for six months using a stainless steel grab. The stainless steel grab was washed with seawater and then with deionised distilled water before the next sampling. The sediment samples were stored in sampling bags and kept at +4 °C until analysis. For analysis, 2 g of the samples were weighed using a precision balance and infused with 1 M 100 mL HNO_3 solution for 1 hour at 50 °C according to USEPA (1996) methods. Based on this process, solid-liquid separation was performed, and analysis of the sample was carried out using ICP-OES (Thermo - X Series II, Istanbul University-Cerrahpasa Central Laboratory).

Chemical structure analyses

The deteriorations of the chemical structures and surface morphology of the sticks were determined by Fourier transform infrared analysis (FT-IR) (JASCO FT/IR-6400) and scanning electron microscopy (SEM) (JEOL JSM -5600, Japan). The FT-IR spectroscopy has been used to calculate the plastic composition and the degree of surface oxidation, and in particular the changes in the carbonyl band (C=O) (Rouillon et al., 2016). This has led to the development of the method now known as the carbonyl index (CI). It is possible to identify the chemical changes that occur during the life of the material and explain the degradation of the mechanical properties by detecting the functional groups in different bands using FT-IR analysis (Almond et al., 2020). Thus, as the CI increases, the stability of the particle decreases. To better highlight the degree of ageing of the litter, the most damaged particles, i.e. 2% of the collected samples, were selected and analysed as in recent studies (Lares et al., 2018; Akarsu et al., 2022).

The adsorption of metals by cotton swabs was also studied using energy dispersive X-ray spectroscopy (EDX). Furthermore, the metal contamination of the lake sediment was monitored during the sampling period (6 months) so that it can be determined how much of the pollutant is adsorbed on the cotton buds.

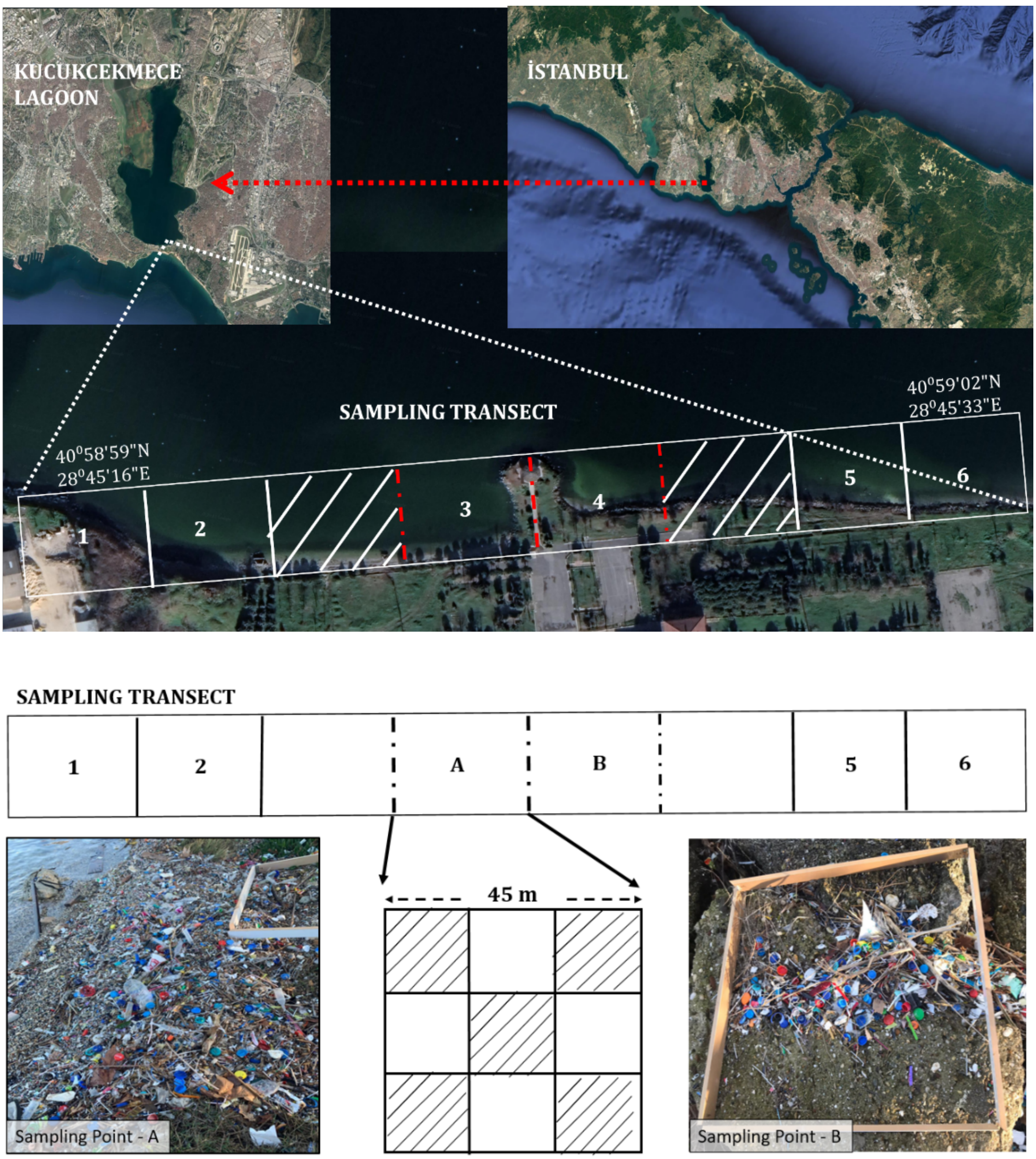

Figure 2. Sampling points **(a)** pebble beach and **(b)** rocky beach at Küçükçekmece Lagoon coastal area.

Indexing Tools

Carbonyl index (CI) is often used to measure the oxidation during the life of polyolefins and to predict their service life and to develop stabilization additives for materials (Focke et al., 2011; Siddiqa et al., 2015).

$$Carbonyl\ index\ (CI) = \frac{A_1}{A_2} \quad (1)$$

where A_1 is the absorbance at 1715–1735 cm^{-1}, carbonyl group; and A_2 is the absorbance at 1471/1460/1452/1495 cm^{-1} — reference peaks of each polymer —, respectively (Rodrigues et al., 2018).

A CI value of 1 or higher indicates that the polymer has undergone significant transformation, with the relative degree of oxidation of the surface from 0 to 0.15 being described as "low", from 0.16 to 0.30 as "medium", and for values above 0.31 as "high".

Håkanson's mathematical approach (Hakanson, 1980), which has been consistently applied in previous studies on heavy metal pollution in sediments and microplastics, has been used to assess the potential ecological risks from cotton buds (Effendi et al., 2016; Xu et al., 2018; Pan et al., 2021). Therefore, the potential ecological risk factor (E_r^i), plastic concentration factor (C_f^i), toxicity response factor (T_r^i), and the percentage of polymer types collected at each sampling site (*Pn*) were estimated using equations (2-5) (Prarat and Hongsawat, 2022).

$$C_f^i = C_s^i / C_b^i \quad (2)$$

$$Pn = C_n / C_i \quad (3)$$

$$T_r^i = P_n x S_n \quad (4)$$

$$E_r^i = T_r^i x C_f^i \quad (5)$$

Where C_s^i is the observed concentration of cotton bud sticks at each sampling site and C_b^i is the background concentration at the study site. However, the minimum value was used as the baseline in this study since no similar study has been conducted in this area before. Similar assumptions have also been made in other studies (Prarat and Hongsawat, 2022). T_r^i is the percentage of each polymer type in the total sample at each sampling site (Pn) multiplied by the hazard classification for the polymers (Sn) as introduced by the Lithner approach (Lithner et al., 2011). The hazard classification for the polymer is based on its classification, which ranges from 1 to 13,844. The highest level of hazard score belongs to polyurethane and the lowest is polypropylene (PP) (Lithner et al., 2011; Yuan et al., 2022).

The categorization based on the Ecological Risk Index (E_r^i) occurs as follows: E_r^i less than 40 indicates a low potential ecological risk (Category I), while E_r^i values between 40 and 80 suggest a moderate potential ecological risk (Category II). On the other hand, E_r^i values ranging from 80 to less than 160 correspond to a considerable potential ecological risk (Category III), E_r^i values between 160 and less than 320 present a high potential ecological risk (Category IV), and an E_r^i value of 320 or higher signifies a very high potential ecological risk (Category V) (Malli et al., 2023). Consequently, Categories I and II can be classified as friendly, while Categories III, IV, and V are categorized as unfriendly regarding potential ecological risk (Li et al., 2021). Notably, this classification is provided in terms of hazard risk.

Statistical Analysis

For many decades, the Bray-Curtis Similarity Index has been used to obtain information and determine where correlations and patterns exist in data (Silva-Cavalcanti et al., 2009; Velez et al., 2019; Mandic et al., 2022). Therefore, the frequency of cotton buds found during the monthly sampling period was analyzed using cluster analysis (Bray-Curtis similarity analysis) to understand whether the occurrence of cotton buds differed significantly between sampling sites. The similarity between the sections in terms of sampling period and stations was estimated with the Bray-Curtis similarity index [log (x + 1)] using the Multi-Variate Statistical Package (MVSP 3.0) software (Shiker, 2012).

Results

Abundance and density of cotton buds

In total, 854 cotton bud sticks with a total weight of 149.41 g were identified and counted at two sampling sites for six months. The highest number of cotton swabs at the two sampling sites A and B were 395 and 153, respectively, while the lowest numbers were 19 and 14, respectively (Table 1). Overall, 61% of the cotton buds were detected at sampling site A, which means that 50% more plastic had accumulated on the gravel beach. The values of the cotton buds are listed separately for each sampling month in Table 1. Notably, the highest amount of litter was in November, while it moved in an orderly fashion between July and October. Using Bray-Curtis similarity analysis, Figure 3 shows the differences between sites A and B. In the similarity analysis, November was different from the other months in a statistically significant manner. Regarding the temporal variation in the amount of litter, the weight and frequency of cotton buds matched. Similarly, Poeta et al. (2016) showed that the high abundance of cotton buds on the Italian coast occurred in autumn and winter. In following years, many studies found a high presence of cotton buds during the rainy season (Williams et al., 2017; Poeta et al., 2022).

When the station-based data were examined using the Bray-Curtis similarity analysis regardless of the month difference, December and November were relatively different from the other months. However, Figure 3 shows that a Bray-Curtis similarity of 0.16 and 0.18 is referred to as a Bray-Curtis similarity percentage of 16 and 18. The similarity of the months in the summer and autumn periods is statistically significant and clustered. November and December, when the meteorological conditions are more distinct, show significant similarity although they are different from the other months.

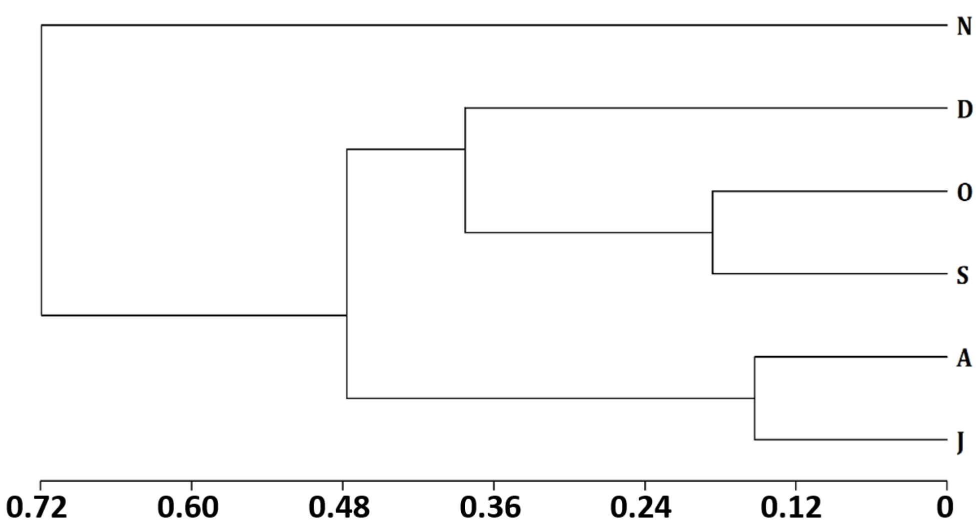

Figure 3. Bray-Curtis similarity analysis for the monthly change in cotton bud sticks respective of the stations.

Table 1. Distribution of cotton bud sticks according to abundance and weight for the sampling period.

	Sampling Time (2021)					
Sampling Point	**July**	**August**	**September**	**October**	**November**	**December**
A	25	37	23	19	395	22
B	18	14	56	38	54	153
Total Litter	43	51	79	57	449	175
Average Weight (g)	0.17495					
Total Weight (g)	7.53	8.92	13.82	9.97	78.55	30.62

Chemical and physical structure analyses

The results show that 22.2% of the samples had a low degree of oxidation, while 33.3% and 44.5% had medium and high degrees of oxidation, respectively. The lowest CI value was 0.122, the highest value was 0.403, and the mean value was 0.246 (Figure 4). Previous studies in the literature show that the average polymer carbonyl index value is about 0.348 (Akarsu et al., 2021), and the highest CI value found in these studies is about 1.8 (Akarsu et al., 2022).

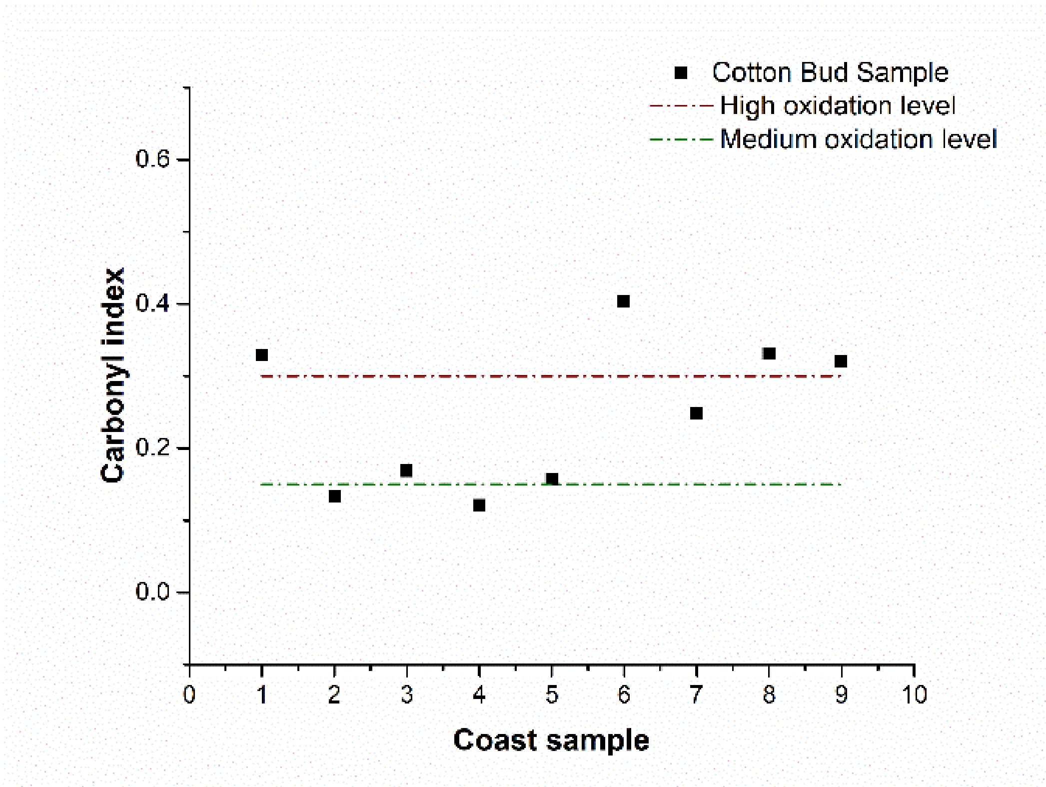

Figure 4. Oxidation levels (carbonyl index – CI) of sampled cotton bud.

Interaction between cotton buds and metal elements in the aquatic environment

Previous studies have showed that metals can deposit on plastic waste by the influence of biofilms (Liu et al., 2021). The formation and development of biofilms on plastic waste can vary depending on the waste's morphology, physical, and chemical properties, thus increasing its adsorption capacity for pollutants (Rummel et al., 2017).

Figure 5a presents a SEM image of non-used cotton buds, highlighting their smooth and intact surface morphology. However, Figure 5b shows fouling organisms, including biofilm formation, on the cotton bud's surface, which can act as a vector for the spread and transport of aquatic organisms in the marine environment.

Furthermore, The EDX spectrum of the cotton bud sticks in Figure 5c shows the relative intensity or concentration of elements detected by EDX analysis, including a significant amount of aluminium (Al) and iron (Fe), along with other anions and cations. The concentrations of Fe and Al were 3300 and 300 mg.kg^{-1}, respectively, which is much higher than the values reported by Vedolin et al. (2018), Dobaradaran et al. (2018), and Foshtomi et al. (2019). Our findings show that cotton buds can accumulate metals despite exposure levels being lower than those reported in many studies.

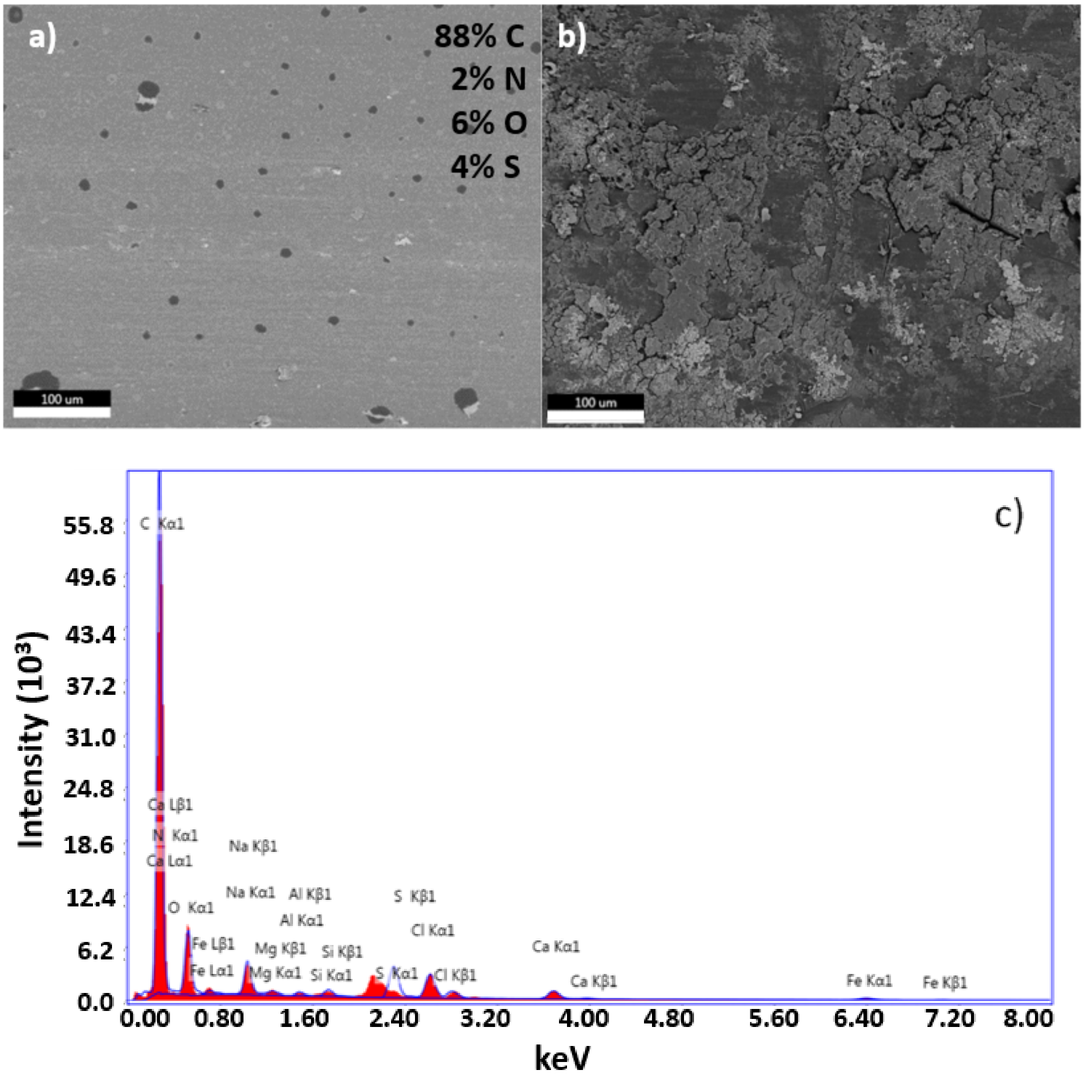

Figure 5. SEM image of **a)** non-used cotton bud stick, **b)** used cotton bud stick, **c)** EDX analysis of used cotton bud stick sample. The EDX analysis shows the elemental composition of the sample, with the intensity of the peaks indicating the relative abundance of each element present, where keV refers to kilo electron volts, which is a unit of energy commonly used to describe the energy of X-rays.

Furthermore, the metal concentration in the sediment of the lagoon was measured, finding that the metal concentrations in the sediment were significantly lower than the Fe and Al enrichment in the cotton buds. As with the cotton bud sticks, although Fe and Al were the metals detected in the highest amounts, other types of metals such as nickel (Ni), lead (Pb), chromium (Cr), copper (Cu), and zinc (Zn) were also found in the sediment. The average concentration of Fe, Al, Ni, Pb, Cr, Cu, and Zn were 17.77 mg kg^{-1}, 11.51 mg kg^{-1}, 1.53 mg kg^{-1}, 0.99 mg kg^{-1}, 0.71 mg kg^{-1}, 0.25 mg kg^{-1}, and 0.23 mg kg^{-1} respectively (Table 2). Corroborating findings, studies on this topic have shown that Fe and Al have a more stable structure and their retention capacity is greater than that of other anions such as Cu, Zn, and Ni (Tarlan and Ahmetli, 2007; Dinu, 2015). Considering the previous studies in the sediments of Küçükçekmece Lagoon (Algan et al., 2004; Balkis et al., 2007), the concentration of heavy metals has significantly decreased compared to 15 years ago. In this context, Table 2 shows the concentrations of heavy metals in the current study are lower than those reported in the previous studies.

Table 2. The concentration of metal (mgkg^{-1}) in the sediments of Küçükçekmece Lagoon.

	Fe	Al	Pb	Zn	Cu	Cr	Ni
July	19.67	12.77	1.44	0.92	0.67	0.24	0.19
August	17.93	10.43	1.47	1.11	0.61	0.27	0.22
September	15.39	13.17	1.63	0.98	0.74	0.31	0.26
October	15.48	12.86	1.60	0.97	0.71	0.30	0.21
November	16.02	9.78	1.57	1.00	0.69	0.21	0.26
December	22.14	10.07	1.46	0.97	0.85	0.17	0.21
Average (2021)	17.77	11.51	1.53	0.99	0.71	0.25	0.23
Algan et al., 2004	-	-	30.00	104.00	20.00	63.00	15.00
Balkis et al., 2007	-	-	17.20	40.80	27.80	57.90	31.60

Risk assessment and management strategies of cotton bud stick pollution

Although polymers have some toxicity on their own, this varies depending on their chemical constituents (Xu et al., 2018). Polypropylene has the lowest risk value among polymers. Therefore, it is extremely important to show its abundance in determining the risk factor. In total, 854 cotton bud sticks were found at the sampling stations, with an average value of 71.16 litter m^{-2} per month. Cotton buds are usually made of polypropylene, which was confirmed by using a Fourier Transform Infrared Spectrometer (FTIR) model JASCO 6400.

Both study areas in November and December had a hazard level of IV. Furthermore, only one area, the sampling site B in August, was slightly polluted (II), which vary from month to month. Even if the sampling sites are considered individually, the results of the overall assessment indicate a significant risk. Compared to July-October, the results for November and December showed a higher amount of plastics and thus higher risk factors. Since the types of polymers collected in the study areas vary, the extent of polymer toxicity also varies. Therefore, the pollution level cannot define the actual plastic pollution. However, the pollution level can help to determine the toxicity caused by plastics in the environment, which can be a reference when determining ecological risks.

Table 3. Potential risk assessment of polypropylene cotton bud stick in sediments of Küçükçekmece Lagoon.

Sampling		E_r	Hazard Level	Risk Estimation
Site	**Time**			
A	July	178.571	III	UF
	August	264.286	III	UF
	September	164.286	III	UF
	October	135.714	III	UF
	November	2,821.429	IV	UF
	December	157.143	III	UF
B	July	128.571	III	UF
	August	100.000	II	F
	September	400.000	III	UF
	October	271.429	III	UF
	November	385.714	III	UF
	December	1,092.857	IV	UF
A+B	July	307.143	III	UF
	August	364.286	III	UF
	September	564.286	III	UF
	October	407.143	III	UF
	November	3,207.143	IV	UF
	December	1,250.000	IV	UF

UF: Unfriendly, F: Friendly.

Discussion

Current state of cotton bud pollution in coastal areas

Most studies have focused on general plastic litter and have reported on a wide range of categories, usually 12 or more. For instance, in a study by Asensio-Montesinos et al. (2019) on beach litter in Alicante province (SE Spain) during spring and summer, an average of 0.062 litter m^{-2} was recorded in spring and 0.116 litter m^{-2} in summer, across 33 different categories of litter. However, the number of plastic litter items detected per unit area was relatively low compared to our study. Other studies, such as those conducted by Scisciolo et al. (2016), Asensio-Montesinos et al. (2019), and Marin et al. (2019) on the beaches of the Caribbean coast (0.91 ± 0.50 litter m^{-2}), Alicante coast of Spain (0.12 litter m^{-2}), and the Silveria coast of Brazil (2.0 litter m^{-2}), respectively, reported significantly lower numbers of plastic litter items than what we found in our study. However, Poeta et al. (2016) found a significantly higher number of plastic litter items ranging from 14.9 to 41.7 per square meter.

Notably, recent studies have aimed to provide more precise information on the abundance of cotton buds on beaches. For example, Poeta et al. (2022) reported a higher proportion of cotton buds, accounting for 42.3% of the 52,824 beach litter items, compared to the numbers found in our study. Similarly, higher values for the frequency of cotton buds have been observed in previous studies conducted on Mediterranean coasts (Fortibuoni et al., 2021; Cesarini et al., 2022).

The CI value has a direct relationship with the pollution level of plastic litter, with higher CI values indicating a greater risk of harm to the environment and organisms that come across the litter. Our findings show that nearly half of the particles exhibited a high degree of oxidation (CI > 0.31). Prata et al. (2020) also investigated the calculation of CI for plastic litter and found that it varied between 0.055 and 0.435, with an average value of 0.2657 for polypropylene particles. This result is consistent with the findings of Akarsu et al. (2020), who studied the determination of the carbonyl index of disposed facemasks and found that the average CI value was 0.253. Studies reported that PP was more oxidized than the PE particles. This is most likely due to the lower resistance of the PP particles to UV radiation and gradual ageing (Rodrigues et al., 2018). In most cases, particle color, shape, and polymer type were the main factors affecting the carbonyl index value of the polymers (Prata et al., 2020). However, in this case, we determined the carbonyl index for the same type, color, and shape of litter. Therefore, CI values above 0.3 present higher exposure of the particles to solar radiation and oxygen concentrations and the possibility of further degradation.

Many factors can influence the pollution level of plastic litter in aquatic environments, such as the presence of other contaminants. Studies have shown that plastic litter can act as a carrier for other pollutants, such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), and persistent organic pollutants (POPs). The interaction between metals and plastic waste has not been studied until recently, thus polymers were assumed to be inert to aqueous metal ions (Vedolin et al., 2018). However, recent studies report that the presence of adsorbed metals in plastic waste (Ashton et al., 2010; Holmes et al., 2014) is due to weathering and/or degradation in the aquatic environment (Liu et al., 2022). For example, unused polyvinyl chloride (PVC) and polypropylene (PP) have been spilled along the Chinese coast and plastics have been shown to accumulate higher concentrations of heavy metals such as chromium (Cr), cadmium (Cd), copper (Cu), lead (Pb), and manganese (Mn) (Gao et al., 2019). Similarly, Santos-Echeandía et al. (2020) showed that the sorption behavior of heavy metals on MPs is related to the physical and chemical properties of MPs. Sources of metal pollution commonly found in aquatic environments include wastewater discharges, e-waste, antifouling paints, and smelting (Deheyn and Latz, 2006; Li et al., 2015; Huang et al., 2019).

The chemical toxicity of plastic can vary depending on the type of polymer used in its production. Different polymers have different chemical structures, which can affect their physical and chemical properties, including their toxicity potential. Thus, based on frequency abundance and polymer structure of cotton bud sticks as indicators, we performed a chemical toxicity risk assessment. We determined a hazard level of IV for both sampling sites. Even when considering the individual sampling sites, the results of the overall assessment presented a significant risk that varies from month to month. Therefore, the pollution level alone is unable to accurately define the actual plastic pollution. However, it can be used as a reference value to determine the toxicity caused by plastics in the environment and to assess ecological risks.

Considerations, strategies, and innovations in cotton buds' management

Cotton buds are disposable plastic products with the highest consumption time among ear hygiene products. Moreover, they harm the national economy, human health, and natural ecosystems with their waste (Fazey and Ryan, 2016; Poeta et al., 2016, 2022; Cesarini et al., 2022). These products are a problem for human health and the environment, and many studies have shown that their use can be undesirable (Hickman, 2011; Shakeel et al., 2015). Unfortunately, these products are still commonly used for personal care. Cotton buds become plastic waste after a very short period of use (1-2 minutes) and accelerate their main threat to the natural ecosystem after this stage. They can leave a lot of effective and permanent damage and cause the death of many organisms. Due to increasing misuse, the problems due to cotton buds contribute to the issue of plastic pollution, which is already a major challenge to governments, and their quite serious impact on the environment is quickly being felt (Werner et al., 2016; Poeta et al., 2022).

Poor management of plastic waste is one of the main reasons why plastic has become a major environmental problem. The rising tide of waste is a political problem for governments. Moreover, governments are importing their waste, which is mostly plastic. According to recent reports, most European countries have chosen Turkey as the main destination for their waste (TG, 2021). Unfortunately, however, most of this waste is landfilled, incinerated, or left in bags, thus the recycling rate in Turkey is low. To support this finding, the rate of inadequately managed waste in Mediterranean countries has been estimated to be 48.8% on average (Jambeck et al., 2015; Veiga et al., 2016). Such large responsibility is not acceptable for Turkey, which is already trying to tackle plastic waste.

The existence of a sustainable environment must be considered in the context of the socio-economic and educational background of the local community. Moreover, environmental education, waste management, and legislative and policy reforms are the three key components of the globally established framework to change littering behaviour. Therefore, only local governments and environment ministries should take responsibility for the management of cotton buds. Despite bans, ministries of health and education can be collaborated with and awareness raising studies can be conducted. With these awareness studies, the unnecessary use of cotton buds and the destruction of nature can be better explained to people. Due to conscious consumers, the process can be better managed.

As studies in the literature show, environmental education and awareness raising should be introduced in schools as a strategy to reduce wasteful behaviour in the population (Eastman et al., 2013). Mourgkogianni et al. (2018) conducted a study in Greece that supports this finding. This study was a comprehensive survey of managers of 101 WWTPs, representing 33% of the WWTPs in Greece. The results showed that urban residents had a better behaviour and mentality towards the environment than suburban residents. This occurred since urban residents are better informed about the functioning of WWTPs. Rayon-Viña et al. (2018) also reported that social and demographic factors influence public attitudes, resulting in younger and more frequent beachgoers being significantly more conscious of marine litter. Therefore, social factors such as public acceptance of control measures and public awareness of appropriate litter management should also be considered (Bremner and Park, 2007; Rayon-Viña et al., 2022). Battisti and Gippoliti (2019) suggest that the achievement of multiple goals by citizens is possible, along with social relationships and the proper allocation of roles and responsibilities, which are the strategic factors that encourage an unaware public to develop environmentally friendly behaviors.

Many studies have been conducted on the surveying and management of waste in coastal dunes. Andriolo et al. (2021), for example, recommend to analyze the geographical distribution of litter and measure the size of items with UAS imagery, as well as to control a large area and different dune sectors. Furthermore, Gallitelli et al. (2021) investigated this using Carpobrotus spp. as a litter trap for various anthropogenic materials in coastal dune systems. The authors suggest that plant management measures could potentially help to solve the beach litter problem.

To ensure that all units work together to solve this problem, creative problem-solving exercises should be conducted as soon as possible, aimed at developing the ability to see and focus on the real problem. Awareness of cotton bud complications is an essential public health issue. The environmental quality and cleanliness of these beaches on the Istanbul coast can only be achieved if the management solutions that we highlighted are implemented (Figure 6). Coordinated action with national and local governments will provide the greatest possible protection for coastal areas and seas.

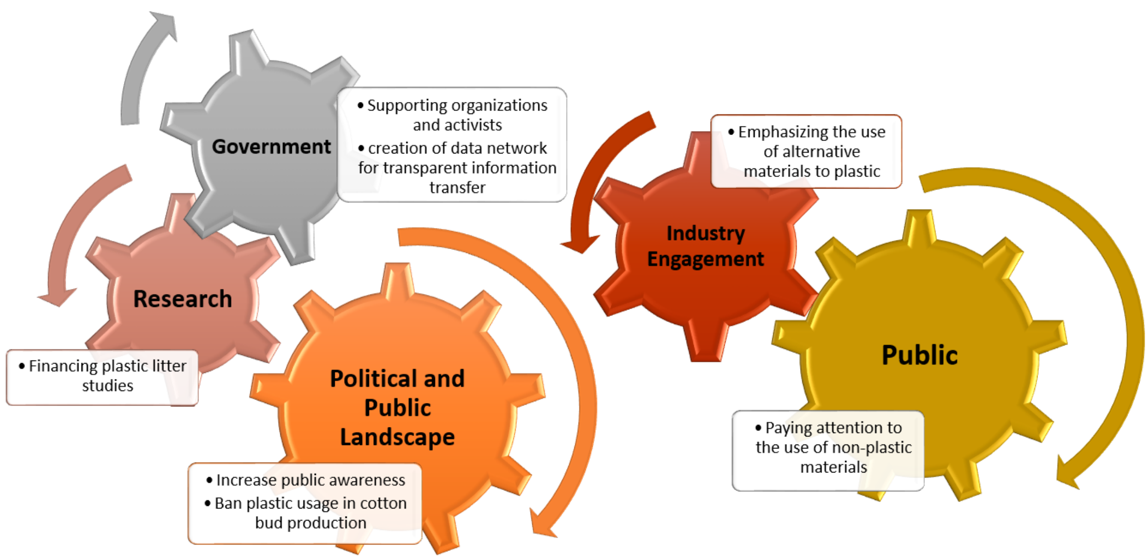

Figure 6. A schema for changing public perception of complementary elements of social behaviour.

Conclusions

As far as we know, our study is the first to track the accumulation of cotton bud sticks on the coast over a six-month period. According to our evaluations, Küçükçekmece Lagoon has a high level of cotton buds pollution, which increases towards winter (hazard level IV). Since the study area is completely closed to humans, as well as meteorological factors, the waste is transported into the lake via the streams (Ispartakule, Nakkaşdere and Sazlıdere) and accumulates on the beach. Recent studies have also confirmed that winds and rivers are the main contributors to the transfer of waste from terrestrial sources to the sea (Fortibuoni et al., 2021; González-Fernández et al., 2021).

Many cotton bud sticks (854 cotton bud sticks) came from the structural feature of the lagoon coast, which offered little resistance to anthropogenic forces. Depending on consumer behavior, cotton buds thrown down the toilet for disposal are transported via the sewage system to wastewater treatment plants. On the other hand, wastewater treatment plants are not sufficiently efficient in removing cotton buds. Thus, developing strategies to prevent cotton buds from entering water bodies is essential.

The analysis of the carbonyl index showed that almost half of the samples from Küçükçekmece Lagoon were significantly oxidized. Thus, the samples have spent a considerable time in the environment and have decomposed, which could lead to the adsorption of certain pollutants or the formation of microplastics. The EDX results present the formation of biofilms and the accumulation of Fe and Al on the litter.

The assessment of the potential risk of cotton buds has shown that the hazard level and the amount of plastic are two important indicators of the level of pollution. To reduce pollution from cotton buds, new laws and regulations should be enacted for the use of an alternative material that can be used instead of polypropylene. Turkey has considerable potential to cooperate with the European Union's environmental policy. Although the cotton swab is not yet widespread throughout the country, the government should take measures to minimize its use. However, despite conducting a significant number of transects and plots, our findings would benefit from additional data to better understand the path of litter and develop effective mitigation strategies. This could be achieved by increasing the number of transects and plots, which would yield a more comprehensive and robust result.

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