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Characterisation of wastes collected from beaches, coastlines, marine surface cleaning processes and ships: A case study of Istanbul

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Abstract

Marine waste management is crucial for Istanbul because of the significant location for intercontinental transition, international trade, tourism, industry and shipping. This study is the first one realised in Turkey for the detailed characterisation of marine waste. The amount and characteristics of solid wastes originating from beaches, coastlines, sea surface cleaning processes and ships (both cargo and cruise ships) were determined. It was observed that marine wastes includes a significant amount of recyclable materials. Although, it was ascertained that the amount and composition of waste differs according to the collecting sources, the majority of wastes are composed of different types of plastics. The average calorific value of marine waste was determined as 2500 kcal kg^{-1}, which is higher than that of mixed municipal solid waste. There is a lack of studies on the pathways of disposal alternatives of marine waste after collection. As landfilling is the common pathway for disposal after collecting, it is clear that recycle/reuse and energy recovery options are possible for marine waste.

Keywords

Marine waste, recyclables, plastics, combustible waste, calorific value

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Introduction

Solid wastes are defined as the waste materials originated from domestic, industrial and commercial processes. These wastes are generally managed by using a sophisticated strategy involving source separation, recycling, reutilisation and final disposal (US EPA, 2008). Implementation of waste management strategy for municipal solid wastes is being performed widely. The European Commission published the Marine Strategy Framework Directive (Directive 2008/56/EC) to protect European seas. However, as a European Union (EU) candidate country, Turkey has not been yet published a local directive or regulation for the harmonisation of marine waste control and disposal. The only regulation about the control of marine waste is the Regulation on Waste Collection from Ships and Control of Waste in Turkey. However, this regulation covers only ship-based solid wastes. Thus, there is no management strategy for the wastes collected from the marine environment, such as beaches, coastlines and marine surface cleaning activities, performed at inland seas in Turkey.

Marine litter can be defined as solid waste that has been discarded or reaches the sea as a result of human activities (Rayon-Viña et al., 2018). These activities have various origins, such as tourism, transport, recreational, sewage and shipping (Dias and Lovejoy, 2012; Somerville et al., 2003). Wastes collected from the marine environment are considered a growing threat for seas and coastlines in the last decade. The majority of these wastes are composed of slowly decomposing plastics (Derraik, 2002; Ryan et al., 2009; Topçu et al., 2013). The high amount and light weight of the plastics allows them to be easily transported via wind, wastewater and rivers by inadequate disposal or littering (Li et al., 2016). Consequently, accumulation of waste materials in sea and coastlines causes an increasing marine and coastal pollution problem (United Nations Environment Programme [UNEP], 2015).

Marine wastes are not generated or treated as constant wastes. Instead, they are wastes from unknown sources, thrown,

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Table 1. Sampling points used in this study.

1. Beaches	a. Karaburun (European side)
	b. Silivri (European side)
	c. Sile (Asian side)
	d. Caddebostan (Asian side)
2. Sea Surface	a. Eminonu (European side)
	b. Istinye-Tarabya (European side)
	c. Kadıkoy (Asian side)
	d. Kuleli (Asian side)
3. Coastline	a. Yenikapi-Zeytinburnu (European side)
	b. Bebek (European side)
	c. Tuzla (Asian side)
	d. Harem-Uskudar (Asian side)
4. Ships	a. Cargo ships
	b. Cruise ships

abandoned or disposed to coasts and seas. Marine litter generated as a result of sea-based activities involve the disposals of fisher, passenger, trade, military, research and pleasure ships, oil-gas infrastructure and fish farms (UNEP, 2015).

Marine waste causes serious socio-economical implications, such as damage to local biota and visual, aesthetic and economic damage to tourism income and other local users (Munari et al., 2016). Also, marine waste adversely affects coastal tourism that has considerable economic values worldwide (Ghermandi and Nunes, 2013; KIMO, 2010). Thus, there is a strong correlation between the density of beach use and marine waste production (Santos et al., 2005). Waste amount and composition are affected by urbanisation and changes during the summer owing to density of beach use (Ariza et al., 2008).

The literature on marine waste characterisation shows that plastics are the dominant waste group of marine waste (Bouwman et al., 2016; Hengstmann et al., 2017; Kordella et al., 2013; Munari et al., 2016; Pasquini et al., 2016; Pasternak et al., 2016; Rees and Pond, 1996). Pasquini et al. (2016) reported that in the marine waste from 67 stations in the Northern and Central Adriatic Seas plastics were found in the amount of 80% by numbers and 62% by weight. The fundamental reason of the predominance of plastics is their overuse and incapability of biodegradation (Derraik, 2002; Ryan et al., 2009; Topçu et al., 2013). Additionally, the high percentage of plastics can be caused by the decomposition of the other marine waste constituents (paper, cardboard, wood, food waste) in the marine environment and sinking of metal and glass.

There is a very intense traffic in Canakkale Strait and the Bosphorus, which is the only alternative of maritime transportation between the Mediterranean and the Black Sea. Especially, the Bosphorus is a very heavy marine transportation zone owing to its critical location for intercontinental transition and international commerce. Thus, the maritime pollution is very important for Istanbul because of its critical location to the transit access point in tourism, trade, industry and international shipping.

Literature studies about the characterisation of marine waste are drastically increased in the last decade. However, the quantity of the wastes is less documented and these studies are generally relevant to small regions. Also, most of the reported data based on different sampling approaches and devices prevents the proper comparison of the studies (Alvito et al., 2018). Thus, the knowledge about the marine waste amount and characteristics is limited, and determination of the approximate waste amount and its characteristics aid the developing of proper strategies for marine waste management (Claereboudt, 2004; Santos et al., 2005). Several studies about wastes from seas surrounding Turkey (Black Sea, Aegean Sea and Mediterranean Sea) was realised by a few research groups in recent years (Aydın et al., 2016; Balas et al., 2003; Topçu and Öztürk, 2010; Topçu et al., 2013; Tudor et al., 2002).

This study aims to determine the characterisation of solid wastes originating from beaches, coastlines, sea surface cleaning processes and cargo and cruise ships in Istanbul. Several analysis, such as the waste characterisation, moisture content, volatile solids content and calorific values, were realised in order to determine the physical properties of solid wastes collected from sea-based activities. Additionally, the volume and the amount of collected wastes were determined.

Material and methods

Waste sources and sampling

In this study, 14 different points located on both Asian and European sides of Istanbul, which is the most populated city of Turkey, were selected for the characterisation of solid wastes arising from beaches, coastlines, sea surface cleaning processes and ships in Istanbul. Sampling points and their locations are shown on Table 1 and Figure 1. The selected locations are the most used and visited locations by both local people and tourism attractions. Thus, it is believed that these locations are representative to all other identical marine waste sources.

Waste collection and cleaning operations of beaches (4 million m^2), coastlines (around 515 km, including coasts, piers and walking lines) and sea surface (around 5 million m^2) is being done by Istac Inc., which is an establishment of Istanbul Metropolitan Municipality. The cleaning operation is being organised according to the seasonal variations on the waste amount, for example three times a week in summer season and once a week in winter. Some images of the cleaning process and cleaning vehicles are shown in Figure 2.

According to the Turkish Regulations on waste collection and disposal from ships, port waste reception facilities should collect the household wastes (also bilge water) in accordance with request from ships. Two types of ships (cargo and cruise) were selected and solid waste samples were collected from these ships according to their waste disposal requests.

This study was conducted in the summer season and solid waste samples were collected in July, which is the most intense period of the summer season. Approximately 2 m^3 of solid waste samples were collected for analyses from each source shown in Table 1. Waste samples were collected randomly during the waste collection operations directly from the field. Waste samples were collected on

Figure 1. Sampling points in Asian and European sides of Istanbul.

Figure 2. Waste collection and cleaning operations (a: Coastline cleaning, b: sea surface cleaning, c and d: beach cleaning).

Monday (representing weekend because it is the first waste collection operation after weekend) and Thursday (representing weekdays) and immediately transferred to the analyses area.

Analyses

Waste samples were collected from the selected locations three times during the study. Waste characterisation analyses were realised in accordance with the Turkish Standards (Turkish Standards Institution (1996) Solid Wastes, ICS 13.030). The wet weight of each sub-group given in Table 2 in total waste mass was weighted in a portion of the 1 m^3 sample after homogenisation via mixing, and the percentage of each group in total mass was calculated.

After the waste characterisation, moisture content, volatile solid content and the calorific values of samples were determined in accordance with the standard methods. Moisture and volatile solid contents were determined according to Turkish Standard Methods (TS 10459/1992), and the calorific values were determined according to DIN 51900 standard by bomb calorimeter (LECO AC500, USA).

Results and discussions

Characterisation of waste collected from beaches

The results of waste characterisation analyses realised on the samples from Karaburun (1.a) and Silivri (1.b) beaches from the European side and Şile (1.c) and Caddebostan (1.d) beaches from the Asian side are given in Table 3.

Table 2. Waste characterisation components.

Materials	*Instructions*
Biodegradable waste	Food waste, vegetables, fruit, yard wastes
Plastic bags	Any kind of plastic bag, pochette
Paper–cardboard	Any kind of paper – corrugated cardboard
Composite	Milk box, fruit juice box
Plastics	Any kind of plastic derivative waste except plastic bottles
Bottles	Water bottle, soft drink bottles
Glass	Any kind of glass
Metals	Any kind of metal
Electrical–electronic waste	Telephone, radio, etc.
Hazardous waste	Battery, paint box, detergent box, medicine boxes, medical waste
Diaper	Diaper, hygienic ped
Textile	All types of textile materials
Other combustible	Shoe, carpet, bag, belt, foam, food packaging, board
Other non-combustible	Stone, dust, sand, ceramic, ash

The average biodegradable waste (food waste, yard waste, etc.) amount of solid waste samples from Karaburun, Silivri, Şile and Caddebostan beaches are 32.1%, 41.4%, 32.8% and 68.9%, respectively. Similarly, the rate of the total recyclable materials (glass, metal, plastic bags, bottles and plastics, paper and cardboard, composite materials) is 38.1%, 35.8%, 30.9% and 16.8%, respectively. The rate of the total combustible wastes (food waste, yard waste, paper and cardboard, plastics, textile, diaper and other combustibles) from Karaburun, Silivri, Şile and Caddebostan beaches are calculated as 77.5%, 86.7%, 82.7% and 82.2%, respectively.

According to the waste characterisation study results from four beaches that were selected to represent beaches of Istanbul city, the average amounts of biodegradable, recyclable and combustible wastes can be calculated as 43.8%, 30.4% and 82.3%, respectively.

The available data about the waste amount collected from the beaches are recorded as the amount of collected plastic bags for Istanbul. Therefore, the mass and volume calculations of the collected wastes are also included in this study. The densities of the wastes from 1.a, 1.b, 1.c and 1.d regions were calculated as 155, 185.2, 156 and 190.2 kg m^{-3}, respectively, with an average of 172 kg m^{-3}. According to these results, the average amount of waste collected from Karaburun, Silivri, Şile and Caddebostan beaches daily are calculated to be 718 kg (4.6 m^3), 1760 kg (9.5 m^3), 1134 kg (7.3 m^3) and 432 kg (3.2 m^3), respectively. According to the data about the waste amounts collected throughout 12 months from the beaches of Istanbul for the last 3 years, the average amount of collected wastes from beaches can be calculated as 8900 kg day^{-1} (52 m^3 day^{-1}). It was revealed with respect to these outcomes that approximately 3900 kg day^{-1} biodegradable waste, 2700 kg day^{-1} recyclable waste and 7300 kg day^{-1} combustible waste are being collected from the beaches of Istanbul city.

According to the results of the analysis performed on four different beaches, it was found that the biodegradable waste amount was higher in Silivri and Caddebostan, while plastic bags, paper–cardboard, metal and glass were higher in Karaburun and Sile. Silivri and Caddebostan regions are of high socio-economic level. Thus the amount of biodegradable waste was expected to be higher. Sile and Karaburun beaches are the most popular beaches in the city. Therefore, the amount of recyclable materials are higher in these sites owing to the high amount of visitors, especially at weekends in summer season.

Table 3. Characteristics and physical properties of waste samples collected from beaches (%).

	1.a (Karaburun)	1.b (Silivri)	1.c (Sile)	1.d (Caddebostan)	Average (%)
Waste group					
Biodegradable waste	32.1	41.4	32.8	68.9	43.8
Plastic bags	10.5	9.7	8.5	4.6	8.3
Paper–cardboard	7.5	6.9	4.0	2.5	5.2
Composite	0.6	0.7	0.8	0.2	0.5
Plastics	4.4	2.1	2.0	0.3	2.2
Bottles	4.8	7.1	5.4	1.9	4.8
Glass	7.4	7.7	8.5	6.3	7.5
Metals	3. 1	1.6	1.7	1.2	1.9
Electrical–electronic waste	0.0	0.0	0.4	0.0	0.1
Hazardous waste	0.3	0.0	0.4	0.2	0.2
Diaper	2.2	1.5	0.8	0.5	1.3
Textile	2.8	6.7	7.6	0.8	4.5
Other combustible	12.8	10.5	20.8	2.5	11.7
Other non-combustible	11.7	4.0	6.3	10.2	8.0
Physical properties					
Moisture content, %	27.6	43.0	35.7	31.0	34.3
Volatile solids, %	64.0	77.0	77.3	28.3	61.7
High calorific value (kcal kg^{-1})	2932.0	3570.0	3603.0	1135.3	2810.3
Low calorific value (kcal kg^{-1})	1795.3	1787.7	2068.3	895.0	1704.0

Table 4. Characteristics and physical properties of waste samples collected from surface cleaning operations (%).

	2.a (Eminonu)	2.b (Istinye)	2.c (Kadikoy)	2.d (Kuleli)	Average (%)
Waste group					
Biodegradable waste	36.2	36.1	53.0	41.1	41.6
Plastic bags	11.7	9.9	8.2	7.2	9.2
Paper–cardboard	5.7	0.4	3.9	6.3	4.1
Composite	0.7	0.2	0.5	1.2	0.6
Plastics	4.2	9.9	4.7	7.1	6.5
Bottles	6.4	3.3	5.6	5.7	5.2
Glass	3.2	3.1	4.5	5.1	4.0
Metals	0.9	0.6	1.5	2.3	1.3
Electrical–electronic waste	0.1	0.0	0.2	0.3	0.2
Hazardous waste	0.2	0.7	0.4	0.3	0.4
Diaper	0.3	0.0	0.0	0.8	0.3
Textile	4.9	1.3	0.9	3.2	2.6
Other combustible	24.3	31.4	16.7	19.1	22.9
Other non-combustible	1.4	3.1	0.2	0.3	1.2
Physical properties					
Moisture content, %	55.0	42.7	49.3	45.0	48.0
Volatile solids, %	82.7	75.7	71.7	81.0	77.8
High calorific value (kcal kg^{-1})	4109.7	4468.7	3762.7	4308.0	4162.3
Low calorific value (kcal kg^{-1})	1540.7	2309.7	1547.0	2054.3	1862.9

After the characterisation studies, moisture content, volatile solids and calorific value analyses were performed on the waste samples from beaches. The results of these analyses are given in Table 3. The average moisture content of the wastes collected from the beaches was 34.3% and the average low and high calorific values were determined as 1704 and 2810.3 kcal kg^{-1}, respectively. The calorific value of the wastes collected from the beaches is nearly equivalent to the mixed municipal solid wastes in terms of calorific value (Saltabaş et al., 2009). Rayon-Viña et al. (2018) reported the plastics as the most abundant items (64%) collected from beaches, including polystyrene and hard plastic fragments, caps/lids, bags and swab sticks. Vlachogianni et al. (2018) also reported that the waste composition of beaches of the Adriatic and Ionian Seas consist of 74%–92% plastics, 3.2% glass/ceramics, 1.5% metals, 1.4% paper and 1.1% textile. Hengstmann et al. (2017) indicated the plastics as the predominant waste group on average as 83%. The high amount of plastics in beaches is caused by the use of plastic in almost all human activities and its long persistence in the environment (Derraik, 2002). Plastic usage should be limited by policies in order to minimise their amount in marine waste. Also, cigarette butts, which are a good indicator of pollution from beach users, are reported as the second most frequently recorded marine waste type (Laglbauer et al., 2014; Lopes da Silva et al., 2015; Santos et al., 2005) when the characterisation is made by the number of waste groups.

Characterisation of waste collected from sea surface cleaning operations

Sea surface wastes can be transported long distances by currents and so they contaminate remote areas from the source. For this reason, sea surface wastes like plastics are considered as a global pollutant (Santos et al., 2005; Waldichuk, 1989), and these plastics act as a layer on the sea surface (Barnes, 2002).

Eminönü (2.a) and Istinye (2.b) on the European side and Kadıköy (2.c) and Kuleli (2.d) regions on the Asian side around Istanbul were selected for the characterisation of solid wastes that collected as a consequence of cleaning operations realised by sea surface cleaning boats. Waste characterisation analyses were realised on the solid wastes collected from each region on three various days and the average results are given in Table 4.

Biodegradable wastes consist of the largest group of wastes collected from sea surface cleaning operations in the Eminönü (2.a) region with a rate of 36.2%. Of the wastes from this region, 32.7% were composed of recyclable wastes and 24.3% of the wastes were classified as other combustible wastes. The total combustible waste amount was calculated as 94.3%.

Biodegradable wastes consist 36.1% of the waste collected from sea surface cleaning operations in Istinye (2.b) region. The amount of other combustible wastes was 31.4%, and the total combustible waste amount was calculated as 92.7% in this region. Total amount of recyclable waste in the waste mass was 27.4% and majority of them were composed of plastic bottles and plastic bags or pochettes.

The amount of biodegradable and other combustible wastes were determined as 53.0% and 16.7%, respectively, in Kadıköy region. Total combustible waste amount was calculated as 93.3%, while the total recyclable waste amount was found out as 28.7% in this region. In Kuleli (2.d) region, the amount of biodegradable wastes, combustible wastes, total combustible wastes and total recyclable wastes were determined as 41.1%, 19.1%, 91.7% and 34.8%, respectively. Additionally, the densities of the wastes coming from Eminönü, İstinye, Kadıköy and Kuleli regions were determined as 155.2%, 156.2%, 118.2% and 83.6 kg m^{-3} and the

average waste density of the wastes from sea surface cleaning operations was calculated as 128.3 kg m^{-3}.

Of wastes being collected per month, 28.4, 46.5, 17.2 and 29.6 m^3 were from the sea surfaces of Eminönü, İstinye, Kadıköy and Kuleli regions, respectively. According to these results, it was revealed that averagely 42,700 kg per month and 1420 kg per day wastes are collected owing to the sea surface cleaning services. Among those wastes, an amount of 590 kg day^{-1} of biodegradable waste and 440 kg day^{-1} of recyclable waste were being collected from the sea surface. The total combustible waste amount in the waste mass was calculated as 1321 kg day^{-1}.

Data about the waste amounts collected from the sea surface cleaning services around Istanbul for the last 3 years show that 332.8 m^3 $month^{-1}$ wastes were collected.

Solid waste collected from sea surface cleaning operations are mainly based on human activities. Heavy materials, such as metals and glass, will sink, while the light materials, such as plastics and bottles, will float. Therefore, the amount of lightweight materials, such as plastics, are expected to be in a higher rate in the wastes from sea surface cleaning operations.

Moisture content, volatile solids, and calorific value analyses on the wastes collected by the sea surface cleaning services were performed apart from the waste characterisation studies. The results of these analyses are given in Table 4. Accordingly, the average moisture content of the wastes collected from the sea surfaces was found to be 48.0% and the lower and higher calorific values were determined as 1862.9 and 4162.3 kcal kg^{-1}, respectively. The lower calorific value is within the boundaries of the calorific values (1500–2500 kcal kg^{-1}) given for mixed domestic solid wastes (Saltabaş et al., 2009).

Charazterisation of waste collected from the coastline

Solid waste samples from Yenikapı-Zeytinburnu (3.a), Bebek (3.b), Tuzla (3.c) and Harem-Üsküdar (3.d) coasts were collected on three various days, as previously described, in order to analyse the waste components and characteristics. The results of the characterisation studies of the waste samples collected from the selected coastline are given in Table 5.

The average biodegradable waste amount in total wastes collected from Yenikapı-Zeytinburnu (3.a) coastline was determined as 7.4%. The total recyclable waste amount was calculated as 73.9% and the total combustible waste amount was specified as 76.1% in this region.

Biodegradable wastes were the highest portion among the wastes in Bebek (3.b) coastline and these wastes had an average amount of 45.6% in total waste mass. The total recyclable waste amount was 31.7% and the highest group was composed of plastic bags/pochettes with a rate of 10.9%. The total combustible waste amount in the wastes collected from this region was detected as 90.7%.

The portions that have the highest amount in the wastes collected from Tuzla (3.c) coastline are glass and plastic bags/pochettes with a rate of 37.0% and 16.5%, respectively. The biodegradable waste amount in the cumulative wastes was detected as 9.0%. The total recyclable waste amount was found out as 76.1% and the rate of total combustible waste amount was 56.7%.

The rate of biodegradable waste in the wastes collected from the Harem-Üsküdar (3.d) coastline was detected as 20.1%. The largest portion among the wastes collected in this region was glass with a rate of 24.7% and total recyclable waste amount in the waste mass was specified as 66.6%. In addition, it was calculated that the wastes collected from this region contain combustible waste with a rate of 72.1%.

According to the average results from the waste characterisation analyses realised on the samples collected from four coastlines, it was determined that of the wastes collected from the coastline, the average biodegradable waste amount was calculated as 20.5%. The average amount of glass was 22.1% of waste collected from coastlines. The total recyclable waste amount was calculated as 62.2%, while the glass, plastic bags/pochettes and paper–cardboard amounts were 22.1%, 13.8% and 10%, respectively. Average total combustible waste amount in the waste mass was determined as 73.9% in the waste collected from the coastline.

The very limited data on the waste composition of the coastline showed that the coastline waste comprised of 60% plastic, 15% rope and netting (also including plastic and textile), 13% foam, 10% other including rubber and 2% metal (Polasek et al., 2017). Topçu et al. (2013) designated the ingredients of the wastes collected during four seasons from 10 coasts of the Western Black Sea seaside. They reported that the sea sides were polluted with marine wastes and these wastes were mainly composed of small sized (<10 cm) plastic components, bottles and bottle caps. Moreover, it was stated that 47% of the collected wastes were caused by foreign ships of neighbouring countries or international transportation.

The densities of the wastes collected from 3.a, 3.b, 3.c and 3.d regions were determined as 80.0, 109.6, 102.8 and 105.8 kg m^{-3}, respectively, with an average density of 100 kg m^{-3}. According to these results, the average waste amounts collected from Yenikapı-Zeytinburnu, Bebek, Tuzla and Harem-Üsküdar coastlines were calculated as 144 kg (1.8 m^3), 66 kg (0.6 m^3), 154 kg (1.5 m^3) and 244 kg (2.3 m^3) per day, respectively.

Considering the waste amounts collected from the coastlines around Istanbul, the waste amount collected from the European side was specified as 4900 kg day^{-1}, while the wastes collected from Asian side was determined as 2780 kg day^{-1}. The difference in the waste quantities is owing to the unequal population distribution in both sides of Istanbul. Almost 35% of the population live in the Asian side, while 65% live in the European side. The total amount of wastes collected from coastlines around Istanbul was 7680 kg day^{-1} (76.8 m^3) from European and Asian sides.

The characteristics of waste collected from the coastline differs according to the regional characteristics. The Yenikapı/Zeytinburnu location, which is one of the most densely populated areas of Istanbul, produces the highest amount of plastic and

Table 5. Characteristics and physical properties of waste samples collected from the coastline (%).

	3.a (Yenikapi-Zeytinburnu)	3.b (Bebek)	3.c (Tuzla)	3.d (Harem-Uskudar)	Average (%)
Waste group					
Biodegradable waste	7.4	45.6	9.0	20.1	20.5
Plastic bags	16.1	10.9	16.5	11.7	13.8
Paper–cardboard	14.2	5.1	6.1	17.4	10.7
Composite	1.0	0.7	0.8	0.7	0.8
Plastics	4.3	4.1	3.4	2.1	3.5
Bottles	15.3	3.4	8.9	6.9	8.6
Glass	19.8	6.7	37.0	24.7	22.1
Metals	3.2	0.8	3.3	3.1	2.6
Electrical–electronic waste	0.0	0.0	0.0	0.0	0.0
Hazardous waste	0.7	1.8	2.8	0.2	1.4
Diaper	0.0	0.2	0.0	0.9	0.2
Textile	1.6	1.1	3.3	0.6	1.6
Other combustible	16.2	19.8	8.6	11.7	14.1
Other non-combustible	0.2	0.0	0.2	0.0	0.1
Physical properties					
Moisture content, %	25.0	46.7	15.0	24.3	27.8
Volatile solids, %	81.7	81.7	72.7	81.0	80.6
High calorific value (kcal kg^{-1})	4232.3	4606.7	3657.0	3743.7	4060.0
Low calorific value (kcal kg^{-1})	2999.0	2150.3	3043.3	2713.3	2727.0

paper/cardboard waste. Additionally, the region includes various commercial affairs and this causes an increase in the amount of packaging waste in the waste stream. Bebek is one of the highest income level regions of Istanbul, and the area attracts too many visitors, especially in the summer season owing to the unique Bosphorus view. Thus, the amount of biodegradable waste was determined in higher rates in this region. Shipping and fishing activities are common in Tuzla and Uskudar regions, causing the detection of metals, glass and other recyclable materials with higher amounts.

In addition to the waste characterisation analyses, moisture content, volatile solids and calorific value analyses were performed on the wastes collected from the coastlines of Istanbul. The results obtained from the analyses are given in Table 5. Consequently, average moisture content of the wastes collected from the coastlines was found as 27.8%, and higher and lower calorific values were determined as 3966 and 3484 kcal kg^{-1}, respectively.

Characterisation of ship-based waste

Istanbul is in a significant location in terms of passenger and cargo transportation. Ship-based waste resources were classified as cargo (4.a) and cruise ships (4.b) and waste characterisation analyses were realised on the samples taken from both resources in various days. The wastes generated in ships are pressed and baled. Thus, determination of volumetric amounts of the wastes was difficult. The volume of each waste sample obtained from the ships was supposed to be 1 m^3 in waste characterisation analyses. The results obtained from the analyses are shown in Table 6.

It was revealed that the total recyclable waste amount and total combustible waste amount in the wastes generated by the cargo ships were 47.3% and 94.6%, respectively. The other combustible wastes compose the highest portion among the wastes caused by ships with a rate of 34.9%. The amount of recyclable wastes (paper–cardboard, plastic bags/pochettes, textile, plastic bottles and plastics) caused by cargo ships were determined as 15.9%, 10.9%, 10.2%, 9.8% and 4.8%, respectively.

The wastes generated by cruise ships also have the same features. The amount of paper–cardboard ws 34.3% in the wastes collected from cruise ships. The amount of plastic bottles, plastic bags/pochettes and plastics were determined as 14.2%, 8.2% and 5.4%, respectively. The rate of the other combustible wastes was 29.1%. The total amount of recyclable waste and total combustible waste in the waste mass were detected as 66.6% and 97.5%, respectively.

The biodegradable waste amount in the wastes generated by cargo and cruise ships can be neglected. According to the average results of the waste characterisation studies from the cargo and cruise ships, it was seen that the wastes contain around 56.9% total recyclable materials. Because the rate of glass in the wastes was below 1%, it was not considered here.

The wastes collected from ships were mostly composed of packaging waste and these wastes were not exposed to water. Thus, the densities were too low. According to the results obtained from waste characterisation studies realised on waste samples of 1 m^3 approximately, the densities of the wastes generated by cargo and cruise ships were determined as 73.5 and 46 kg m^{-3}, respectively, with an average density of 60 kg m^{-3}.

According to the data about the waste amounts collected from ships throughout 12 months for the last 3 years, the annual waste amount was 9214 m^3 and it was noticed that the peak waste formation occured within the period of July to October. The annual waste amount collected from ships in Istanbul was 552.840 kg and monthly average waste amount was 46.070 kg.

Table 6. Characteristics and physical properties of waste samples collected from ships (%).

	4.a (Cargo ships)	4.b (Cruise ships)	Average (%)
Waste group			
Biodegradable waste	5.4	0.3	2.9
Plastic bags	10.9	8.2	9.5
Paper–cardboard	15.9	34.3	25.1
Composite	2.8	3.1	2.9
Plastics	4.8	5.4	5.1
Bottles	9.8	14.2	12.0
Glass	1.9	0.0	0.9
Metals	1.3	1.4	1.4
Electrical–electronic waste	0.0	0.0	0.0
Hazardous waste	0.9	1.1	1.0
Diaper	0.0	0.8	0.4
Textile	10.2	2.1	6.2
Other combustible	34.9	29.1	32.0
Other non-combustible	1.3	0.0	0.7
Physical properties			
Moisture content, %	13.5	13.3	13.4
Volatile solids, %	90.5	89.3	89.8
High calorific value (kcal kg^{-1})	4574.0	4127.0	4306.0
Low calorific value (kcal kg^{-1})	3892.0	3503.7	3659.0

Table 7. The amount of recyclable materials in the waste sources.

Recoverable waste components	Beaches	Sea Surface	Coastline	Ships
	(kg y^{-1})	(kg y^{-1})	(kg y^{-1})	(kg y^{-1})
Glass	243.820	20.805	620.500	0.000
Paper–cardboard	168.995	21.170	299.300	138.720
Metals	61.685	6.570	73.000	7.740
Bottle	155.855	27.010	240.900	59.760
Plastics	71.540	33.580	98.550	28.200
Plastic bags	269.735	47.450	386.900	52.500
Total	971.630	156.585	1719.150	286.920

In addition to waste characterisation analyses, moisture content, volatile solids and calorific value analyses on the wastes collected from the cargo and cruise ships were performed and the results obtained from these analyses are given in Table 6. Consequently, average moisture content of the wastes collected from the ships was found to be 13.4%, and higher and lower calorific values were ascertained as 4306 and 3659 kcal kg^{-1}, respectively. The lower calorific value of the wastes collected from the ships points out that the wastes collected are highly combustible.

Recyclable waste amounts

The amounts of recyclable materials in the wastes collected from four different marine waste sources (beaches, coastline, sea surface cleaning processes and ships) in Istanbul are given in Table 7. Although the collected marine waste is a very diverse mix of waste, it can be clearly seen that beaches, sea surface cleaning operations, coastline and ships contain an important amount of recyclable waste. However, in order to determine the economic benefit via recycling these wastes, a detailed feasibility study should be conducted.

Marine waste collected from four sources indicates that these wastes are almost source separated and have a high potentially economic value to be recycled. The organic content and calorific value of marine waste are also considered and it can be concluded that marine waste can be potentially recycled and/or reused in waste-to-energy applications. However, this waste stream generally ends their life in landfills. A new approach for the management of marine-based waste should be used to gain economic advantages. Pettipas et al. (2016) developed some recommendations for Canadian marine waste monitoring and awareness, including (i) law and waste management strategies, (ii) education, outreach and awareness, (iii) source identification and (iv) increased monitoring and further research. These recommendations can be used as a starting point for marine waste management in other countries.

There is a lack of studies on the pathways of disposal alternatives of marine waste after collection. It is clear from Table 7 that,

besides landfilling as a common pathway, recycling and reuse and also energy recovery is possible for almost the whole part of the collected marine waste. In order to minimise environmental impacts of marine waste, further investigations on treatment options according to the waste hierarchy are necessary (Schneider et al., 2018).

Conclusion

The marine transportation between the Mediterranean and the Black Sea is realised through the Canakkale Strait and the Bosphorus. The Bosphorus, particularly, has much more heavy traffic because of its significant location for intercontinental transition and international trade. Continuous and increasing waste input and its accumulation in the marine environment diversely effects marine life, humans and the economy.

Marine waste management is crucial for Istanbul, which is a transition point for tourism, trade and industry and world ship transportation. Marine waste is present at beaches, coastlines, sea surface and ships. Coastlines and beaches are the highest source of marine waste in Istanbul, comprising of almost 85% marine waste. Recyclable materials, including plastics, paper–cardboard, metals and glass are the most dominant types of waste from the all sources. Additionally, it can be concluded that the socio-economic development of the region, the density of the population and the type of trade sector considerably affect the waste characteristics. The average calorific value of waste collected from the analysed sources is approximately 2500 kcal kg^{-1}, which is higher than that of mixed municipal solid waste, indicating the feasibility of energy recovery from marine waste.

Recyclable wastes compose a significant portion of the marine wastes. It was observed that plastics were the main ingredients. In order to determine the economic benefit gained by recycling marine wastes, a comprehensive feasibility study should be done and awareness with education should be implemented in its scope.

Studies on management of waste generated from marine sources are very limited. This study is the first one realised in Turkey for the detailed characterisation of marine waste. A new circular on the preparation and implementation of marine waste action plan prepared after the results of the study were announced by the ministry, which is the first step for the development of alternative methods for marine waste management in the light of circular economy.

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