Environ Sci Pollut Res
https://doi.org/10.1007/s11356-017-0676-9

RESEARCH ARTICLE

Cigarette butts abundance and association of mercury and lead along the Persian Gulf beach: an initial investigation

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Received: 5 August 2017 / Accepted: 1 November 2017

Abstract The toxic metal contents of cigarette butts and distribution of cigarette butts have not been studied well in maritime environment. In the present study, cigarette butts distribution and the associations of Hg and Pb from cigarette butts were monitored along the Persian Gulf with 10 days interval sampling time. The number of cigarette butts, and Hg and Pb associations of butts were found to vary widely between 2 and 38 items per square meter, 2.5 and 86.32 ng/g cigarette butt (CB), as well as 650 and 8630 ng/g CB, respectively. Wilcoxon signed-rank test showed that there were no significant differences between the number of butts, and Hg and Pb contents of the butts at different sampling times. Considering amount of cigarette butts littered yearly, this study demonstrates that remarkable toxic metals of Hg and Pb may enter maritime environment each year and may introduce critical hazards to aquatic organisms, enter food chain, and finally human body.

Keywords Bushehr · Cigarette butts · Lead · Mercury · Persian Gulf

Responsible editor: Philippe Garrigues

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11356-017-0676-9) contains supplementary material, which is available to authorized users.

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Introduction

Cigarette butts are a potential source of contaminants to the marine environment. In region with considerable contents of cigarette waste, ecological hazards may occur, as chemical components are leached from the cigarette butts (Novotny et al. 2009). It is estimated that nearly 4.95 trillion cigarette butts to be wasted every year, worldwide (http://cigwaste.org/ (Cigarette Butt Advisory Group 2009)). Cigarette butts are the single most collected item of whole waste by count during the coastal cleanups worldwide (Novotny et al. 2009; Moore et al. 2001). Beside unsightly, cigarette butt litter may have adverse health effects for humans and animals. Cigarette butts are generally thrown everywhere in environment and public areas such as coastal areas, forests, parks, pavements, roads, and streets where children, pets, and wildlife may be exposed to cigarette butts risks (Novotny et al. 2009). It has been demonstrated that cigarette butts leach out many chemicals such as different toxic metals as well as organic contaminants in water

Published online: 07 December 2017

and may be a continuous origin for pollution of aquatic environments after throwing away. It was reported that toxicity of cigarette butts in part can be because of toxic metals (Moerman and Potts 2011; Micevska et al. 2006). Although toxic metals in cigarette butts and mainstream smoke have been widely evaluated, limited studies have tried to recognize and quantify the leakage components from cigarette butts. Hg and Pb are identified as the highly toxic metals (Mudgal et al. 2010; Liu and Liang 2008). Although Hg is not an abundant chemical element in the environment, it has become widespread due to many industrial applications such as produce batteries, lamp, cement production, electronic and electrical devices, and production of vinyl chloride monomer (Pirrone et al. 2010; Pacyna et al. 2010). Because of its high toxicity and very high bioaccumulation factor (up to 106) in the food chain, the monitoring of Hg in the marine environment is very crucial (Leopold et al. 2009; Booth and Zeller 2005; Braune et al. 2005). Furthermore, the widespread existence of Pb in the environment comes from anthropogenic activities. The most significant sources of Pb exposure are industrial emissions, automobile exhaust gases, soils, and polluted foods (Komárek et al. 2008).

Some studies reported the content levels of Hg and Pb in cigarette. Panta et al. (2008) reported Hg content of whole cigarettes, cigars, and chewing tobacco packets as follows: 20.8 ± 1.0 ng/g in the cigar, 13.0 ± 1.3 ng/g in the cigarettes, and 6.3 ± 0.6 ng/g in the chewing tobacco (on fresh weight basis); the cigarette's tobacco and filler accounted for more than 97% of the Hg found in the whole cigarette. Kowalski and Wierciński (2009) found Hg contents of examined cigarette ranged from 2.95 to 10.2 ng per cigarette. Wang et al. (2007) also reported Hg contents in cigarette filters ranged from 0.002 to 0.051 mg/kg (Wang et al. 2007). Afridi et al. (2013) found the level of Pb in filler tobacco of different cigarettes in the range from 0.67 to 1.67 μg/g, while Massadeh et al. (2005) reported a range from 2.10 to 3.23 μg/g for the Pb content of cigarette tobacco.

Due to adverse health and environmental effects of toxic metals including Hg and Pb, many studies reported the concentration levels of toxic metals in marine environment, marine organisms, and animals in different parts of the world (Table 1). But there is no report yet on Hg and Pb contents from cigarette butts in marine environment. So in the present study, we aimed to (1) investigate the number and abundance of cigarette butts per square meter of beaches for the first time in the region of the Persian Gulf and (2) determine the cigarette butts content levels of two notorious toxic metals including Hg and Pb along the northern part of the Persian Gulf in the Bushehr seaport coastal area. It should be noted that to the best of our knowledge, the present study is the first study on Hg and Pb contents of cigarette butts in marine environment.

Materials and methods

Study area and sampling

To determine the quantity of cigarette butts as well as the content levels of Hg and Pb with cigarette butts, fields monitoring were carried out at nine stations (S_1–S_9) in summer 2015. Selected stations were TV park (S_1), Jofreh (S_2), Shoghab (S_3), Rishehr (S_4), Lian park (S_5), Bandargah (S_6), Negin island (S_7), Abassak island (S_8), and Shif island (S_9) along the northern part of the Persian Gulf (Fig. 1). All selected stations have a texture of sand in the surface with grain sizes up to 250 μm. Sediment samples were collected from top 10 cm at the intertidal zone (at high tide) on strand from a 1-m^3 area (volume of sample: 1 m^2 × 0.1 m). First visible cigarette butts were separated from the sediment surface with forceps (with wearing gloves), then the collected sediments were transferred to the laboratory for final separation and enumeration. As there is no any cleanup program in examined areas, to compare the number of cigarette butts as well as Hg and Pb content levels at different times, sampling at each beach examined was done two times (second sampling was done in the same place by using Global Positioning System (GPS), Garmin model) with a time interval of 10 days. So in total, a number of 18 sediment samples (two times in every selected station) were collected. Different environmental parameters during sampling days such as average and maximum height of wave, average period of wave, minimum and maximum temperature of seawater, average air temperature, direction of dominant wind, and average speed of wind are shown in supplementary 1.

Reagent, solutions, and sample preparation

The utilized reagents were of analytical grade. HCl and HNO_3 applied for the extraction were of supra pure quality (Merck, Germany). All glassware and plastic were cleaned by soaking in dilute HNO_3 (10% (*w*/*v*)) and washed with distilled water before use. All solutions were prepared using ultrapure water (resistivity 18.2 μΩ cm).

Metal analysis

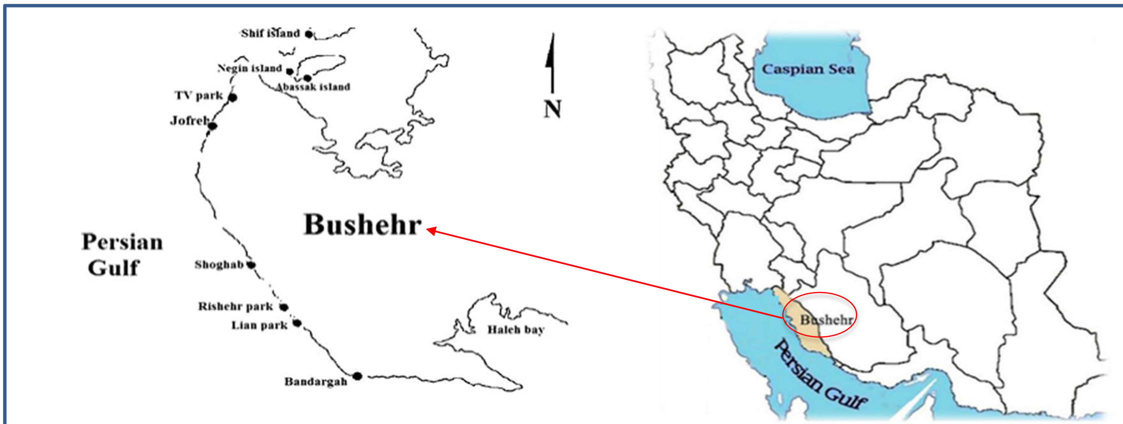
Cigarette butts from each beach examined were selected without considering the amounts of adherent substances. First, adherent substance was manually removed from the beached cigarette butts by using a small cleaning brush. Then, Hg and Pb were extracted from cigarette butts by using a modified aqua regia extraction. Aqua regia was prepared by mixing 3 M HNO_3 and 2 M HCl in a ratio of 1:3 (Ashton et al. 2010). Weighed cigarette butts from every examined beach were separately added to polypropylene centrifuge tubes, and 20 ml of aqua regia was added; afterwards, the tubes were shaken at

Table 1 The concentration levels of Pb and Hg in marine environment, marine organisms, and animals in different parts of the world

Sampling sites	Sample type	Pb content	Hg content	References
South-west Anatolia, Turkey	Fish/tissues of *Leucis cephalus*	0.068–0.874 μg/g	–	Yılmaz et al. 2007
South-west Anatolia, Turkey	Fish/tissues of *Lepomis gibbosus*	0.070–0.920 μg/g		Yılmaz et al. 2007
Urban streams of Semarang, Indonesia	Fish/guppy, *Poecilia reticulate*	Polluted station, 6.9 ± 7.7 μg/g Non-polluted station, 0.8 ± 0.7 μg/g	–	Widianarko et al. 2000
Elechi creek in Port Harcourt, Nigeria	Fish species/tissues of *Sarontheron melanotheron*	2.3 ± 0.13 mg/kg	–	Vincent-Akpu and Babatunde 2013
River Orogodo (Agbor, Delta State, Nigeria)	Sediment	0.3–0.96 mg/kg	–	Issa et al. 2011
Ria de Vigo, funnel-shaped, fault-bounded coastal embayment in Galicia, NW Spain	Sediment	160.1 ± 1.2 mg/kg	–	Rubio et al. 2000
Jade Bay in NW Germany	Sediment	16 ± 10 μg/g	–	Beck et al. 2013
SW England	Foams	111 μg/g	–	Turner 2016
Northern coast of Qeshm Island, Persian Gulf, Iran	Oysters/tissue and shell of *Saccostrea cucullata*	Soft tissue, 10.74 μg/g Shell, 26.06 μg/g	–	Shirneshan and Riyahi Bakhtiari 2012
Lengeh Port, Qeshm and Hormoz Islands in Persian Gulf, Iran	Sediment and shell of rocky oysters (*Saccostrea cucullata*)	Sediment, 0.86–180.78 μg/g Shell, 0.06–613.94 μg/g	–	Kazemi et al. 2013
Alaro stream ecosystem of south-west Nigeria	(Mollusca: thiaridae)/freshwater snail *Melanoides tuberculata*	10.12–14.12 ppm	–	Tyokumbur and Okorie 2014
Mediterranean marina, Port Camargue, France	Sediment	Up to 94 μg/g	Up to 0.82 μg/g	Briant et al. 2010
Brown Bay (Beagle Channel), Ushuaia, Tierra del Fuego, Argentina	Mussels/*Mytilus edulis chilensis* and sediment	Sediment, 10.19–28.76 μg/g Gill and digestive gland, 3.37–15.57 μg/g	–	Giarratano et al. 2010
Eastern part of the Johore Straits, Malaysia	Green-lipped mussel/soft tissues of *Perna viridis*	Foot, 11.4 ± 1.49 μg/g Gill, 14.2 ± 11.9 μg/g Muscle, 11.0 ± 4.20 μg/g	–	Yap et al. 2012
Scotland, Great Britain	Mammals/common porpoise (*Phocoena phocoena*)		Liver: mean levels for females were 6.03 mg/kg and for males 3.42 mg/kg	Falconer et al. 1983
Ontario lakes, Canada	Fishes/walleye (*Stizostedion vitreum vitreum*) and northern pike (*Esox lucius*)	–	Walleye: *Stizostedion vitreum vitreum*, 0.65 μg/g Northern pike: *Esox lucius*, 0.52 μg/g	Wren et al. 1991
Welsh coast and the Irish Sea, Scotland	Marine mammals/striped dolphin *Stenella coeruleoalba*	Liver: mean levels 0.05–7.0 μg/g	Liver: mean levels 0.5–280 μg/g	Law et al. 1992
Uppanar estuary, southeast coast of India	Molluscs: *Meretrix meretrix*, *Crassostrea madrasensis* *Cerithidea cingulate*	*M. meretrix* tissue, 0.278 ± 0.01 ppm *M. meretrix* shell, 0.083 ± 0.01 ppm *C. madrasensis* tissue, 0.285 ± 0.01 ppm *C. madrasensis* shell, 0.034 ± 0.01 ppm *C. cingulate* tissue, 0.072 ± 0.01 ppm *C. cingulate* shell, 0.070 ± 0.01 ppm	–	Kesavan et al. 2013

Table 1 (continued)

Sampling sites	Sample type	Pb content	Hg content	References
Ada and Aveglo at the Volta estuary, Ghana (March to September, 2008)	Clam/tissue of the clam *Galatea paradoxa*		Ada: Small-sized clams, 0.028–0.049 μg/g Medium-sized clams, 0.035–0.049 μg/g Large-sized clams, 0.044–0.059 μg/g Aveglo: Small-sized clams, 0.037–0.055 μg/g Medium-sized clams, 0.042–0.056 μg/g Large-sized clams, 0.037–0.074 μg/g	Adjei-Boateng et al. 2010
Clear Water Bay, Kowloon, Hong Kong	Five species of marine bivalves: Scallops, *Chlamys nobilis* Clams, Ru*ditapes philippinaru* Oysters, *Saccostrea cucullata* Green mussels, *Perna viridis* Black mussels, *Septifer virgatus*		Scallops: *C. nobilis*, 60.3 ± 14.2 ng/g Clams: R. philippinaru, 30.2 ± 4.1 ng/g Oysters: *S. cucullata*, 47.4 ± 15.3 ng/g Green mussels: P. viridis, 70.3 ± 15.3 ng/g Black mussels: S. virgatus, 91.9 ± 18.8 ng/g	Pan and Wang 2011



Distance (km) between different stations	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9
S_1	-	2.66	9.21	10.76	12.71	21.36	1.13	4.05	9.57
S_2		-	6.68	8.32	10.30	19.26	2.82	4.38	12.18
S_3			-	2.34	4.30	14.82	9.07	9.62	18.48
S_4				-	2.3	12.38	10.53	10.45	19.79
S_5					-	10.65	12.26	12.03	21.06
S_6						-	20.76	19.04	28.39
S_7							-	2.95	9.46
S_8								-	9.72
S_9									-

Stations	Geographical coordinates &location	
TV park (S_1)	28°59′43.62″ N	50°49′42.78″E
Jofreh (S_2)	28°58′20.13″N	50°49′15.14″E
Shoghab (S_3)	28°54′49.56″N	50°48′50.89″E
Rishehr (S_4)	28°53′52.78″N	50°49′48.38″E
Lian park (S_5)	28°52′49.76″N	50°50′16.25″E
Bandargah (S_6)	28°49′14.51″N	50°55′22.76″E
Negin island (S_7)	28°59′32.33″N	50°50′22.87″E
Abassak island (S_8)	28°59′5.28″ N	50°52′5.76″ E
Shif island (S_9)	29°1′1.38″ N	50°52′1.87″ E

Fig. 1 Geographic coordinates and location of sampling stations along the Persian Gulf

100 rpm for 24 h. Then, the contents were filtered by pouring into a 50 volumetric flask through a Whatman filter paper (pore size, 2.5 μm). The same bulk preparation of aqua regia was used all over extraction for all blanks and calibration to ensure consistency in the analysis of extraction. The filtered samples were analyzed for the contents of Hg and Pb by using a cold vapor and graphite furnace atomic absorption spectrophotometer (Varian AA240, USA). Every sample was measured three times, and the mean value is reported here. The limit of detection (LOD) and the limit of quantification (LOQ) were calculated as 3 and 10 sd/m, respectively. Where sd is the standard deviation for ten measurements of the calibration blank, and m is the slope of the calibration curve. The measured LOD and LOQ values were calculated per mass of cigarette butts. These values for Hg were 9.1×10^{-4} μg/mg and 2.1×10^{-3} μg/mg, respectively. The values obtained for Pb were 9.8×10^{-4} μg/mg (LOD) and 2.28×10^{-3} μg/mg (LOQ).

Statistical analysis

Statistical analysis of data was performed with the statistical package for the social sciences (SPSS, Version 21). To see the effect of the current sea, the Wilcoxon signed-rank test was used for statistical significant differences between the number of cigarette butts, and Hg and Pb contents of cigarette butts at different sampling times. The Spearman correlation coefficient test was also used to analyze any significant relationship between environmental parameters shown in supplementary 1 and the number of cigarette butts, and Hg and Pb contents of cigarette butts. Differences in mean values were accepted as being significant if $p < 0.05$.

Results and discussion

The number of cigarette butts, and Hg and Pb contents of the cigarette butts along the northern part of the Persian Gulf in the Bushehr seaport coastal area, as measured, is shown in Fig. 2a–c. The number of cigarette butts, and Hg and Pb contents of cigarette butts was found to vary widely between 2 and 38 items per square meter, 2.5 and 86.32 ng/g cigarette butt (CB), and 650 and 8630 ng/g CB, respectively. The Wilcoxon signed-rank test showed that there were no significant differences between the number of cigarette butts, and Hg and Pb contents of the cigarette butts at different sampling times along the urban coastal area. The mean numbers of cigarette butts were 10.78 and 9.33 items per square meter at the first day and after 10 days of sampling times, respectively. The Spearman correlation coefficient analysis also demonstrated that there were no significant correlations between the number of cigarette butts, and Hg and Pb contents of the cigarette butts with environmental parameters (including average and maximum height of wave, average period of wave,

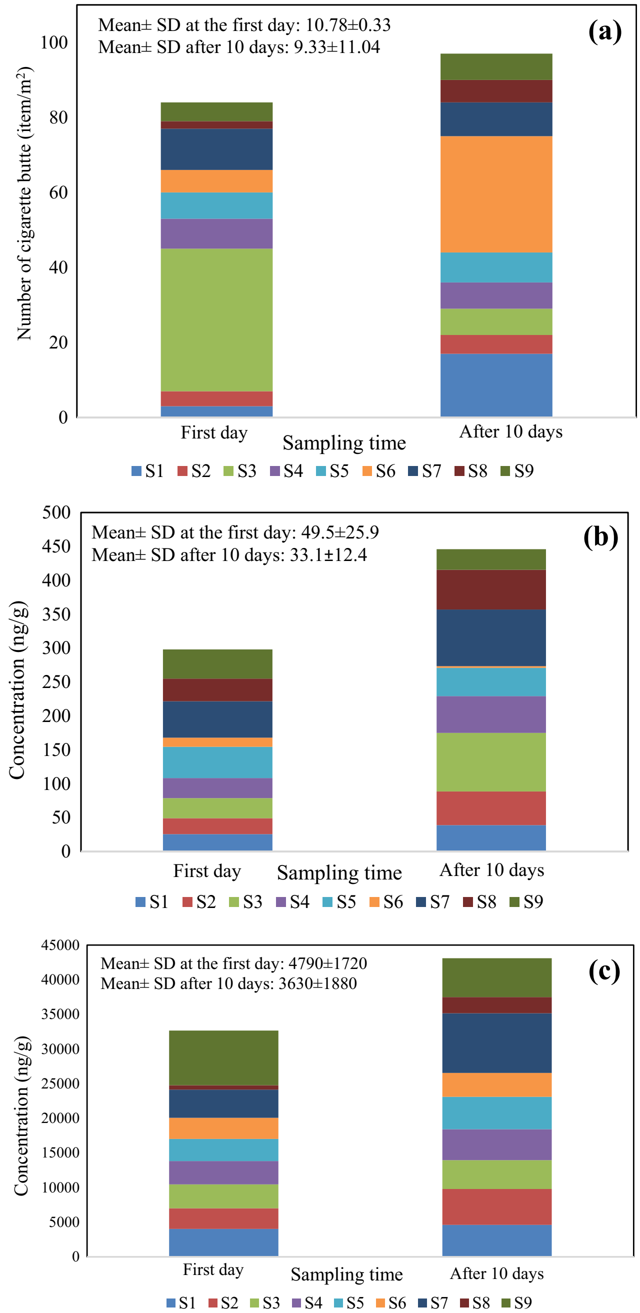


Fig. 2 Number of cigarette butts (**a**) and associations of Hg (**b**) and Pb (**c**) with cigarette butts

minimum and maximum temperature of seawater, average air temperature, direction of dominant wind, and average speed of wind) shown in supplementary 1. This can be due to low differences in the most mentioned environmental parameters during the sampling times. But it seems further studies are necessary to discover these correlations. Especially comparative studies in different areas with diffident environmental parameters such as direction of dominant speed, average speed of wave, and height of wave are highly recommended. Cigarette butts are the most common form of litter in the world

(Novotny et al. 2009), and they were found to be a major source of coastline accumulation of debris (Hoellein et al. 2014). Collected cigarette butts per unit of area in former studies from other regions of the world are compared with the present study in Table 2. As seen in Table 2, most of reported data on cigarette butt numbers per unit of area are in the urban areas. But measured numbers of cigarette butts in our study compare to marine environment/Armação dos Búzios, Brazil (Oigman-Pszczol and Creed 2007) are quite high and showed that the northern part of the Persian Gulf in the Bushehr seaport coastal area is heavily polluted.

Even higher number compare to our result was also reported in the urban beaches in the eastern coast of Mallorca (Balearic Islands). Beach-goers, direct throw by smokers, and water channeled by open sewer systems (there is no storm water collection system in Bushehr and storm water flow directly by channel to the Persian Gulf) appear to be the major potential sources of cigarette butts along the urban shorelines in Bushehr. However, some of these cigarette butts may also be transported from other urban areas by wind or storm water and finally end up on the coasts. Cigarette butts on beaches may be accessed by children, sea creatures, birds, and even pets. There are some reports on accidental ingestion of cigarette butts in children especially those < 6 years old (Smolinske et al. 1988; Malizia et al. 1983; Bonadio and Anderson 1989; Mcgee et al. 1995; Kubo and Chishiro 2008; Centers for Disease Control and Prevention (CDC)1997; Quirk 2009; Bronstein et al. 2012), and in some cases, severe toxicity have been seen. Also, there is a report on cigarette butts ingestion by sea turtles (Stanley et al. 1988). It should be noted even there are no well-documented reports on cigarette butts ingestion by wildlife, but it does not mean such ingestion does not happen.

The mean values of Hg contents of cigarette butts were 49.5 and 33.1 ng/g CB at the first day and after 10 days of sampling times, respectively. The mean values of Pb content of cigarette butts were 4790 and 3630 ng/g CB at the first day and after 10 days of sampling times, respectively. The toxic metals leached from cigarette butts have been identified and quantified by only a few studies, and except a study (Dobaradaran et al. 2017), these studies were not in marine environments. It should be noted that except a recent study by Dobaradaran et al. (2017) on content levels of Cd, Fe, As, Ni, Cu, Zn, and Mn with cigarette butts, there are no studies so far on toxic metal and especially Hg and Cd contents of cigarette butts in marine environments and coastline areas. They reported that Cd, Fe, As, Ni, Cu, Zn, and Mn contents of cigarette butts were found to vary widely between 0.16 and 0.67 μg/g, 79.01 and 244.97 μg/g, 0.12 and 0.48 μg/g, 1.13 and 3.27 μg/g, 4.29 and 12.29 μg/g, 6.39 and 21.17 μg/g, and 38.29 and 123.1 μg/g, respectively. They found that there were no significant differences between Cd, Fe, As, Ni, Cu, Zn, and Mn contents of the cigarette butts at different sampling times and concluded notable metals may enter the marine environment annually. In a study, Moriwaki et al. (2009) determined the concentration levels of Pb (0.72 mg/g), Cr (0.18 mg/g), Cd (0.024 mg/g), and Cu (2.1 mg/g) in cigarette butts collected from waste on roadside. In another study, Moerman and Potts measured the contents of Al, Cd, Pb, Cr, Ni, Ba, Fe, Cu, Sr, Zn, Mn, and Ti leached from cigarette butts collected from container adjacent to building on the university campus as well as unsmoked cigarette. With the exception of Cd, they found all metals in leachates at different rates 1 day after sample addition. They reported that there was no clear correlation between pH values of aqueous soaking solution and leached metal levels. They also reported that the concentration level of Pb ranged from 1.12 to 1.42 μg/g after different periods of soaking from 1 to 34 days. Finally, they concluded that cigarette litter can be a point source of metal contamination, and metal leachates from cigarette butts may enhance the risk of acute damage to local organisms (Moerman and Potts 2011). The reported leached levels of Pb, Cd, Cr, and Cu in Moriwaki et al. (2009) study were two to seven times more than the levels in Moerman and Potts study. Moerman and Potts (2011) said that these differences are due to difference in leaching methods used. So, further studies are required to establish a standard leaching method for metals detection from cigarette butts.

Table 2 Collected cigarette butts in different regions around the world and compare with present study

Location of sample collection	Number/density of cigarette butts	Reference
Marine environment/Armação dos Búzios, Brazil	Mean butts density, 0.1376 items/m^2 (13.76 items/100 m^2)	Quirk 2009
Typical suburb in Japan (Ueda city)	0.00015 items/m^2/month (mean) (150 items/km^2/month)	Moriwaki et al. 2009
Urban beach/eastern coast of Mallorca/Balearic Islands	Mean butts 36 items/m^2 (max: up to 68 items/m^2)	Martinez-Ribes et al. 2007
Urban environment/San Diego, California	Mean butts 38.1 items/m^2 (range 11–77)	Marah and Novotny 2011
Urban waters/Berlin, Germany	2.7 items/m^2 (average concentration)	Green et al. 2014
The present study (northern part of the Persian Gulf)	Between 2 and 38 items/m^2	–

Cigarette filters are made of cellulose acetate and may act similar to other plastics in transporting of metals in marine environments. In a study, Ashton et al. determined the concentration levels of metals including Pb, Ag, Cd, Cr, Co, Fe, Cu, Mn, Zn, Al, Mo, Sb, Sn, U but not Hg with plastic production pellets in the marine environment. They concluded that plastic fragments (micro- and macro-) accumulate and transport metals in the marine environment and can be used as metal pollution indicators. Metals on plastic materials are adsorbed to the surface of plastic materials or connected with biogenic or hydrogenous phases, and can take place in a relatively bioaccessible form to fauna that ingest them by mistake (Ashton et al. 2010). In another study, interactions between metals with plastic production pellets under estuarine conditions were studied (Holmes et al. 2014). It was found that adsorption of metals including Pb, Cd, Cr, Co, Ni, and Cu was much greater in beached pellets than to virgin pellets, likely due to the weathering of and adsorption and abrasion of charged minerals by the former components. Holmes et al. (2012) also monitored adsorption of Cd, Pb, Ni, Cr, Cu, Co, and Zn to plastic resin pellets in the marine environment and found that plastics may indicate a major vehicle for metals transport in the marine environment.

In a study, it was shown that the Hg content in the filter was higher after than before smoking the cigarette for most examined cigarette brands (Kowalski and Wierciński 2009), and this can highlight that cigarette litter and cigarette butts may also be a main diffuse source for metal contamination in marine environments after throwing away. There is a big question regarding metals leaching from cigarette butts in marine environments. Cigarette butts may release metals by leaching, but at the same time, they may concentrate metals from aquatic environments. It was reported that if leaching occur in a closed system, maybe dynamic equilibrium happen between aqueous soaking solution and the cigarette butts (Moerman and Potts 2011), but in aquatic environments, water replacement occurs surrounding the cigarette butts in a rate that exceeds that of equilibrium. The obvious leaching of metals enhances the risk of acute damage to local species (Moerman and Potts 2011). It was suggested that the toxicity of cigarette butt leachates is in part due to trace and toxic metals (Micevska et al. 2006). In a study in 2011, it was found that the toxicity of cigarette butt leachates increased from unsmoked cigarette filters (no tobacco) to smoked cigarette filters (no tobacco) to smoked cigarette butts (smoked filter + tobacco). The researchers affirmed the toxicity of cigarette butts to fish and some other representative marine organisms, representative marine bacteria, and daphnids (Slaughter et al. 2011). In another study by Register on freshwater cladoceran *Daphnia magna*, it was found that 48-h LC50 values of smoked cigarette tobacco, smoked cigarette filter, and unsmoked cigarette filter leachates were 0.125 and 0.25, 1 and 2, and > 16 cigarette butts/l, respectively. All mentioned leachates were acutely toxic to *Daphnia magna* (Register 2000). Micevska et al. (2006) also reported that leachates from different brands of smoked butts were toxic to *Ceriodaphnia* cf. *dubia* as well as *Vibrio fischeri* with 48-h EC50 (immobilization) value of 0.03–0.08 butts/l and 30-min EC50 (bioluminescence) value of 0.3–2.7 butts/l, respectively. Lastly, Warne et al. (2002) reported acute toxic effects of smoked cigarette butts, smoked cigarette filters, and unsmoked cigarette butts leachates to the freshwater cladoceran *Ceriodaphnia* cf. *dubia* at 0.06, 0.16, and 1.7 butts/l (48-h EC50 (immobilization)), respectively (Warne et al. 2002). Also, in the case of *Vibrio fischeri*, they reported 30-min EC50 (bioluminescence) values of 0.58, 1.25, and > 970 butts/l for smoked cigarette butts, smoked cigarette filters, and unsmoked cigarette butts leachates, respectively. These results can assist researchers in assessing the potential ecological risks of cigarette butts to marine environments in further studies. Therefore, considering the estimated number of cigarette butts littered annually (4.95 trillion), the results of this study indicate that considerable toxic metals of Hg and Pb may enter marine environments and coastline areas each year from cigarette litter and finally reach aquatic food chain and adversely affect marine environment and organisms as well as human health via different ways.

Conclusion

The present study is one of a limited number of studies that reports metals associations with cigarette butts and the first study that report Hg and Pb leached in the marine environment. In this study, cigarette butts abundance as well as the content levels of Hg and Pb with cigarette butts were monitored along the northern part of the Persian Gulf. The results of this study confirmed the abundance of cigarette butts in marine environment and suggest that littered cigarette butts are major sources for prolonged metals contamination such as Hg and Pb in coastline area. Considering the different response of organisms to metals in former studies, more research is necessary to comprehensively understand the leaching behavior of toxic metals from cigarette butts in marine environment. Further studies are highly necessary to answer all scientific questions that exist on this topic such as the release of all other toxic compounds from cigarette butts to aquatic ecosystems, the effects on environmental quality and ecological risks, chemical toxicity of cigarette butt leachates on water and aquatic organisms, the diffusion pathway in the marine environment, and leachates from cigarette butts after their biodegradation. Finally, the results of this study can be helpful for policy makers find effective solutions to prevent hazards that may introduce by cigarette butts to marine environments, aquatic organisms, and human health.

Acknowledgments The authors are thankful to the Bushehr University of Medical Sciences for their financial and technical support to the present study as well as the laboratory staff of the Environmental Health Engineering Department for their cooperation. This project was partly supported by Iran National Science Foundation (Research Chair Award No. 95/INSF/44913).

Funding This work was supported by the Bushehr University of Medical Sciences [grant numbers 9197].

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