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Estimation of concentration and risk assessment of PAHs in urban water resources due to cigarette butt littering

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Filtered cigarettes are now the dominant form of tobacco consumption worldwide, resulting in the production of 5 trillion/year cigarette butts as hazardous waste. Most cigarette butts are littered by smokers, and the trapped pollutants quickly leak into the environment. In this study, the density of littered cigarette butts in urban environment was interpreted by Cigarette Butt Pollution Index and the ecological risk and carcinogenic risk due to water pollution caused by leaked PAHs from the littered cigarette butts were assessed. The results showed that the density of littered cigarette butts in the most polluted location was 0.61 butts/m^2, while in the best conditions the density was 0.01 butts/m^2. According to the observed densities, the Cigarette Butte Pollution Index was 0.75 in the cleanest location and 12.2 in the most polluted location. The results showed that cigarette butt littering in the studied city caused the leakage of 88,181 g/year of polycyclic aromatic hydrocarbons. The average polycyclic aromatic hydrocarbons leakage into the urban environment was 0.2844 µg/m^2. The ecological risk associated with the three types of PAHs, including Dibenzo(a, h)anthracene, Naphthalene, and Acenaphthene, was moderate, while the ILCR was calculated to be 5.4E-08. Reducing the density of littered cigarette butts in the studied urban environment and preventing the health and environmental consequences resulting from them requires reduce cigarette butt littering by smokers and increase the efficiency of the urban cleaning system.

Keywords PAHs, Waste management, Cigarette butt, Urban environment

The development of urbanization and its relationship with the variety of consumption has major challenges in the management of cities, including significant solid waste generation[1–3]. Municipal solid waste management is difficult due to the diversity of solid waste types and the different consequences of each[4,5]. The behavior of citizens in littering waste in the urban environment leads to the production of one of the important types of municipal solid waste, which is called litter[6]. High dispersion in the environment, difficult collection, leakage of various pollutants, low contrast with the environment, and the possibility of direct impact on organisms, especially in the aquatic environment, are characteristics that make litter management more difficult than other types of solid waste[7]. One of the most important types of litter is littered cigarette butts (LCB), which are often littered by smokers in urban environments[8,9].

The significant consumption of filtered cigarettes and the high rate of littering of smoking waste by smokers has caused LCB to consist a significant proportion of the litter composition in the urban environment and public places, which known as hazardous waste due to the its pollutants and toxicity[9]. The presence of various pollutants in cigarette smoke that will be trapped in the filter during smoking leads to the generation of toxic waste[10]. These pollutants that Polycyclic Aromatic Hydrocarbons (PAHs) one of them, are collected in the woven Y-shaped cellulose acetate fibers of the filter, but their durability in the filter is not permanent[11,12]. Pollutants leak from the cigarette butt immediately after littering it and will cause soil and water pollution[13,14]. Therefore,

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after littering the cigarette butt, pollutants leak from it. The concentration of leakage depends on the initial concentration of the pollutant in the filter, as well as the durability of the littered cigarette butt[15]. Also, the rate of pollutant leakage from the littered cigarette butt depends on the humidity, so that the rate of pollutant leakage will increase with the increase of humidity[16]. Therefore, although the density of LCB in the environment is effective in the concentration of the leaked pollutant into the environment, however, by increase in durability and the increase in humidity, the leakage ratio will increase[13]. Various conditions such as low contrast with the environment, especially in places such as beaches, and the low-access points ratio, which reduce the efficiency of the cleaning service, are effective in increasing the durability of LCB, as a result, increasing the concentration of pollutant leakage[17]. Therefore, the quantity, durability, weather conditions, and the efficiency of the urban cleaning system are effective factors in pollutant leakage from LCB[15,17].

Initial concentration of PAHs in smoke and the performance of the filter in trapping them has caused these pollutant reported in LCB[18]. In previous studies, PAHs were investigated in LCB and different concentrations of them have been reported[19]. However, the lack of knowledge about the fate of leaked pollutants such as PAHs from LCBs and the adverse environmental and health consequences of exposure to them is a significant knowledge gap in the management of this hazardous waste. For example, nicotine leakage from LCBs and the resulting contamination of water resources have been reported, such that leaked nicotine from one LCB pollute a thousand liters of water[13]. The rate of leakage of PAHs from LCB into the urban environment is affected by two groups of factors, including controllable factors and out-of-control factors. Climatic conditions and the initial concentration are among the uncontrollable factors in urban waste management. However, with waste management activities, the density and durability of LCB can be reduced as controllable factors. The aim of this study was to qualitatively classify the urban environment in terms of cigarette butt density, and assess the ecological and carcinogenic risk due to leakage of PAHs into the environment caused by the littering of cigarette butts in the urban environment.

Method

Study area

This study was conducted in Behbahan, Iran. As shown in Fig. 1, Behbahan is located in Khozestan province in southwestern Iran at 30.3353–30.3713°N, 50.1050-50.1702°E. Behbahan is located in a hot climate and its average rainfall is 366 mm and its average temperature is 30ºc. Per capita production of solid waste in Behbahan is less than 500 g/day, which is lower than the average of the country[20]. Organic wastes constitute the main part of Behbahan's urban solid wastes at a rate of 60%, while the ratio of plastic wastes in this city is about 8.7%. In the studied city, a manual urban cleaning system was used to collect litter, including LCB. There were no special storage containers for LCB in the city, but waste storage containers were installed in all city area.

Field investigation

The survey of the urban environment was done by observing and counting LCB. For this purpose, the city was divided into three main land-uses: commercial, residential, and recreational, and LCB were counted in different locations of each land-use[21]. In total, data for this study were collected from 12 locations, including 5 locations in commercial use, 4 locations in residential use, and 3 locations in recreational use. Observations were made in each location at the distance of two intersections and on the entire sidewalk plus one meter from the depth of the street[22]. In order to take advantage of daylight and the maximum time interval with urban cleaning, all the studied locations were observed in the evening at two hours before sunset[22]. To determine the weight of LCB, three samples (including 100 LCB) were collected from each studied locations and weighed after being transported to the laboratory.

Estimation of pollutant leakage

Cigarette Butt Pollution Index (CBPI) is a special tool to determine the pollution status caused by LCB, which is used in this study based on applying the observed cigarette butt density in formula 1[6]. To determine E coefficient in Formula 1, the main characteristics including average rainfall, distance to underground water, low access points, and land type were considered[23]. Finally, based on the result of the calculation, the status of each studied locations was interpreted in one of the categories shown in Table 1[23].

The concentration of leaked PAHs was estimated by considering the observed density in the studied locations, the initial pollutant concentration in the litter, and the leakage ratio[15,17]. For this purpose, the obtained data in the field investigation were applied in formula 2. Although the leakage ratio of various types of PAHs is not the same, but their initial concentration in this hazardous litter reported by 5.76–50.74 μg/g[15]. The leakage ratio of Naphthalene, Acenaphthene, was more than 20%, and the leakage ratio of Benzo[a]pyrene less than 1%, reported[15].

$$CBPI = DCB \times E \tag{1}$$

$$Leaked\,PAHs = \sum (IPAH \times LR \times DCB) \tag{2}$$

DCB is the density of LCB, IPAH is initial concentration of each PAH in cigarette butt, LR is leakage ratio of each PAH from cigarette butt.

Risk assessment

In this study, BaP equivalent concentration (BaPeq) was used as a widely used technique to assess the carcinogenic risk of exposure to PAHs in water[24]. In this method, the risk from exposure to each type of PAH is defined using

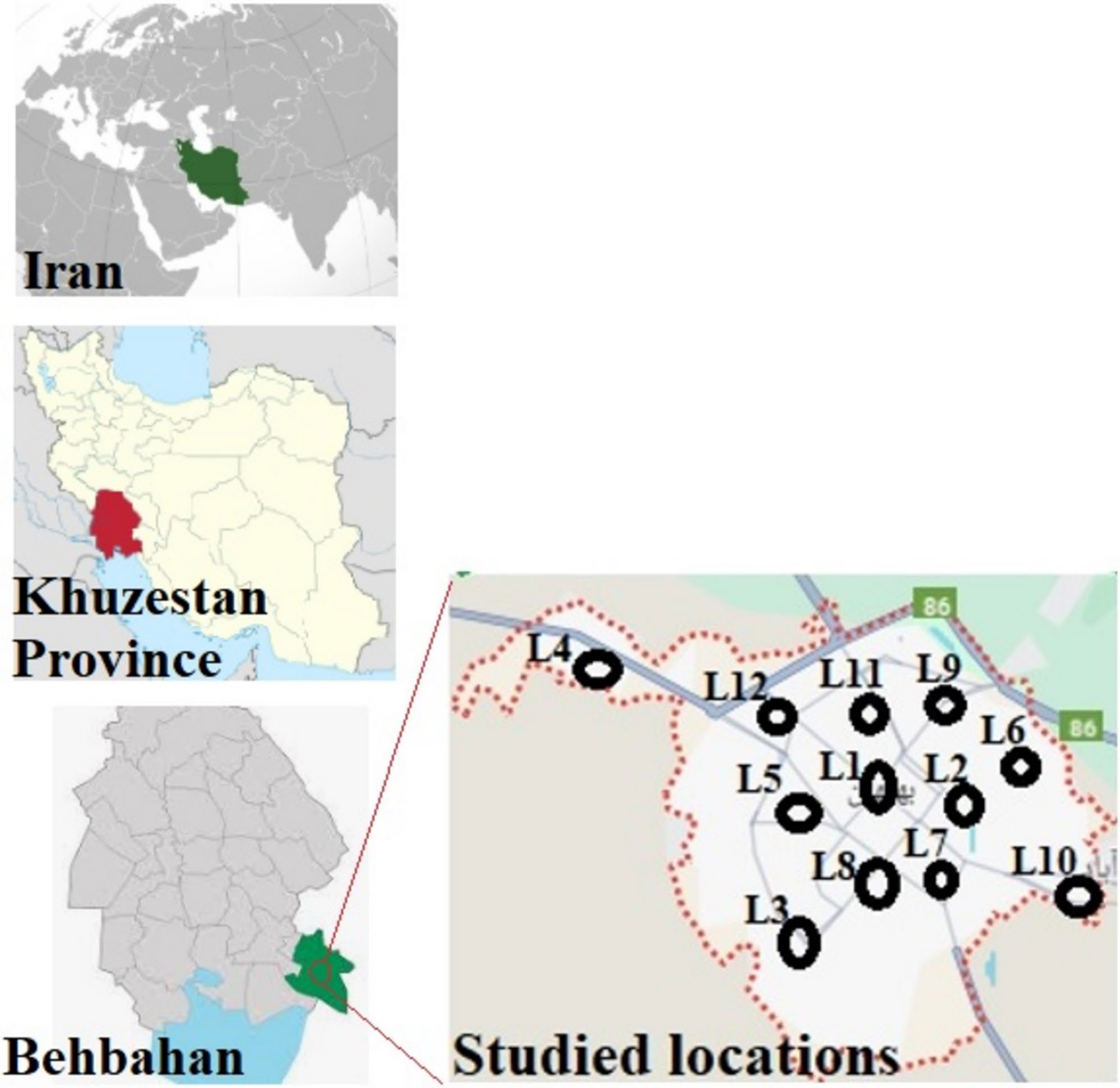

Fig. 1. Study location.

		Calculated CBPI
Interpretation	Very low pollution	< 1
	Low pollution	1.1–2.5
	Pollution	2.6-5
	Significant pollution	5.1–7.5
	High pollution	7.6–10
	Sever pollution	> 10

Table 1. Classification of urban environment based on LCB' pollution (6).

ILCR	Incremental lifetime cancer risk	Calculate by formula
CS	Sum of PAHs concentrations as BaPeq (ng/l)	Calculate as TEQ
IR	Ingestion rate (L Day^{-1})	3
CSF	Slope factor (mg kg^{-1} day^{-1}) $^{-1}$	7.3
ED	Exposure duration (years)	70
EF	Exposure frequency (day $year^{-1}$)	365
BW	Body weight (kg)	70
AT	Average exposure time (ED×365 days $year^{-1}$)	25,550

Table 2. Details of parameters in formula 6.

Locations	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12
Land-use*	Co	Co	Rc	Rs	Rs	Co	Rs	Rc	Rc	Rs	Co	Co
Density (butt/m^2)	0.56	0.43	0.04	0.12	0.15	0.61	0.10	0.06	0.03	0.11	0.38	0.48
Related weight (gr/m^2)	0.16	0.13	0.01	0.03	0.04	0.18	0.03	0.02	0.01	0.03	0.11	0.14

Table 3. Density and related weight of littered cigarette butt in studied area. *Co (Commercial), Rs (Residential), Rc (Recreational).

the toxicity equivalent factor (TEF) based on BaPeq [25]. BaPeq was calculated for each of the studied PAHs using Formula 3 [26]. After calculating BaPeq, the toxic equivalent quotient (TEQ) was calculated using Formula 4, which included the sum of the calculated TEF[24].

$$\text{BaPeqi} = (\text{PAHi} \times \text{TEFi}) \tag{3}$$

$$TEQ = \sum (PAHi \times TEFi) \tag{4}$$

Risk quotient (RQ) was also used to calculate the eco-toxicity of the studied water polluted by PAHs[25]. In this study, Formulas 5 and 6 were used to calculate RQ[26]. RQ_{NCs} less than 1 indicates a negligible risk due to the concentration of PAHs in water, while RQ_{MPCs} greater than 1 indicates a high ecological risk due to the concentration of PAHs in water. Also, RQ_{NCs} greater than 1 and RQ_{MPCs} less than 1 indicate a moderate ecological risk[24].

$$RQ_{NCs} = C_i/NC_s \tag{5}$$

$$RQ_{MPCs} = C_i/MPC_s \tag{6}$$

where RQ_{NCs} and RQ_{MPCs} are RQs of the NCs and MPCs for individual PAHs, respectively. NCs is negligible concentrations and MPCs is the maximum permissible concentrations of individual PAHs that detailed in Table 4.

Also, in this study, formula 6 was used to calculate incremental lifetime cancer risk (ILCR)[25]. The parameters for calculation of the ILCR are given in Table 2. ILCR was calculated based on the related risk to ingestion of water contaminated with PAHs and the estimated concentrations. The concentration of pollutants (sum of PAHs) was considered as BaPeq.

$$ILCR = CS \times IR \times EF \times ED \times CSF/BW \times AT \times 10^6 \tag{7}$$

Results and discussion

The results of calculating the density of LCB in the studied urban environment are listed in Table 3. Based on this, the average of observed density in all studied locations was 0.255 butt/m^2. The lowest observed density was 0.41 butt/m^2 less than the highest observed density. These results showed that the distribution of cigarette butt pollution in the urban environment was not the same. In this situation, spatial variation was evident in cigarette butt pollution, which was caused by the impact of urban land-use on the difference in the visitor papulation[22,27]. The difference in the number of visitors in different streets due to the effect on the increase in the potential of cigarette butt littering due to the more population was one of the reasons for the different observed density, such that it was more in commercial land-use than in other land-uses[28]. In addition, the accumulation of LCB, which is related to the low efficiency of the cleaning service can also be effective in the observed density[17,28], but due to the same efficiency of cleaning service in the studied city, this factor had no effect in the observed spatial version[21]. Increasing the durability of LCB in places such as tree-pits and bicycle stations, which are called low-access points, where it is difficult to collect LCB, will cause the aggregation of LCB is effective in increasing the density of this litter in the urban environment[29]. However, considering that most smokers littering LCB[30,31], the effect of the density of people on the number of LCB in urban environment is important. Therefore, it is important to prevent littering behavior of smokers to reduce the density of LCB[32].

Calculated index for the studied locations and its comparison with the observed cigarette butt density in each location is shown in Fig. 2. The results showed that the highest CBPI was equal to 22, while the minimum calculated CBPI was equal to 2. Based on the results of index analysis, the ratio of locations that were in low pollution status was 41.6%, while the locations in the severe pollution status constituted 16.6% of the studied area. As shown in Fig. 3, the main question is the disproportion of the distribution of the studied locations based on CBPI and density. The main reason for this variation is the difference in pollutant leakage from LCB affected by weather conditions and durability[16]. Increasing humidity in the environment provides higher leakage of trapped pollutants in the cigarette filter, including PAHs[19]. Also, the longer durability of cigarette will lead to more pollutant leakage[13]. These due to the difference in the existence of low access points and also the humidity ratio, especially in recreational land-use, caused an increase in the E coefficient that increased the calculated CBPI[33,34]. Therefore, it seems that CBPI is a more efficient and better than the density for interpreting the pollution status[6]. The average CBPI in the studied area was 4.837, which indicated the pollution status. Therefore, LCB are a source of PAHs and some other pollutants such as heavy metals in the urban environment[15], whose risk intensity is not the same due to the effect of different weather conditions and the efficiency of the waste management system[17].

The results of the estimation of PAHs leakage from LCB in the studied locations are shown in Table 4. The results showed that the difference in concentration of PAHs leakage in the studied locations was consistent with the differences in calculated CBPI. Based on this, the highest concentration of PAHs leakage was equal to 0.678 μg/m^2, while the lowest concentration of PAHs leakage was equal to 0.033 μg/m^2. On average, PAHs leakage in the studied city was equal to 0.2844 μg/m^2. The consumption of filtered cigarettes in Iran is reported by 65 billion annually[35]. According to the population ratio of the studied city in total population of Iran, assuming the same consumption pattern in the city compared to the country, the annual cigarette consumption in studied city was estimated by 93,300,000. On the other hand, the ratio of littering LCB by smokers has been reported between 75% and 94% [36], assuming a ratio of 85% for the studied city, the potential of PAHs emission was estimated to be equal to 88,181 g/year. Leaked pollutants from LCB, including PAHs, can cause soil and water pollution. For example, it is possible to pollute a thousand liters of water due to nicotine leaked from just one cigarette butt[13]. Even in the case of controlling the littering of LCB and collecting them from trash bins, the environmental and health risk is not eliminated. For example, an increase in the concentration of pollutants in landfill leachate due to an increase in the weight ratio of LCB in solid waste reported[35]. The leakage of pollutants such as PAHs from LCB can cause toxic consequences, mutagenesis, carcinogenesis, changes in growth, and even early death for exposed organisms[36]. Specifically, complications such as cancer, immune system disorders, hormonal disorders, and nervous system disorders reported in exposed with PAHs[37].

As shown in Table 5, the calculated TEQ was 0.173 ng/L. This value represents the BaPeq concentration of PAHs that leaked from littered cigarette butts in urban environments into water sources. However, this value could be higher in rainy conditions due to higher leakage of the pollutant[15]. However, the calculated TEQ is significant compared to other studies[24–26]. Due to the PAHs leakage, the ILCR was calculated to be 5.40E-08, which is interpreted as insignificant carcinogenic risk[25]. Of course, the importance of leaked PAHs from littered cigarette butts in ecological risk is also considered. As shown in Table 5, the calculated RQ_{NCs} associated with Dibenzo(a, h)anthracene, Naphthalene, and Acenaphthene was greater than 1, while the calculated RQ_{MPCs} for this group of PAHs was less than 1. Therefore, this condition indicated moderate risk[26]. Therefore, considering RQ_{NCs} less than 1, the individual ecological risk of other PAH types was negligible[24]. Considering that the RQ_{MPCs} associated with any of the PAH types was not higher than 1, the leakage of PAHs from littered cigarette butts did not lead to high risk conditions in the ecosystem[25].

Pollution caused by leakage of PAHs trapped in cigarette filter and its subsequent consequences and as a result soil and water pollution is influenced by three factors: the cigarette consumption, the ratio of littering,

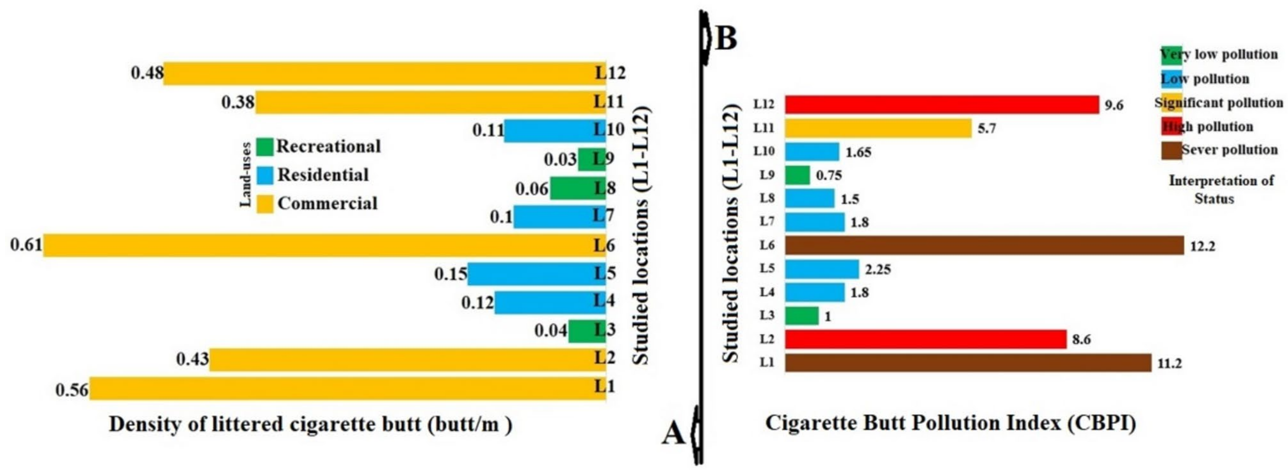

Fig. 2. Cigarette butt density (**A**) and calculated CBPI (**B**) in studied locations.

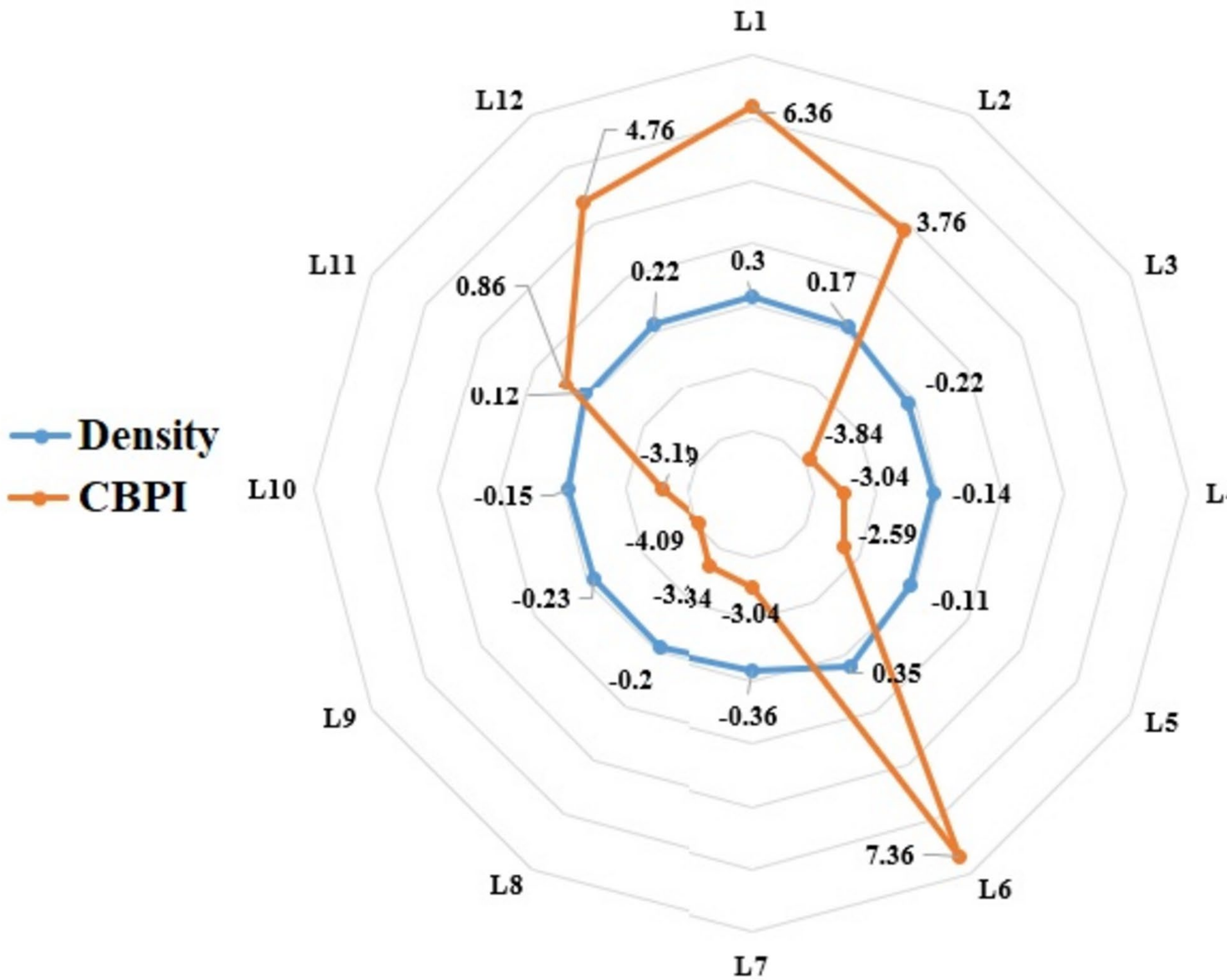

Fig. 3. Comparison of the distance from the average in CBPI and in the density of LCB.

and the efficiency of the cleaning service[17]. Therefore, different scenarios for reducing the leakage of PAHs from LCB lead to a reduction of the related risk, defined by improving the conditions caused by these three factors. Government planning and using the potential of NGOs to reduce smoking, especially among young people, is a necessity in controlling diseases related to cigarette smoke[38]. These activities will reduce smoking and generation of LCB. But one of the main problems in the management of LCB includes expensive and difficult collection, which is directly affected by the behavior of smokers in littering LCB[39]. Increasing the awareness of citizens about the health and environmental consequences related to LCB and correct the behavior of smokers will be effective in reducing the uncontrolled leakage of PAHs[32]. However, changing the behavior of smokers to reduce cigarette butt littering and reducing smoking are goals that will be pursued in the long term. Therefore, in an urgent measure, increasing the efficiency of the cleaning service in collecting LCB can reduce the amount of PAHs leakage[17]. The efficiency of the urban cleaning service is increased by using adapted equipment for better collection of LCB in low-access points[22].

Conclusion

The density distribution of LCB in Behbahan and the concentration of leaked PAHs were studied. In addition, the ecological and carcinogenicity risk caused by the contamination of water sources due to the leaked PAHs from littered cigarette butts were assessed. The results showed that in commercial land-uses, the density of LCB was 3.1 times higher than in residential land-uses. Calculating the status of pollution based on CBPI showed that 41.6% of the studied area was in the low pollution status, 8.3% in the significant pollution status, and 16.6% in the severe pollution status. Therefore, cigarette butt was a source of PAHs entering Behbahan's urban environment. The leakage of various types of PAHs from the LCB was estimated at 88,181 g/year. LCB are an abundant and scattered source of PAHs, which has made it difficult to control. To reduce the leakage of PAHs, scenarios should be defined based on factors affecting the density and durability of LCB, which include the cigarette consumption, the ratio of cigarette butt littering, and the efficiency of the cleaning service in collecting these litter.

Locations	PAH types															
	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Anthracene	Phenanthrene	Fluoranthene	Pyrene	Benzo(a)anthracene	Chrysene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzo[a]pyrene	Indeno(1,2,3-cd) pyrene	Benzo(g, h,i) perylene	Dibenzo(a, h) anthracene
L1	0.4799	0.0018	0.0588	0.0200	0.0023	0.0033	0.0049	0.0035	0.0025	0.0020	0.0024	0.0017	0.0021	0.0033	0.0033	0.0301
L2	0.3685	0.0014	0.0451	0.0153	0.0018	0.0025	0.0037	0.0027	0.0019	0.0015	0.0018	0.0013	0.0016	0.0025	0.0025	0.0231
L3	0.0342	0.001	0.0042	0.0014	0.0001	0.0002	0.0003	0.0002	0.0002	0.0001	0.0002	0.0001	0.0001	0.0002	0.0002	0.0021
L4	0.1028	0.0004	0.0126	0.0042	0.0005	0.0007	0.001	0.0007	0.0005	0.0004	0.0005	0.0003	0.0004	0.0007	0.0007	0.0064
L5	0.1285	0.0005	0.0157	0.0053	0.0006	0.0008	0.0013	0.0009	0.0007	0.0005	0.0006	0.0004	0.0005	0.0009	0.0009	0.008
L6	0.5228	0.002	0.064	0.0218	0.0025	0.0036	0.0053	0.0038	0.0027	0.0022	0.0026	0.0019	0.0023	0.0036	0.0036	0.0328
L7	0.0857	0.0003	0.0105	0.0035	0.0004	0.0006	0.0009	0.0006	0.0004	0.0004	0.0004	0.0003	0.0003	0.0006	0.0005	0.0053
L8	0.0514	0.0002	0.0063	0.0021	0.0002	0.0003	0.0005	0.0004	0.0002	0.0002	0.0002	0.0001	0.0002	0.0003	0.0003	0.0032
L9	0.0257	0.0001	0.0031	0.001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0016
L10	0.0942	0.0004	0.0115	0.0039	0.0004	0.0006	0.0009	0.0007	0.0005	0.0004	0.0004	0.0003	0.0004	0.0006	0.0006	0.0059
L11	0.3256	0.0012	0.0399	0.0136	0.0016	0.0022	0.0033	0.0024	0.0017	0.0014	0.0016	0.0011	0.0014	0.0023	0.0022	0.0204
L12	0.4114	0.0015	0.0504	0.0171	0.002	0.0028	0.0042	0.003	0.0021	0.0017	0.002	0.0015	0.0018	0.0028	0.0028	0.0258

Table 4. The concentration of PAHs leakage from LCB in the studied locations (μg/m^2).

Land-uses	PAH types															
	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Anthracene	Phenanthrene	Fluoranthene	Pyrene	Benz_a_anthracene	Chrysene	Benzo_b_fluoranthene	Benzo_k_fluoranthene	Benzo_a_pyrene	indeno_123cd_ pyrene	Benzo_ ghi_ perylene	Dibenz_a_h_ anthracene
Co*	8.40E+00	3.27E-01	1.03E+00	3.51E-01	4.13E-02	5.79E-02	8.64E-02	6.24E-02	4.44E-02	3.62E-02	4.24E-02	3.07E-02	3.77E-02	5.92E-02	5.88E-02	5.28E-01
TEF	0.001	0.001	0.001	0.001	0.01	0.001	0.001	0.001	0.1	0.01	0.1	0.1	1	1	0.001	0.1
NCs	1.2	0.7	0.7	0.7	0.7	3	3	0.7	0.7	3.4	0.1	0.4	0.5	0.4	0.3	0.5
MPCs	1200	70	70	70	70	300	300	70	70	340	10	40	50	40	30	50
BaPeqi	8.40E-03	3.27E-04	1.03E-03	3.51E-04	4.13E-04	5.79E-05	8.64E-05	6.24E-05	4.44E-03	3.62E-04	4.24E-03	3.07E-03	3.77E-02	5.92E-02	5.88E-05	5.28E-02
TEQ								1.73E-01								
RQ_{NCs}	7.00E+00	4.66E-01	1.47E+00	5.01E-01	5.90E-02	1.93E-02	2.88E-02	8.91E-02	6.35E-02	1.06E-02	4.24E-01	7.68E-02	7.53E-02	1.48E-01	1.96E-01	1.06E+00
RQ_{MPCs}	7.00E-03	4.66E-03	1.47E-02	5.01E-03	5.90E-04	1.93E-04	2.88E-04	8.91E-04	6.35E-04	1.06E-04	4.24E-03	7.68E-04	7.53E-04	1.48E-03	1.96E-03	1.06E-02
ILCR								5.40E-08								

Table 5. Risk assessment of leaked PAHs from littered cigarette butts into water resources. *Concentration (ng/L).

Data availability

The datasets generated and analyzed during the current study were available from the corresponding author on reasonable request.

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Declarations

Competing interests
The authors declare no competing interests.

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