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RESEARCH ARTICLE

Effect of cigarette butt on concentration of heavy metals in landfill leachate: health and ecological risk assessment

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Abstract

Cigarette butt is known as hazardous waste with numerous toxic and carcinogenic pollutants which impose serious concern for both the environment and human. Heavy metals are recognized as the most common pollutant in the cigarette butts. The concentration of some heavy metals (cadmium, chromium, nickel, lead and zinc) in leachate obtained from the pilot landfill with commingled waste and freshly smoked cigarettes butts were analyzed. The results showed that the addition of 0.76% (in weight) freshly smoked cigarette butts in landfilled waste increased total heavy metal concentration by 4.8%, while addition of 1.3% (in weight) freshly smoked cigarette butts leads to increased 3.72% of total heavy metals concentrations. An increased 10.52% and 3.43% health risk values were found from the leachate of the landfill pilot, where 1% freshly smoked cigarette butt and a littered cigarette were added, respectively. Overall, it can be concluded that cigarette butt landfilling is not recommended for management of this type of waste and is necessary to be replaced with less hazardous ways such as recycling.

Keywords Landfill leachate · Cigarette butt · Heavy metal · Risk assessment

Introduction

Smoking is a common phenomenon in different societies, even in countries where health and environmental aspects are important. Cigarette butt (CB) is known as toxic litter with detrimental and serious effects on environmental resources and living organisms [1–4]. Filter was added in the structure of cigarettes to keep smoker healthy via trapping the chemicals found in cigarette smoke [5]. As a result, CB is created with adsorbed toxic chemicals as post-smoking waste. CB is a waste with different types of pollutants including heavy metals [1, 6–8], nicotine [2], polycyclic aromatic hydrocarbons (PAHs) [8, 9], benzene, formaldehyde, cyanide, and other compounds which is estimated to be 4000–7000 components [1, 10–12], of which, 70 components are known as carcinogenic agents [1].

The effects of CB on different living organisms have been tested; detrimental effects have been reported and documented for these living organisms [4, 10, 13, 14]. In addition the high concentration levels of toxic chemicals in CB, the compounds including heavy metals, nicotine, and PAHs are confirmed to leach in the environment [2, 9, 15].

Over the recent years, CB has been a serious challenge. As most smokers do not dispose of CB appropriately in trash bins and put it off the ground [1, 11, 16, 17], collecting this litter is difficult and a costly process [17]. In many cases, CB collection has been reported to be a low-efficient process; this has caused CB to be observed extensively in various urban areas such as beaches [5, 7, 8, 10]. Furthermore, the common disposal in waste management such as landfill and incineration for CB is less embraced due to concerns imposed about pollutant emission [18]. However, the rate of leached materials due to presence of CB in landfilled waste into the environment has not been estimated, to date.

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The existence of different toxic chemical pollutants in various components of the solid waste leads to adverse effects on human health. Risk assessment is a relatively new and fast developing science, both in terms of its adoption as a formalized analytical process applied to environmental issues, and as a policy tool to assist regulators in the decision-making process [19]. Heavy metals in leachate containing CB components may find their way to drinking water resources. Therefore, the health risk assessment attributed to exposure to drinking water contaminated with heavy metals are required. The health risk assessment due to emission of heavy metals in solid waste stream is required. In addition, the health risk assessment paves the way to aware the importance of heavy metals in CB leached from solid waste into environment.

This study aimed to estimate the human and ecological risk of some heavy metals found in landfill leachate containing CB components in a pilot scale landfill. Therefore, the human and ecological risk associated with chromium (Cd), cadmium (Cr), nickel (Ni), lead (Pb), and zinc (Zn) in landfill leachate with CB components were estimated.

Method

Landfill pilot

To conduct the experimental study, three landfill pilots with the same size and characteristics were designed. At first, these pilots were filled with synthetic commingled solid waste [20, 21] based on Tehran municipal solid waste composition [22]; next, 5.5 kg municipal solid waste with 78% (in weight) organic waste, 5% paper and cardboard, 6% plastic, 2.5% metal, 1% tires, 3.5% textiles, 2% glass and 2% wood was disposed of in pilot 1(P1) as the control without CB addition. In pilot 2 (P2), 140 freshly smoked CBs (0.76% in weight) provided from seven most common used cigarette brands in Iranian market was added to the municipal waste composition. In pilot 3 (P3), 1.3% (in weight) collected littered CBs from urban streets was added in the municipal waste composition. The littered CBs were collected from the potential urban environment including malls, cafes, and urban transport stations in the evening [17, 23]. Commingled waste mass was shredded in 3 cm in length [20, 24, 25] and then loaded between two layers, including cover layer and bottom layer in the pilot; the bottom of the pilots was covered with a 5-cm gravel layer for transfer of leachate into hopper [21, 26, 27].

Heavy metal analysis

The leachate sample for heavy metals measurement was performed based on procedure outlined by the method 1311, USA EPA. After each sample preparation, the upper liquid was separated after centrifuging in 3000 rpm for 30 min and filtered through a 0.45-μm membrane filter (Millipore). The concentration of heavy metals in the solution was measured using a GF-AAS system (made in Australia).

Scenarios and risk assessment

Given the obtained heavy metals concentration in pilots, three scenarios were assumed and assessed. Before scenario assessment, the risk of 1% weight ratio of freshly smoked CB and littered CB in waste mass was assessed. Given that more than 75% of people leave CB as litter in the environment [1, 11, 16, 17], the first scenario (S1) was developed based on presence of 1% CB (in weight) in municipal waste composition (75% littered CB and 25% freshly smoked CB) (S1). In the second scenario (S2), the presence of 1% CB (in weight) in municipal waste composition with equal ratio of littered CB (50%) and freshly smoked CB (50%) was assessed. In the third scenario (S3) also, to investigate the effect of attempts for reducing CB littering by people in the landfill process, the existence of 1% CB (in weight) in municipal waste composition with the ratio of 25% littered CB and 75% freshly smoked CB was developed.

The health risk following exposure to released heavy metals from landfill leachate containing CB into groundwater resources, the worst scenario was employed. According to Baderna et al., it is assumed that the leachate may be diluted by 100 times in groundwater [28]. Therefore, the chronic daily intake (CDI (mg/kg day)) was calculated using the following equation [29, 30]:

$$CDI = [(C\ water \times WI \times ED \times EF)/(BW \times AT)] \quad (1)$$

where, C water is pollutant's concentration in water; WI refers to water intake (2 L/day); ED is exposure duration (30 years); EF is exposure frequency (350 days/year); BW is body weight (70 kg); AT is exposure averagetime:30 years for non-carcinogenic risk,70 years (lifetime) for carcinogenic compounds. Then, the hazard quotient (HQ) was calculated for non-carcinogenic compound in order to estimate possible toxic effects on humans due to the ingestion of leachate- contaminated water, using Eq (2):

$$HQ = CDI/RfD \quad (2)$$

where, HI is the hazard index and RfD is the reference dose for the selected compounds (mg/kg day). The RfD is a numerical estimate of a daily oral exposure to the human population, including sensitive subgroups such as children, that is not likely to cause harmful effects during a lifetime [31–33] . RfD values for Cd, Cr, Ni, Pb and Zn were 0.0005, 0.003, 0.02, 0.0035 and 0.3 mg/Kg body weight.day, respectively. For purpose of human risk assessment, exposures associated with HQ < 1 were deemed negligible (ISPRA, 2008). The overall HQ was considered as follows:

$$\Sigma HQ = HQ_{Cd} + HQ_{Cr} + HQ_{Ni} + HQ_{Pb} + HQ_{Zn} \quad (3)$$

Results

The data obtained from the pilot landfill leachate showed that the presence of CB in waste mass composition increased the concentration of all heavy metals studied. However, increased levels of all heavy metal concentrations were observed when the littered CB and freshly smoked CB were added to the waste composition. According to the findings obtained from the present research, the increased total concentration of all heavy metals in P2 was found to be 5.11% higher than that in P1. While, the total heavy metal concentration in P3 was found to be 3.85% more than that in P1. In the P1 the concentration of Cr, Cd, Pb, Ni, and Zn were 1.23, 0.511, 0.823, 1.07, and 4.69 mg/L, respectively.

The total concentration of five studied metals in the control pilot without CB, with freshly smoked CB, and with littered CB were found to be 8.329, 8.755, 8.650 mg/L, respectively. According to the results, given the existence of heavy metals in CB due to performance of the filter in trapping pollutants from cigarette smoke, CB is known as an origin source of heavy metals in landfill leachate. In addition, according to Table 1, the concentration levels of heavy metals in landfill leachates with different waste composition vary depending on the CB type.

The HQ values for exposure to heavy metals through consuming drinking water polluted with leachate is presented for various proportional ratio of CB to waste in weight (Fig. 2). As observed, the HQ values for the landfill leachate with 1% of freshly smoked CB and with 1% littered CB was increased from 0.474 in control pilot to 0.524 and 0.491, respectively. According to Fig. 1, addition of 1% of freshly smoked CB and littered CB to waste bulk composition lead to increased the HQ values by 10.52 and 3.43%, respectively.

However, Fig. 2 shows that the ecological risk of Cr, Cd, and Pb concentration in the landfill leachate and pilot loaded with 1% freshly smoked CB and littered CB (in weight) were estimated to be 0.296 and 0.278, respectively. The ecological risk of the landfill leachate in control pilot without CB was estimated to be 0.269. The increased ecological risk values of 1% (in weight) freshly smoked CB and 1% (in weight) littered CB in landfilled waste was found to be 10.05 and 3.22%, respectively.

Given the difference in the concentration levels of heavy metals in landfill leachate obtained from different pilots loaded with freshly smoked CB and littered CB in waste composition, among the assumed scenarios, the risk of S3 caused by landfilling municipal solid waste and 0.75% weight ratio of freshly smoked CB and 0.25% littered CB was estimated to be 0.516.

However, according to Fig. 3, the risk associated with S2 by landfilling municipal solid waste with 0.5% weight ratio of freshly smoked CB and 0.5% littered CB was estimated to be 0.508. In case of sS1, the risk for landfilling municipal solid waste with 0.25% weight ratio of freshly smoked CB and 0.75% littered CB was calculated to be 0.499. Based on Fig. 3, the ecological risk values in S1, S2, and S3 were estimated to be 0.283, 0.287 and 0.292, respectively, indicating higher effect of freshly smoked CB on the rate of HQ values and ecological risk. Moreover, the existence of 1% CB (in weight) in S3 increased the rate of HQ values and ecological risk by 8.74 and 8.34%, respectively as compared with waste composition without CB (Fig. 4). However, these increases for HQ values in S1 and S2 were estimated to be 25.4 and 68.07%, respectively more than S1 and S2, respectively. Figure 4 also shows that the corresponding ecological risk in S3 caused by the concentration of Cr, Cd, and Pb in landfill leachates was found to be more than the other two scenarios.

However, based on the conditions studied in the present research and composition of municipal solid waste in Iran, the risk caused by the existence of heavy metals in CB for 1 kg of the freshly smoked CB and 1 kg of the littered CB in municipal solid waste mass, were estimated to be 691.518 and 258.982, respectively, (Fig. 5).

Discussion

Although cigarette filters are designed for trapping the pollutants of cigarette smoke [34, 35], the trapped pollutants are gradually leached into the environment. The rate of heavy metals leakage from CB is not equal; Pb and strontium (Sr) have a more leaching ratio (59%), while this value for aluminum, and titanium are predicted to be approximately 1.2 and 0.7%, respectively [15]. It should also be noted that the initial concentration of heavy metals in CB was not equal. In addition, the CB from smoking

Table 1 Increased heavy metal contents in the leachate of freshly smoked CB (P2) and littered CB (P3)

Pilot	CB weight ratio	Increased metal concentration in leachate (micrograms per liter) compared to P1				
		Cr	Cd	Pb	Ni	Zn
P2	0.76%	25	16	273	28	84
P3	1.3%	17	13	155	30	106

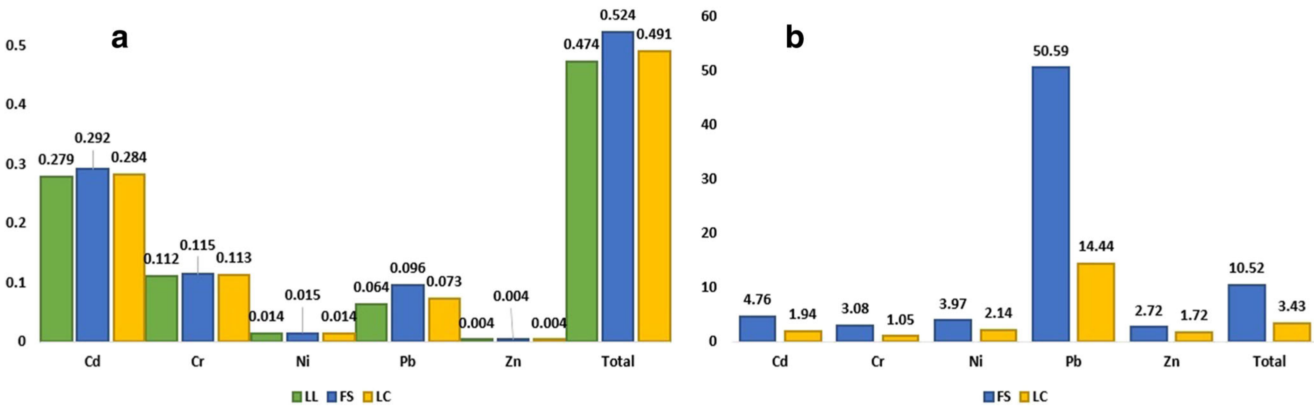

Fig. 1 **a**: HQ values for landfill leachate without CB (LL), landfill leachate with 1% weight ratio freshly smoked CB (FS), and landfill leachate with 1% weight ratio littered CB (LC); **b**: The percentage increase in HQ values for landfill leachate with 1% weight ratio freshly smoked CB (FS), and landfill leachate with 1% weight ratio littered CB (LC) compared to landfill leachate without CB

different brands of cigarettes, has a different concentration levels of particular metals [11]. Generally, the concentration and type of different pollutants in various cigarette brands are different from each other because the origin of the pollutants in the planting tobacco for the production of cigarettes in the factory is affected by different factors including the type of soil, type of tobacco, added materials during manufacturing in the factory, and characteristics of the filter such as density and porosity [7, 10, 15, 36]. The smoking behavior in smokers is different. The smoking behavior can affect the rate of smoke passage from the filter and consequently change the concentration levels of pollutants [10]. Given these parameters and considering that loaded freshly smoked CB in P2 was provided from seven high-consumption cigarette brands in Iran, the results provided in Table 1 about P2 can ideally represent current conditions of solid waste management in Iran. However, given that there is no accurate method for estimating the durability of littered CB in different environments such as urban environment and environmental factors such as humidity affect the rate of pollutant leakage from littered CB [2, 37, 38], the amount of remaining pollutant in littered CB as the result of pollutant leakage from the landfill leachate depends on environmental factors and the quality of streets cleaning, Therefore, although the samples of loaded littered CB in P3 are collected randomly may not represent the existing condition in Iranian cities, the difference between the data in Table 1 for P2 and P3 shows well the leakage of some pollutants from littered CB into the environment before collecting. Although this issue has decreased the risk of pollutants caused by littered CB in waste mass compared to freshly smoked CB, however, given the proven negative effects of CB on organisms [10], it can lead to a serious concern for living organisms. In a similar study, Dobaradaran et al. studied the concentration of some metals in littered CB in the northern coasts of the Persian Gulf. The authors investigated marine current effects on metal concentration in CB with sampling 10-day interval sampling in the beach. They showed that the mean concentration of Cd, Ni, and Zn concentration (first day, after 10 days) was respectively (0.38, 0.35), (2.3, 1.87) and (15.31, 12.35) microgram per CB gram, indicating metals leakage from CB in the environment [7] .

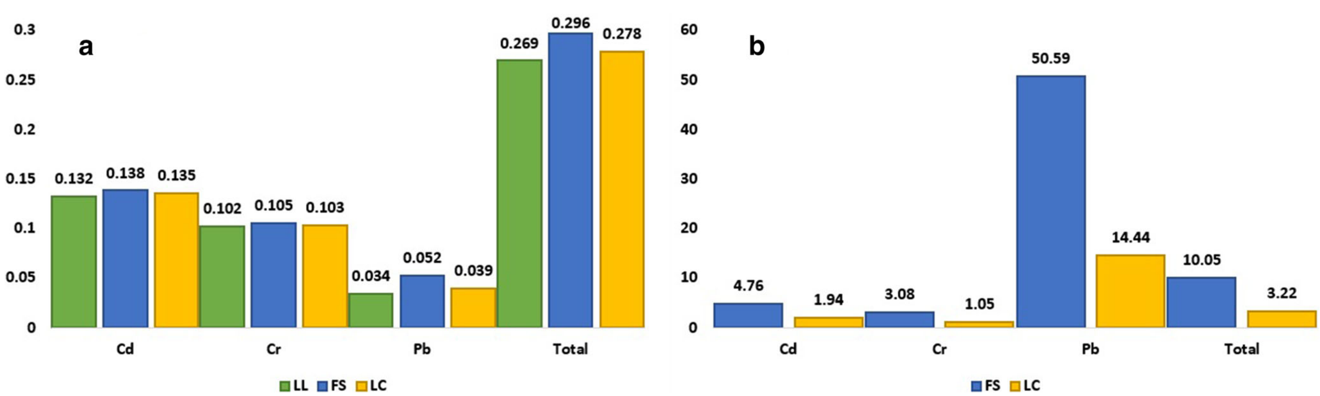

Fig. 2 **a**: Ecological risk for landfill leachate without CB (LL), landfill leachate with 1% weight ratio freshly smoked CB (FS), and landfill leachate with 1% weight ratio littered CB (LC); **b**: The percentage increase in Ecological risk for landfill leachate with 1% weight ratio freshly smoked CB (FS), and landfill leachate with 1% weight ratio littered CB (LC) compared to landfill leachate without CB

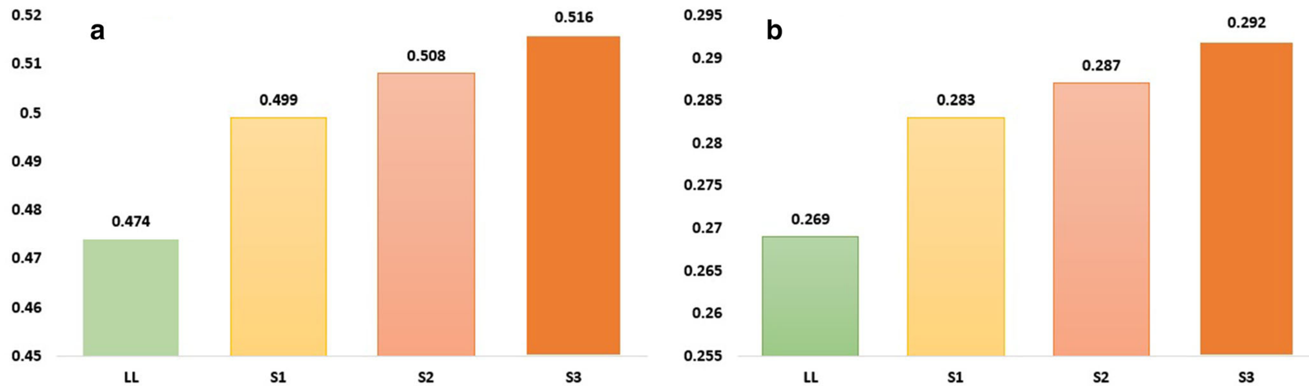

Fig. 3 **a**: HQ values for landfill leachate without CB (LL) and landfill leachate with CB in different scenarios (S1, S2, S3); **b**: Ecological risk for landfill leachate without CB (LL) and landfill leachate with CB in different scenarios (S1, S2, S3)

The results obtained from the present research indicated that smokers' behaviors can affect the disposing of CB and consequently the fate of its pollutants. Although smokers leave CB in the environment as litter [16, 17], some methods and suggestions such as labeling, waste tax, fines, and education have been proposed for reducing CB littering [35, 39, 40]. Focusing on the increased public knowledge as an important solution for CB littering [35, 39], leads to increased freshly smoked CB compared to litter CB in the municipal solid waste composition in the future. In this case, the emission of CB will be reduced and accordingly lower the respective detrimental effects on the environment. However, comparing the S1 to S3, it can be concluded that these conditions increases the risk owing to higher concentration of pollutants in waste mass. As indicated in Fig. 3, these conditions increased the risk attributed to five heavy metals in landfill leachate, considering the increase of correct disposal of CB from 25 to 75% by smokers, is equal to 25% for each 1% weight ratio CB in waste mass.

Although there is no similar study in the field of the effect of trapped pollutants in CB on increasing the risk of landfill leachate, there are some studies in the field of risks from different pollutants of landfill leachate. Investigating the contamination of drinking water by leachate mixing by Iqbal et al. in a young landfill site showed that drinking water was contaminated by heavy metals and *E. coli* within the 2 k radius of the site. The results of their study showed that arsenic (As) and Cd has the highest HQ of 1.36 and 1.53 respectively, whereas their cancer risk effect (CRE0) in drinking water was also positive with 6.1×10^{-4} and 4.78×10^{-3}, respectively, as well as the overall potential ecological risk index (PERI) of the metals was high (312.49) which was highly degrading for the environment [41]. Negi et al. in India reported that leachate is the potential source of groundwater contamination. The authors reported that the hazard index of three landfill sites were estimated to be 0.61, 0.53, and 0.01 mg/kg/day in pre-monsoon and 0.38, 0.24, and 0.01 mg/kg/day in post-monsoon indicating non-carcinogenic health risks [42]. In the study on health risk assessment of heavy metal pollution in groundwater around an exposed dumpsite in southwestern, Nigeria, Laniyan et al. reported that the concentration of Pb and Cd in water was beyond proposed permissible limits in the World Health Organization's (WHO) Standards. The authors reported that the origin of heavy metals has been attributed to the leakage of such metals from the wastes such as the used battery, tines, and electronics. They also

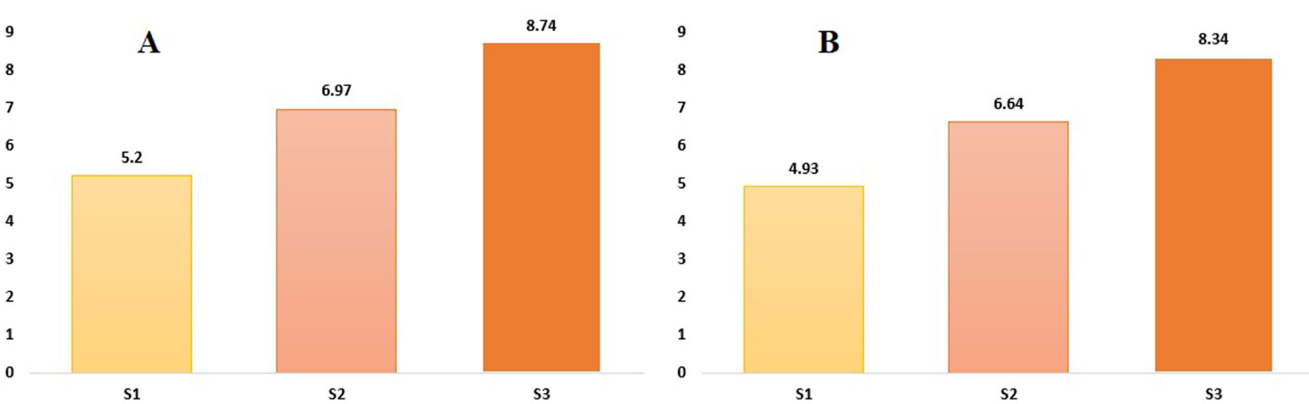

Fig. 4 **a**: The percentage of change in HQ due to exposure with leachate containing HMs at various scenarios; **b**: the percentage of change in ecological risk due to exposure with leachate containing HMs at various scenarios

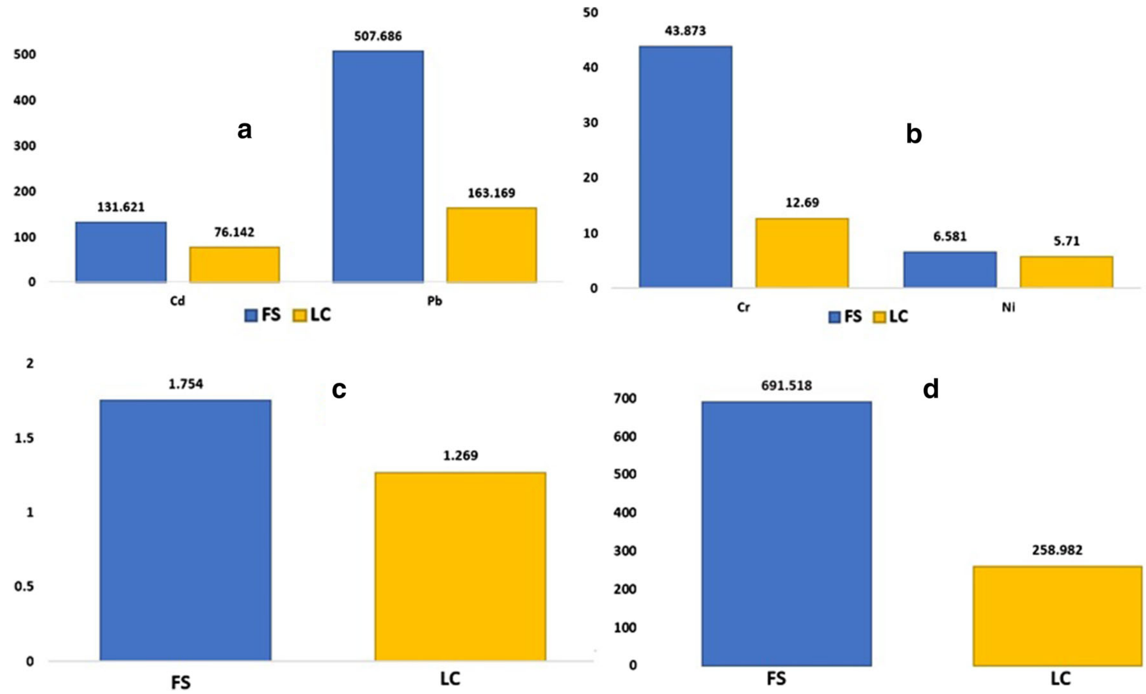

Fig. 5 HQ values caused by the existence Cd and Pb (**a**), Cr and Ni (**b**), zinc (**c**), and total (**d**) in landfill leachate for 1 kg freshly smoked CB (FS) and 1 kg littered CB (LC) in municipal solid waste mass

stated that heavy metal pollution can cause deleterious health effects that can lead to short- and long-term diseases such as keratosis (skin hardening), lung cancer, bladder cancer, and ultimately death if proactive steps are not taken [43]. The leached pollutant from different origins of waste in the leachate such as heavy metals are consequences of presence of CB, they can be indirectly threat via some routes such as accumulation in the plants, affected by leachate, and then their consumption by human beings. For example, Ruchuwararak et al. studied the bioaccumulation of heavy metals in local edible plants near a municipal landfill, they reported that studied plants might cause health hazards to consumers from leakage of Pb and Cd [44]. Therefore, given the stated complications for the existence of heavy metals in landfill leachate on the human's health and the environment in the studies [41–44] and our findings, CB will be important as a resource for releasing these pollutants through leachates.

Regarding municipal solid waste can be as a origin of emission pollutant to the environment and many studies mention this risk [45], proper management of landfill leachate is necessity. Increased concentration levels of heavy metals caused by CB in landfill leachate, the increased corresponding risk will bring a serious concern. Given that CB containing numerous pollutants is prevalent litter in the environment [5, 10], landfilling due to presence of toxic trapped materials leakage in the filter, has ecological and health complications. Given that landfill leachate treatment is a complicated process and also the increasing concentration of pollutants in it will enhance the cost or reduction of treatment efficiency, CB is better to be managed separately from the municipal solid waste. However, separate collection and cleaning the CB from trapped pollutants before landfilling with other components of municipal solid waste is a necessity. The findings of this study can confirm the concern of releasing pollutant from CB as the result of landfilling and incineration as the common methods of final disposal of waste causes CB recycling to be an alternative for CB landfilling [18].

Conclusion

The effect of the presence of CB in the composition of municipal solid waste on the concentration of five heavy metals in landfill leachate was studied. It was found that CB could increase the content of the heavy metals in the landfill leachate. An increase in the heavy metals as a result of CB landfilling with other compounds of municipal solid waste can lead to an increase in the hazard index in landfill leachate. Therefore, based on the findings, the separate management of CB from other municipal solid wastes is of great importance, and low hazardous strategies such as recycling of CB should be taken into account.

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Declarations

Conflict of interest The authors of this article declare that they have no conflict of interests.

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