Determination of the selected heavy metal and metalloid contents in various types of plastic bags

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Abstract

The immense plastic bags (PBs) consumption is the potential threat for environment and public health due to discharging toxic pollutants (i.e., metals and metalloids) throughout its entire life cycle. The purpose of the study was to investigate the heavy metal (HM) contents in PE, HDPE, LDPE and PVC bags with several colors and applications. The HM contents in the PB were analyzed by ICP–OES after acid digestion. Results demonstrated that the HM contents in PB notably disagreed based on the used polymer types, colors and applications. The highest contents of Pb, Cr, Cd, As, Cu and Zn were 66, 75, 16, 28, 96 and 154 in mg/kg unit, respectively in PE bags; 71, 74, 34, 39, 430 and 212 in mg/kg unit, respectively in HDPE bags; 12, 74, 23, 43, 158 and 54 in mg/kg unit, respectively in LDPE bags; and 16, 23, 474, 12, 45 and 90 in mg/kg unit, respectively in PVC bags. Furthermore, 12 out of 36 PB samples were noticed to violate the standards (ISO 8124-3) in terms of Pb, Cr, Cd and As contents. So there is the potentiality of HM and metalloid pollution from discarded PB during treatment, recycling and disposal.

Keywords Environment · Health · Heavy metal · Plastic bag · Pollution

Introduction

Synthetic polymer appeared around 1950s, since then, modern life has become unthinkable without it [51]. Global plastic production surged from 1.5 million tonnes (Mt) in 1950 to 288 Mt. in 2012 and a remarkable part of it is consumed in the packaging sector. The quantity of plastic solid waste (PSW) has also increased and a fraction of which are recycled due to high market demand [39, 61]. However, plastic packaging waste (PPW) and plastic bag waste (PBW) are comparatively unsuitable for recycling, because they cannot be recycled into new materials and resins/granules like as rigid PSW. Consequently, such PSW are left as litters which ultimately expand dumpsite or landfill areas [1, 63].

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Consumption of plastic packaging materials (PPM) is rapidly increasing in the modern society. Plastic bag (PB) has stood as a common form of packaging material and as inevitable in our daily life [6, 7]. Globally, PB production is enhancing day to day and according to Miller [42], about 500 billion to one trillion PB are consumed worldwide annually. PB consumption rate is relatively high in the industrialized countries but developing countries suffer more from PBW pollution due to dearth of awareness and recycling opportunity [7]. For instance, the total amount of PPW soared from 0.2 Mt. in 2015 to 1.5 Mt. in 2017 in China, especially in the postal and courier businesses [57].

Globally, a large number of PBW are released to the environment annually, posing tremendous threats to public health, ecosystem, wildlife, fish and agriculture [28, 38, 52]. Numerous studies have been conducted on PBW; accordingly, PB with a minimum thickness (20–50 µm) has been banned in many countries to eliminate environmental hazards such as urban flashfloods and greenhouse gas (GHG) emission [17, 24, 53]. However, packaging tax is indirectly an effective policy instrument for reducing the PBW generation by switching to use reusable bags [5, 16, 54].

PBW can be collected for effective recycling or disposal by either source separation or post-separation [23]. The curbside collection system can enhance collection efficiency and

its environment friendly way [65, 66]. The annual consumed PPM merely in the postal and courier businesses produced 52,400 t of CO₂ equivalent emissions in China [56]. The adoption of the best recycling practices along with reduction in the consumption of single-use PB demonstrated around 1.46 Mt. of CO₂ equivalent emissions reduction in the European countries [4].

PB and other PPM are often discarded just after single use which are often mixed up with municipal solid waste (MSW) [43]. Subsequently, the resulted PBW and PPW are landfilled, incinerated and recycled or thrown away illegally, where they might gradually discharge toxicity and pollute the surrounding environments [2, 10, 46]. If PBW is burned then release toxic chemicals to the air [26, 28]. It is estimated that 20 Mt. of plastic litters enter into ocean and 100,000 marine animals die each year due to plastic pollution. Single-use PB and PPM are a great source of such pollution [19, 50, 64].

Heavy metals (HM) are blended as additives to improve the physical and chemical properties in PB, or unintentionally added as pollutants [18, 34, 35]. The global annual discharge of additives from PSW (mainly from plasticized PVC) to the marine environments was estimated to be 35–917 t [58]. Still, there is no sufficient information on HM contents in PB. Some toxic HM (e.g., chromium) is banned for using in PPM in the European countries. However, there is no regulation for controlling HM contents in PB worldwide, so such pollution is increasing [1]. Hence, post- and during-disposal of PBW, their impact needs to be concerned as they have long term indirect health and environmental effects [3, 14, 25].

Globally, many researchers have identified different PPM containing high levels of toxic metals. For instance, the contents of Pb and Cr in marine PE litters were estimated as 45 and 14 mg/kg, respectively in Japan [44]. On the other hands, the high levels of HM were detected in some PE rubbish and supermarket bags, whereas Cr and Pb contents in the rubbish

bags violated the standards. There was no similarity among PB of different types and colors in HM contents [25]. In addition, the HM contents in different PB varied based on origins due to violating national or international standards [3, 33].

PB, which is intimately connected to our daily life, has not really been quested as one of the source of HM pollution. Hence, it is tough task to monitor and regulate HM contents in PB. The study was designed to identify the levels of Pb, Cr, Cd, As, Cu, Zn, Mn, Se and Ba in commonly consumed PB based on used colors and intended of usages.

Methodology

Sampling

Total 36 PB samples were collected from supermarkets in Shanghai and details are shown in Fig. 1 and Table SI-1. All the sample bags were brought to homogenous size and dried at 55 °C for overnight before further analysis. All the experimental instruments were soaked in 10% HNO₃ solution overnight earlier on use to remove unwanted contaminants. Subsequently, all wares were rinsed by tap water, followed by distilled water and Milli-Q water and then dried at 55 °C for 2 h.

Digestion method selection

To detect HM contents in plastic products and PSW several digestion methods have been established worldwide such as HNO₃-H₂SO₄, HNO₃-H₂O₂, HNO₃-Microwave and EN1122 [41, 45, 49, 55]. Sakurai et al. [55] showed about 95% of Cd and Cr recovery by HNO₃ and HNO₃-H₂SO₄ digestions with microwave from PE. Pb was found 99% recovery from PE by HNO₃ digestion, but only 1/3 by HNO₃-H₂SO₄ digestion.

Fig. 1 Image of collected several types of plastic bags for analysis

Malaxechevarria and Millán [41] demonstrated 100% Cd recovery from PVC by HNO_3 - H_2SO_4 digestion. Similarly, Özer and Güçer [49] found that Cd and Pb recovery were close to the certified values of PVC by HNO_3 - H_2SO_4 digestion. EN1122 digestion showed 99% and 95% of Cd recovery from PE and ABS, respectively, while 100% and 99% by HNO_3 - H_2O_2 and EPA3051A, respectively. HNO_3 - H_2O_2 exhibited 99% and 96% of Cr recovery from PE and ABS, respectively while 99% and 95%, respectively by EPA3051A. Pb recovery was found 99% and 97% from PE and ABS, respectively by HNO_3 - H_2O_2 and EPA3051A [45]. Use of H_2SO_4 in digestion reduces Pb recovery due to the formation of PbSO_4 and digestion with microwave or without microwave did not affect significantly in HM recovery [1, 45]. Therefore, we adopted HNO_3 - H_2O_2 for the digestion of selected PB samples.

Quality assurance and control

Every time two blanks were digested for HM contents analysis in PB samples to check the contamination and error. Furthermore, all the samples were repeated twice in every test or experiment and also triplicated whereas the first obtained values were not intimate to check the reliability of achieved data. PVC certified reference materials (GBW 08417–08421) from the Administration for Quality Supervision Inspection and Quarantine (AQSIQ) agency, China were used to check the accuracy of the method. The used HNO_3 - H_2O_2 digestion method was compared with HNO_3 - H_2SO_4 and HNO_3 -Microwave methods to check the accuracy. Here, HNO_3 - H_2O_2 was found as better option in HM/metalloid extraction efficiency and ease of operation (Table SI-2).

HNO_3 - H_2O_2 digestion

About 0.2 g of PB sample and 20 ml of 65% HNO_3 acid solution (SinoPharm Company Ltd., China) were poured to PTFE vessel in order. Besides, the sample was soaked for 30 min in the vessel locked with lid and then heated at 175 °C on the heat plate (EHD36 Plus, LabTech, China) for 90 min. After digestion, PTFE vessel with digested solution was cooled down to room temperature. Again, 10 ml of 30% H_2O_2 solution (SinoPharm Company Ltd., China) was added and then heated for 60 min with lid at the same temperature. Finally, the vessel was uncovered to evaporate the solution for 15 min.

ICP-OES analysis

The remained digested solutions were diluted with Milli-Q water and filtered through 0.45 μm membrane filters. Then the filtrates and 2 ml concentrated HNO_3 were transferred to 50 ml volumetric flasks. The 0.2 g sample was still remained in the filtrates because during heating it was covered with lid

to protect from evaporation. Finally, 10 ml of solution was taken to a test tube for ICP-OES analysis (720ES, Agilent, United States). The multi-element standard solutions (SPEX CertiPrep, United States) with 0.0 ppm, 0.2 ppm, 0.4 ppm, 0.6 ppm, 0.8 ppm and 1 ppm were used to create the calibration graphs for the interest elements. The contents of Pb, Cr, Cd, As, Cu, Zn, Mn, Ba and Se in the solutions after acid digestion were analyzed by ICP-OES, and calculated in mg/kg unit. The limit of detection (LOD) for individual elements by ICP-OES is stated in Table 1.

Data analysis

The HM/metalloid contents in different PB based on polymer type, color and usage were arranged in Microsoft Office Excel (Version: 2010) software. Then each HM contents in each polymer type was analyzed by descriptive statistics, regression analysis and the significant difference between PE, HDPE, LDPE and PVC bags were compared by analyzing T-test.

Results

Heavy metal and metalloid standards

Globally, concern regarding HM/metalloid contents in plastic materials is increasing rapidly due to its associated environmental and health hazards. Many countries have their own standards for HM/metalloid contents in different plastic products, especially ASTM F963 [60], AS-NZS 8124-3(or ISO 8124-3) [29], EN 71 [20], 94/62/EC [12] and EU No. 10/2011 [21]. The contents of Pb, Cd, Cr, Hg, Sb and Sn in PB is one of the potential threats to public health and environment from PPM during their service life, recycling and disposal [36]. However, there is no specific standard for HM/metalloid contents in PB though a large volume of PB is globally consumed daily and their application has been diversified. Therefore, HM/metalloid

Table 1 The LOD for HM and metalloid by ICP-OES (Agilent 720) in the study

Element	Wavelength (nm)	Detection limits ($\mu\text{g/L}$)
Pb	220.353	<0.8
Cr	267.716	<0.15
Cd	214.439	<0.05
As	188.980	<1.0
Mn	257.610	<0.03
Se	196.026	<2.0
Cu	327.395	<0.3
Zn	213.857	<0.2
Ba	455.403	<0.03

content in PB can be compared with PPM standards. Amongst the 9 studied HMs/metalloids, the standard values are available only for 6 elements in plastic toys and 4 elements for PPM and food contact PPM (Table 2).

HM/metalloid contents in polyethylene bag

The HM/metalloid contents varied in polyethylene (PE) bags based on colors along with purpose of usage and most of the bags demonstrated lower contents. The selected HM/metalloid contents were measured ranging from not detectable (ND) to 66 of Pb, ND-75 of Cr, ND-18 of Cd, ND-28 of As, ND-96 of Cu, ND-154 of Zn, ND-20 of Mn, ND-26 of Se and 0.01–318 of Ba in mg/kg unit, respectively (Table 3). Descriptive analysis of HM/metalloid contents in different PE bags was conducted and the reported mean values for Pb, Cr, Cd, As, Cu, Zn, Mn, Se and Ba were 13.38, 18.58, 3.5, 5.03, 23.53, 45.47, 8.03, 5.6 and 77.65, respectively in mg/kg unit while the median value were 1.3, 5.1, 0, 0.7, 19.3, 19.2, 7.2, 0.7 and 45.9, respectively. The wide range of metals contents indicated the great temporal variation, resulting from the strongly heterogeneous HM contents.

On an average, the order of HM/metalloid contents in the PE bags with different colors were as blue> multi-color> pink> white> purple> yellow> transparent> green; while in application, garbage> shopping> food. It is clear that dark or multi colors bags contained higher levels of HM than light colors. As such bags are largely utilized for food packaging or wrapping and most of them are single-use, so there are direct consumers' health risks [25, 27, 44].

Amongst 9 PE samples, only 3 violated the standards for HM contents in plastic products includes 67.3 mg/kg of Cr in yellow food bag, 27.9 mg/kg of As in purple garbage bag and 65.8 mg/kg of Pb and 75.1 mg/kg of Cr in black garbage bag. In contrast, Huerta-Pujol et al. [25] found that Cr (87 mg/kg) and Pb (458 mg/kg) in trash bags exceeded the standards for plastic toys by ASTM F963 and ISO 8124-3, and food contact materials by EU No. 10/2011. Nakashima et al. [44] showed Pb and total Cr in PE litters (Ookushi beach), hardly exceeded

100 mg/kg that is regulated by EU regulation on PPM and PPW [22]. Leaching is the predominant factor for discharging HM from PSW to the environment. About 1.54% of the original Pb, Cr and Cd contents in PE building blocks were detected as leachable by HCl at 37 °C [30].

HM/metalloid contents in high density polyethylene bag

The HM/metalloid contents in several high density polyethylene (HDPE) bags are shown in Table 4. Different levels of HM/metalloid contents were observed in different sorts of HDPE bags based on color and application. The HM/metalloid contents of HDPE bags were identified ranging from ND-71 of Pb, ND-74 of Cr, ND-34 of Cd, ND-39 of As, 2–430 of Cu, ND-212 of Zn, 0.2–25 of Mn, ND-13 of Se and 17–251 of Ba in mg/kg unit, respectively. Descriptive analysis of HM/metalloid contents in different PE bags was conducted and the reported mean values for Pb, Cr, Cd, As, Cu, Zn, Mn, Se and Ba were 16.17, 20.88, 10.52, 11.62, 99.01, 98.42, 6.82, 2.98 and 136.56, respectively in mg/kg unit while the median value were 10.39, 8.9, 5.6, 3.1, 37.21, 98.5, 3.7, 0.9 and 130.7, respectively. The wide range of metals contents indicated the great temporal variation, resulting from the strongly heterogeneous HM contents.

On an average, the sequence of HM/metalloid contents order in HDPE bags based on color were as blue> multi-color> purple> white> pink> black> yellow> transparent> green; and the order of usage is miscellaneous> garbage> shopping> polybag> food. As such bags are hardly used for food packaging and largely for shopping and grocery, so there are less direct health risks. However, such bags have indirectly environmental impacts during treatment, recycling and disposal [27, 31, 32].

3 out of 9 samples crossed the permissible limits for HM contents in plastic products includes 39.1 mg/kg of As in yellow ziplock bag, 73.6 mg/kg of Cr in green document bag, and 71.2 mg/kg of Pb, 62.7 mg/kg of Cr and 34.6 mg/kg of As in black polybag. Still, there is no study on HM contents

Table 2 Standards for HM/metalloid contents (mg/kg) in different plastic products

Metal/metalloid	ASTM F963 (Toy)	ISO 8124-3 (Toy)	EN71 (Toy)	94/62/EC (Packaging material)	EU No. 10/2011 (Food contact material)
Pb	90	90	90	100	60
Cr	60	60	60	100	60
Cd	75	75	75	100	60
As	25	25	25	NA	NA
Ba	1000	1000	1000	NA	NA
Se	500	500	500	NA	NA

NA Not available

Table 3 Metal/metalloid contents (mg/kg) in polyethylene bags

Sample	Pb	Cr	Cd	As	Cu	Zn	Mn	Se	Ba
PE-1A	ND	ND	7.9 ± 1.3	ND	10.4 ± 0.2	8 ± 1.1	20.1 ± 3	1.9 ± 2.3	0.1 ± 0.1
PE-2A	0.3 ± 2.4	67.3 ± 1.2	ND	0.7 ± 1.8	ND	16.5 ± 4.1	0.9 ± 0.1	ND	66.2 ± 0.5
PE-3B	1.3 ± 4.8	0.01 ± 0.1	5.3 ± 1.1	ND	28.5 ± 1.9	ND	ND	7.2 ± 1.1	0.01 ± 0
PE-4B	11.7 ± 3.2	5.1 ± 0.1	ND	27.9 ± 0.31	ND	38.2 ± 0.9	9.4 ± 0.1	ND	45.9 ± 0.8
PE-5B	ND	10.2 ± 0.3	ND	9.8 ± 2.1	21.7 ± 1.5	11.1 ± 9.8	2.5 ± 0.1	ND	318.4 ± 7.4
PE-6B	24.8 ± 1.3	ND	17.5 ± 2.6	ND	95.6 ± 2.3	106.8 ± 4.7	14.6 ± 0.01	14.3 ± 2.3	33.6 ± 0.8
PE-7B	1.2 ± 2.4	ND	ND	1.6 ± 6.9	5.5 ± 0.4	19.2 ± 0.4	4.9 ± 0.1	ND	0.5 ± 01
PE-8F	15.4 ± 1.9	9.5 ± 1.6	0.8 ± 0.1	5.3 ± 0.2	19.3 ± 2.2	55.7 ± 4.5	7.2 ± 1.1	0.7 ± 0.1	112.6 ± 7.9
PE-9B	65.8 ± 2.9	75.1 ± 3.2	ND	ND	30.8 ± 3.6	153.7 ± 0.6	12.7 ± 0.3	26.3 ± 32.	121.5 ± 13.7

ND Not detectable, and dark colored value indicates crossing standard limits

in HDPE bags; however, some investigations were conducted on other plastic products, especially PPM. For instance, Kiyataka et al. [32] detected that Pb in three HDPE yoghurt packaging materials (394, 366 and 462 mg/kg) exceeding the EU standard for HM in PPM and PPW. Khan and Khan [31] observed leaching trend less than 2.0 mg/kg of Pb and Cr from different HDPE food containers at 60 °C by distilled water and acetic acid. Similarly, Pb was leached out 1.8 mg/kg by acetic acid and 2.1 mg/kg by HCl from HDPE rubber ball [40].

HM/metalloid contents in low density polyethylene bag

The HM/metalloid contents in different low density polyethylene (LDPE) bags were detected ranging from ND–12 of Pb, ND–74 of Cr, ND–23 of Cd, ND–43 of As, ND–158 of Cu, ND–54 of Zn, ND–17 of Mn, ND–15 of Se and 1–197 of Ba in mg/kg unit, respectively which are shown in Table 5. Descriptive analysis of HM/metalloid contents in different LDPE bags was conducted and the reported mean values for Pb, Cr, Cd, As, Cu, Zn, Mn, Se and Ba were 6.29, 9.69, 7.33, 11.19, 28.62, 22.50, 6.11, 4.23 and 65.77, respectively in mg/kg unit while the median value were 4.14, 0.44, 5.3, 0,

13.45, 8.73, 3.83, 2.4 and 13.27, respectively. The wide range of metals contents indicated the great temporal variation, resulting from the strongly heterogeneous HM contents.

On an average, the order of HM contents in different LDPE bags with regard to colors were as pink > multi-color > black > blue > white > yellow > green > transparent > purple; and in case of usage were as shopping > miscellaneous > garbage > polybag > sampling. According to usage of LDPE bags, there are no direct health effects; however, it has long term indirect health and environmental effects due to illegal disposal and uncontrolled treatment [3, 9, 27].

4 out of 9 LDPE bags exceeded the standards for HM contents in plastic materials includes 42.7, 26.9 and 3.9 mg/kg of As in white polybag, pink shopping bag and blue miscellaneous bag, respectively. Similarly, 78.4 mg/kg of Cr and 27.2 mg/kg of As in multi-color LDPE bag violated the standards. None has yet conducted studies on HM contents in LDPE bags. Therefore, HM contents in LDPE bags can be compared with other analogous plastic products. Bode et al. [9] found that Cd level crossed the standards (ASTM F963, ISO 8124-3, EU No. 10/2011) extremely (>1000 mg/kg) in household mixed PSW and high contents were occasionally found for Se, Ba, Sb and Hg that also varied based on colors. Al-Qutob et al. [3]

Table 4 Metal/metalloid contents (mg/kg) in HDPE bags

Sample	Pb	Cr	Cd	As	Cu	Zn	Mn	Se	Ba
HD-1A	14.6 ± 1.5	ND	3.1 ± 0.2	0.9 ± 0.1	29.4 ± 2.7	65.3 ± 4.5	3.7 ± 0.1	0	130.7 ± 6.9
HD-2B	21.44 ± 1.9	11.57 ± 0.6	ND	ND	1.73 ± 0.3	212.23 ± 0.2	6.33 ± 0.1	2.5 ± 0.6	74.31 ± 1.3
HD-3C	ND	ND	12 ± 0.2	39.1 ± 2.1	37.21 ± 7.2	0	0.17 ± 0.1	0	184.81 ± 31.6
HD-4B	10.39 ± 3.9	4.25 ± 1.5	21.3 ± 3.3	1.61 ± 1.8	10.79 ± 0.3	54.58 ± 5.8	0.25 ± 0.1	4.3 ± 0.3	144.48 ± 2.9
HD-5B	4.83 ± 1.7	6.91 ± 0.3	5.6 ± 0	ND	1.17 ± 2	104.39 ± 25.5	3.52 ± 3.3	0.9 ± 0.1	238.72 ± 1.8
HD-6H	3.59 ± 0.6	20 ± 2.5	ND	10 ± 2.1	429.68 ± 1.4	130.36 ± 12.9	11.19 ± 0.3	0	110.11 ± 1
HD-7E	11.9 ± 1.2	73.6 ± 3.2	34.2 ± 2.7	3.1 ± 0.4	69.3 ± 3.8	98.5 ± 3.7	25.1 ± 4.2	13.2 ± 2.1	78.3 ± 6.1
HD-8F	7.6 ± 0.5	8.9 ± 1.1	18.5 ± 2.9	15.3 ± 2.6	259.4 ± 37.2	63.2 ± 5.2	7.6 ± 1.3	5.9 ± 0.4	250.7 ± 23.3
HD-9C	71.2 ± 3.7	62.7 ± 2.6	ND	34.6 ± 3.2	52.42 ± 0.9	157.24 ± 2.3	3.55 ± 0.1	0	16.88 ± 0.2

ND Not detectable, and dark colored value indicates crossing standard limits

Table 5 Metal/metalloid contents (mg/kg) in LDPE bags

Sample	Pb	Cr	Cd	As	Cu	Zn	Mn	Se	Ba
LD-1G	0.76 ± 0.4	ND	0.9 ± 0.1	ND	5.1 ± 0.3	2.3 ± 0.2	5.2 ± 1.1	2.1 ± 0.3	13.27 ± 1.4
LD-2C	3.24 ± 0.9	0.59 ± 0.9	ND	42.7 ± 2.4	8.92 ± 1.1	44.15 ± 1.3	0.89 ± 0.1	5.3 ± 1.2	2.45 ± 1
LD-3B	10.75 ± 0.5	ND	5.3 ± 0.7	ND	31.16 ± 4.5	8.73 ± 2.6	13.92 ± 0.1	2.4 ± 0.5	7.15 ± 0.2
LD-4F	4.14 ± 1.2	2.6 ± 0.5	12.4 ± 2.1	26.9 ± 2.5	157.92 ± 17.9	54.03 ± 8.1	3.83 ± 0.1	ND	197.27 ± 4
LD-5B	ND	ND	ND	ND	ND	ND	ND	15.2 ± 2.6	8.46 ± 0.2
LD-6H	19.2 ± 2.3	5.2 ± 1.1	23.1 ± 3.6	3.9 ± 0.7	13.9 ± 1.5	65.2 ± 2.8	17.3 ± 2.8	ND	123.7 ± 11.5
LD-7B	6.17 ± 0.7	ND	8.9 ± 1.2	ND	16.36 ± 0.4	ND	ND	3.9 ± 1.3	1.12 ± 0.1
LD-8F	ND	78.4 ± 3.2	5.3 ± 1.4	27.2 ± 1.5	13.45 ± 2.8	25.53 ± 3.5	2.86 ± 0.2	ND	106.29 ± 3.4
LD-9B	12.41 ± 1.1	0.44 ± 0.3	10.04 ± 1.3	ND	10.76 ± 0.3	2.6 ± 1.2	11 ± 2.2	9.2 ± 1.4	132.2 ± 9.7

ND Not detectable, and dark colored value indicates crossing standard limits

observed that Palestine's children's soft toys contained higher levels of HM than Israel, leading threat for the exposures.

HM/metalloid contents in polyvinyl chloride bag

The selected HM/metalloid contents were investigated in the polyvinyl chloride (PVC) bags and are presented in Table 6. The HM/metalloid contents of PVC bags were detected as ND-16 of Pb, ND-23 of Cr, ND-474 of Cd, ND-12 of As, 0.3–45 of Cu, ND-90 of Zn, ND-10 of Mn, ND-9 of Se and 0.4–295 of Ba in mg/kg unit, respectively. Descriptive analysis of HM/metalloid contents in different PVC bags was conducted and the reported mean values for Pb, Cr, Cd, As, Cu, Zn, Mn, Se and Ba were 4.9, 4.76, 102.11, 4.89, 17.01, 31.02, 3.81, 2.54 and 83.83, respectively in mg/kg unit while the median value were 3.1, 0.4, 3.9, 5.3, 12.3, 19.7, 2.1, 1.3 and 34.2, respectively. The wide range of metals contents indicated the great temporal variation, resulting from the strongly heterogeneous HM contents.

On an average, the order of HM contents in the PVC samples were found as, purple > multi-color > white >

pink > green > black > blue > yellow > transparent; and in case of intended of use – document > ziplock. PVC bags are widely used for packaging or storing medicine, goods, chemicals and others for relatively long time due to their rigid structure. They are comparatively suitable for recycling than all other bags [30, 47].

Among the studied HM, only Cd in purple document bag (473.8 mg/kg) and mixed color ziplock bag (391.9 mg/kg) were noticed to exceed the standards for plastic toys or PPM (ASTM F963, ISO 8124-3, and EU No. 10/2011). Nobody has investigated yet on HM contents in PVC bags but several studies done on other PVC products. Omolaoye et al. [47] found that Pb, Cd, Ni, Cu, Zn, Cr, Co and Mn levels were higher in PVC toys compared to non-PVC toys in Nigeria, imported from China. Besides, about 17% of the toy samples violated Pb, Cd and Cr contents standards that pose a threat to the children exposed to such toys. Kumar and Pastore [33] identified some soft PVC toys in India which also exceeded the standards by ISO 8124-3. About 1.54% of the original Pb, Cr and Cd contents in PVC toys were detected as leachable by HCl at 37 °C [30].

Table 6 Metal/metalloid contents (mg/kg) in PVC bags

Sample	Pb	Cr	Cd	As	Cu	Zn	Mn	Se	Ba
PV-1D	ND	0.4 ± 0.2	24 ± 0.1	1.3 ± 0.1	10.01 ± 0.9	ND	ND	1.3 ± 0.2	0.4 ± 0.1
PV-2D	10.2 ± 0.8	ND	3.9 ± 0.5	3.6 ± 0.2	1.1 ± 0.1	90.4 ± 0.6	5.2 ± 0.1	ND	295.4 ± 2.9
PV-3E	2.7 ± 0.5	11.5 ± 1.3	ND	ND	12.3 ± 1.6	14.1 ± 3.9	7.3 ± 1.2	ND	0.2 ± 0.1
PV-4E	3.1 ± 0	2.03 ± 0.3	23.1 ± 5.3	5.3 ± 0.8	27.4 ± 1.7	ND	ND	3.3 ± 1.2	78.5 ± 5
PV-5E	15.7 ± 0.3	ND	473.8 ± 16.5	7.6 ± 0.4	0.3 ± 0.2	43.8 ± 3.6	2.1 ± 0.1	4.5 ± 1.1	271.81.1
PV-6E	ND	0.2 ± 0.3	ND	ND	17.1 ± 1.4	19.7 ± 6.6	7.4 ± 0.2	ND	0.8 ± 0.4
PV-7E	5.2 ± 0.3	5.5 ± 1.2	ND	5.3 ± 0.5	35.3 ± 0.2	42.4 ± 6.6	10.2 ± 1.1	9.1 ± 0.7	34.2 ± 3.1
PV-8D	ND	23.2 ± 3.1	391.9 ± 9.4	11.7 ± 2.4	4.2 ± 0.6	68.8 ± 6.3	ND	4.7 ± 0.5	62 ± 5.6
PV-9E	7.2 ± 1.7	ND	2.3 ± 0.4	9.2 ± 2.2	45.4 ± 3.9	ND	2.1 ± 0	ND	11.2 ± 2.1

ND Not detectable, and dark colored value indicates crossing standard limits

Comparison and discussion

The more toxic HM/metalloid in PB are Pb, Cr, Cd and As which excess level contents is threaten for the environment and public health. Therefore, the significant difference between PE, HDPE, LDPE and PVC bags in case of those HM/metalloid contents were analyzed. The mean contents difference of HM/metalloid for different types of PB was compared using t-Test (Table 7). The mean contents of Pb, Cr, Cd and As in different PB were statistically unequal. There is no statistically significant difference in terms of HM/metalloid contents between PE, HDPE, LDPE and PVC bags because *P* value were greater than 0.05. This could be

explained by the absence of unique standards in blending different HM/metalloid in PB as well as color. So, there is potentiality of HM/metalloid pollution from PB when they are using or discarded for disposing of (discarded).

Disposal of PSW through landfilling is not suitable for being non-biodegradable and containing toxic HM/metalloids. Many scientists are trying to decompose PSW by using microbes (bacteria) and enzyme but still not got popularity due to being cost effective and slow process. Biological MSW treatment methods include composting and anaerobic digestion is also not suitable [1, 7, 28]. Therefore, recycling of PSW is better choice either by mechanical or thermal way as economic and environment friendly. However, mechanical recycling of PBW

Table 7 Comparison of the mean contents of HMs in PBs between PE, HDPE, LDPE and PVC

Heavy metal	Regression analysis			t-Test: Two-sample assuming equal variances					
	R ²	F	Sig. F	t	Sig. (two tailed)	Mean diff.	Std. error diff.	95% confidence interval	
								Lower limit	Upper limit
PE-HDPE									
Pb	0.69	15.4	0.01	−0.11	0.91	−2.78	−0.02	−8.87	6.26
Cr	0.11	0.83	0.39	−0.17	0.86	−2.30	0.85	−2.92	−2.26
Cd	0.16	1.31	0.29	−1.73	0.11	−7.02	−2.01	−11.78	−5.22
As	0.01	0.07	0.80	−0.88	0.39	−5.21	−1.98	−10.09	−1.41
PE-LDPE									
Pb	0.28	2.77	0.14	0.98	0.34	7.09	4.98	2.57	13.58
Cr	0.02	0.11	0.75	0.68	0.51	8.89	1.45	0.19	19.80
Cd	0.36	3.9	0.09	−1.51	0.15	−3.83	−0.48	−7.47	−2.89
As	0.05	0.38	0.56	−0.78	0.45	−4.78	−2.40	−9.98	−0.77
PE-PVC									
Pb	0.01	0.04	0.85	1.17	0.26	8.49	5.39	4.12	14.97
Cr	0.09	0.67	0.44	1.36	0.19	13.82	7.42	7.95	23.24
Cd	0.09	0.69	0.43	−1.54	0.14	−98.61	−60.96	−155.93	−61.92
As	0.17	1.48	0.26	0.51	0.62	1.52	1.73	−0.58	4.34
HDPE-LDPE									
Pb	0.04	0.31	0.60	1.10	0.29	9.87	5.0	3.72	15.04
Cr	0.03	0.21	0.66	0.90	0.38	11.19	0.60	3.32	21.86
Cd	0.00	0.02	0.89	0.64	0.53	3.2	1.53	−0.11	6.75
As	0.11	0.88	0.38	0.05	0.96	0.43	−0.42	−5.08	5.84
HDPE-PVC									
Pb	0.04	0.30	0.60	1.29	0.22	11.27	5.41	5.28	16.43
Cr	0.02	0.17	0.69	1.74	0.10	16.12	6.57	11.24	25.14
Cd	0.00	0.01	0.91	−1.42	0.18	−91.59	−58.95	−147.50	−53.35
As	0.00	0.00	0.95	1.33	0.21	6.73	3.71	3.80	11.45
LDPE-PVC									
Pb	0.08	0.63	0.45	0.49	0.63	1.4	0.41	−0.55	3.50
Cr	0.74	20.29	0.00	0.55	0.59	4.93	5.97	−1.13	12.33
Cd	0.15	1.22	0.31	−1.47	0.16	−94.78	−60.48	−150.76	−56.73
As	0.05	0.38	0.56	1.17	0.26	6.3	4.13	3.12	11.38

Sig. = significance, diff. = difference and Std. = standard deviation. Difference is significant at 0.05 level (two-tailed) when sig. <0.05

is not suitable due to being light weight. Discarded PE, HDPE, LDPE and PVC bags can be disposed of through thermal treatment for either energy or fuel recovery [2, 69].

Among the studied volatile HM (Pb, Cd and Zn), the contents of Pb were higher in PE bags; Zn in PE, HDPE and PVC bags; and Cd in PVC bags. While the contaminant levels of other semi-volatile and non-volatile HM such as As and Cr in PE, HDPE and LDPE bags; Cu in PE and HDPE bags; and Ba in all types of studied PB were similar. The combustion conditions include temperature, oxygen, partial pressure, and compound speciation significantly affects metal volatilization [15, 48]. For Pb and Cd, volatilization was higher at higher temperatures while volatilization of As decreased as temperature increased at above 1000 °C [15]. Cd volatility after 5 min combustion is much higher than Pb at 600 °C, but Pb emission increases to 90% at 1000 °C. Therefore, metal emission increases with combustion time, until it reaches a plateau [13]. Cd exhibited 75% volatilization at 500 °C of PVC waste combustion, while Zn and Pb showed moderate volatilization. However, volatilization of Zn and Pb were depressed in mild-heating combustion as kaolin and calcium can react with them to make more durable metal compounds. Furthermore, the volatility of Cu was lower in incineration due to the existence of Al, Si and Fe [67].

Chlorine emission during thermal treatment is a global challenge because it affects HM release [11]. Metal chlorides are usually more stable than their oxides or sulfides in environment, because the chlorides have a lower Gibbs free energy of formation. Chlorides are more stable than oxides under the same partial pressure of chlorine and oxygen [68]. Almost 100% of Pb and Zn compounds are volatilized regardless of the chlorine content in MSW. Thus, Pb and Zn compounds are converted from reduced metals to metal chlorides such as $PbCl_2$ and $ZnCl_2$ with an increase in the ratio of chlorine to each metal [48]. The formation of $ZnCl_2$ and $PbCl_2$ is strongly affected by chlorine supply, which is a predominant compound of Zn and Pb when high amounts of chlorine are present [68]. During incineration of PVC, the amount of organic compounds and toxic gases such as HCN, SO_2 and HCl increased [8, 62]. The addition of PVC waste during combustion might enhance the release of HM. Therefore, PVC wastes should be isolated from mixed MSW and then treated (thermal) individually due to high possibility of HM/metalloid emission [67]. Considering literature, it is better to recycle PVC bags rather than thermal treatment for energy recovery. The United States and Australia are recycling large volume of PVC wastes due to the depletion of natural resources and low-cost of recycling PVC [59]. Lee et al. [37] also studied the potentiality of PVC waste recycling for materials recovery in Korea.

Conclusion

The environmental and public health burdens are enhancing day to day due to illegal and unfair disposal of huge amount of

PBW worldwide. PSW are recycled and/or treated for recovering energy as-well-as discourage disposal through landfills in the European countries. Among different polymers, usage of PVC in PB production is a potential source of pollution during disposal and thermal treatment. Some PB samples were found to violate the standard limits of Pb, Cr, Cd and As contents that denote potential threat for the exposures and environment. According to the HM contents in bags, the reduced consumption PVC bag is suggested as a management approach. However, PBW have higher low calorific value that is a potential source of energy. Thereby, further study should be conducted on thermal treatment of PB along with pollution control and energy recovery.

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Compliance with ethical standards

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