Research Paper

# Used Batteries in the Municipal Solid Waste Stream: Management of the Challenges and Heavy Metal Contents

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## ABSTRACT

**Background:** Hazardous materials, such as used batteries contain heavy metals and enter the solid waste stream, ending up in landfills. The present study was done to determine the amount of used batteries in Iran and their heavy metal contents in the batteries entering the landfill site in Tabriz.

**Methods:** A questionnaire was applied to assess the current management condition of the used batteries in Tabriz and Ardabil as the representative cities of the entire country. The heavy metal content of 15 AA-sized batteries was determined by inductively coupled plasma.

**Results:** Our findings showed that 14.7% of the used batteries in Iran have been imported, and approximately 76% and 24% of the batteries analyzed at the landfill site were AA-sized and cellphone batteries, respectively. In 60% of the studied batteries, the total heavy metal content was less than 100 mg/kg.

**Conclusion:** The results of this study could be a useful reference for global and local policymakers in developing effective regulations for the use of cleaner materials in the battery industry and controlling the used batteries from their generation to the end of the battery life.

## 1. Introduction

Advanced electronic technologies, such as cellphones, home computers, laptops, digital cameras, radios, remote controls, and electronic toys are now an inherent element of human life [1]. Battery is the common component of these devices, which are classified as primary batteries (e.g. zinc-carbon, alkaline zinc-manganese, mercury-oxide, and silver-oxide) and secondary/rechargeable batteries (nickel-cadmium, nickel-metal hydride, and lithium-ion) [2, 3]. Almost all batteries contain metallic alloys as electrodes or to increase their life span. Therefore, valuable metal components,

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such as cobalt, manganese, and zinc should be recycled in used batteries [4-6]. On the other hand, the inappropriate management, and disposal of used batteries cause severe environmental and health damages, especially due to the presence of hazardous heavy metals [7-16].

In addition to hazardous waste management as an important issue in most developing and some developed countries, used batteries have an ambiguous fate everywhere. According to the reports (EUROPA, 2004), only 45% of household batteries are sent to incinerators or sanitary landfills, and only 17% are recycled [17]. The collection and recovery rates of used batteries differ in other countries; in 2008, the collection rate of the used batteries in Japan was reported to be 26% [2]. According to the European Commission, approximately 800,000 tons of automotive batteries, 190,000 tons of industrial batteries, and 160,000 tons of consumer batteries enter the European Union each year [17]. The rate of battery use is extremely high in developing countries. For instance, nearly one billion batteries were consumed in 2003 in Brazil, which is equivalent to six units per person.

In the landfills and dumpsites, which are particularly large in number in developing countries, heavy metals could potentially leach into the soil, groundwater, and surface waters. Moreover, aquifers may be affected by unlined landfills for several years [18]. As mentioned earlier, batteries are composed of several metallic components, including cadmium, lithium, nickel, zinc, copper, lead, chromium, and mercury [7, 19, 20], and even the trace levels of these elements are extremely harmful to health [9, 14, 21, 22].

Solid waste degradation and leachate production process occur gradually. After several years of waste burial, heavy metals could be released into aquifers and other subsurface water resources. Numerous studies have addressed the issue of heavy metals in landfill leachate, which is partially associated with the disposal of used batteries [2, 23-26]. For instance, in seven evaluated 'spot' samples of different commercial household batteries, it is observed that in the leaching solution, the concentration of elements, such as mercury, zinc, and manganese was above the standard limits of 0.05, 0.2, and 2 mg/L, respectively.

There is a global concern regarding household hazardous wastes, while accurate data are scarce to describe the actual management and handling of spent battery waste. In addition, there is insufficient data on the features of used batteries in Iran, especially in terms of the heavy metal content and waste production rates. Considering the current conditions in Iran and other countries with relatively successful experiences, some practical management strategies have also been proposed to improve the waste management and disposal of used batteries in Iran. The present study was done to quantitatively and qualitatively examine used batteries and their heavy metal content in Iran. The amount of the used batteries delivered to the Tabriz landfill site was considered as a representative sample, and the current management status and future challenges were also discussed. In addition, the handling, recycling, final disposal, and current policies regarding used batteries were assessed.

## 2. Materials and Methods

### The generation rate of used batteries in Iran

In order to quantitatively examine the used batteries in Iran, the date of production and the import/export rates of all types of batteries (automotive, motor vehicles, and industrial batteries) were collected from the organizations and ministries in charge, such as the Ministry of Industry, Mine, and Trade and the Iranian Census Center, from February 2009 to March 2016. As the units of data received from different organizations were not the same (e.g. exports and imports in kg and battery production in numbers), all the measurement units were converted into the kg of used batteries.

Due to the wide variety of batteries, we consulted some experts to assume an average weight for each battery; for instance, 15 kg was considered per automobile battery. Based on the number of the produced batteries by each company, the estimated weight of the batteries produced by the company was calculated. Regarding AA-sized batteries, 15 samples were selected to analyze their heavy metal content and weighed in the laboratory, with the mean weight estimated at 15.89±3.4 g. As the selected companies were not working at full capacity, 30% of the nominal capacity was used in the calculations based on the data received from the Ministry of Industry.

The useful life of the batteries is roughly 2-5 years; in the present study, the useful life of two years was assumed for all the batteries. Moreover, the available data were taken into account for the mentioned period to estimate the amount of the current waste produced from the batteries per year (2009-2016) in Iran. Finally, the weight of the used batteries and population were considered to calculate the kg per capita of the used batteries by dividing the weight of the used batteries into the population.

### Heavy metal contents of household batteries

In order to determine the heavy metal contents of the household batteries, 15 types of batteries were collected as samples from different producers/countries, which were consumed and disposed to the landfill site of Tabriz. Table 1 shows the features of the analyzed batteries. The analyzed batteries were all AA-sized, and the corresponding voltage was 1.5 V, with the exception of battery No. 15 (1.2 V).

In this study, all the experimental materials were purchased from Merck Co. (Germany), except stated otherwise. The experiments were performed at the chemistry laboratory of the School of Health, Tabriz University of Medical Sciences.

To prepare the samples, each collected battery was opened in the laboratory [27]. Depending on each part weight ratio to the total battery weight, 1 g was taken from each spent battery and digested. The digestion of batteries was performed in accordance with the EPA Method 3050B, which has been suggested for solid samples [27-29]. In addition, heavy metal measurement was carried out by inductively coupled plasma (ICP-OES-SPECTRO-ARCOS).

### Amount and percentage of used batteries entering the landfill site

In order to determine the quantity of the used batteries in urban solid waste, the local authorities and landfill site manager of Tabriz city were initially contacted, and the used batteries entering the landfill site were analyzed daily within a period of 21 days. A material recovery facility is located in Tabriz landfill site, and the separation and weighting processes were performed using the recycling facilities and instruments located at the site. On a daily basis, approximately 300 t of comingled waste was sent to the recycling process, and the remainder was directly landfilled without further processing. Battery separation was also performed by conveyors and a trained individual, and the weight percentage of the used batteries was determined.

### Survey of the current status of used battery waste management

In order to assess the current management status (collection, storage, and disposal) of the used batteries in Iran, the two provinces of East Azerbaijan and Ardabil were selected from 31 provinces as the representatives of the entire country. Then, the assessment was carried out in the capital cities of these provinces (i.e., Tabriz and Ardabil, respectively). According to the Iranian Census Center, Tabriz was the sixth most populated city of Iran, and about 42% (1.773 million) of the population of East Azerbaijan lived in this city in 2016. With a population of approximately 600,000, Ardabil was reported to be the eighteenth most populated city in Iran in the same years (S.C.O. Iran, 2016).

In the present study, a combination of methods was applied to assess the current management status, including checklists, site visits and observations, conversations with the authorities, using scientific databases, and contacting municipalities, local and national environmental protection agencies, and other organizations.

## 3. Results and Discussion

### The generation rate of used batteries in Iran

Table 2 shows the number of batteries that were produced, imported to Iran, and exported from Iran from 2009-2015. Accordingly, the production rate was quite fixed during 2010-2012, while the battery production increased by almost 20,000 t/year during 2012-2015. Furthermore, only legally imported and reported batteries were considered in our study. Because the actual import rate may be higher than our estimation, the number of batteries might also be higher than the values presented in Table 2. According to the information in Table 2, 14.7% of the spent batteries were imported.

Table 3 shows the number of the spent batteries and the corresponding per capita generation rate. Accordingly, the generation rate of the used batteries in Iran was within the range of 131.74-273.34 kt/year from 2011-2016. Considering the Iranian population in this period, the corresponding per capita generation rate of the used batteries was estimated at 1.75-3.41 kg/year.

As mentioned earlier, feasible data could not be collected on illegally imported batteries, and their share in waste production per capita generation could not be calculated in the present study. As such, the reported rate might be higher than the estimated rate in Table 3. The table also shows that the per capita battery use almost doubled during 2011-2016.

Table 4 presents the comparison of the per capita generation of battery waste between some countries. Accordingly, the per capita battery use in Australia in 2010 and 2014 was reported to be 5.75 and 7.91 kg/year, respectively, which is almost twice the consumption rate

**Table 1.** Specifications of the studied used batteries

| No. | Battery Name | MC[a] | Note |
|---|---|---|---|
| 1 | Duracell | China | NR[b] |
| 2 | Maxell | Indonesia | Alkaline, mercury- and cadmium-free. NR |
| 3 | Sonika | China | NR |
| 4 | King Power | China | Heavy-duty, mercury-free, NR |
| 5 | Persian Power | Iran | NR |
| 6 | Toshiba | Japan | Heavy-duty, mercury and cadmium free, NR |
| 7 | Duracell | China | Heavy-duty, mercury-free, NR |
| 8 | Sony | Poland | Dry battery, mercury-free, NR |
| 9 | Osel | China | Heavy-duty, mercury-free, NR |
| 10 | Tianbar | China | Heavy-duty, mercury-free, NR |
| 11 | Panasonic | Indonesia | Mercury-free, NR |
| 12 | Unomat | USA | Heavy-duty, NR |
| 13 | Camelion | Germany | Super heavy-duty, NR |
| 14 | Oxel | China | Heavy-duty, mercury- and cadmium-free, NR |
| 15 | C.F.L | Turkey | Nickel-cadmium battery, R[c] |

[a]Manufacturing Country, [b]Not-Rechargeable, [c]Rechargeable.

in Iran. However, the battery use rate in the EU was reported to be about half of the rate of Iran in 2002, while the per capita waste generated in Italy was estimated to be 15% of the Iranian per capita. It seems that the quality of the batteries in Iran is lower compared with the batteries used in other countries (e.g. Italy), which could explain the higher battery consumption rate in Iran. Other studies have also reported the per capita battery waste generation in other countries, while the obtained results cannot be compared due to the inconsistent units used in these reports.

## The heavy metal content of used batteries

Table 5 indicates the heavy metal content of the 15 AA batteries investigated in the present study. Notably, data

**Table 2.** Batteries produced, imported, and exported from 2009 to 2015 (Ton/Year)

| Year | Production | Imported | Exported | Total Consumed |
|---|---|---|---|---|
| 2009 | 112,518 | 19,229 | 8.7 | 131,738,3 |
| 2010 | 162,958 | 15,975 | 17.5 | 178,915,5 |
| 2011 | 165,763 | 14,475 | 1.4 | 180,236,6 |
| 2012 | 167,586 | 28,309 | 0.77 | 195,894,2 |
| 2013 | 185,106 | 44,258 | 0 | 229,364 |
| 2014 | 207,542 | 65,801 | 1.3 | 273,341,7 |
| 2015 | 226,636 | 35,244 | 10.5 | 261,869,5 |

**Table 3.** Used batteries and per capita use between 2011 and 2016

| Year | Used Batteries (Kt) | Population (Millions) | Per Capita (Kg/Year) |
|---|---|---|---|
| 2011 | 131.74 | 75.15 | 1.75 |
| 2012 | 178.92 | 76.08 | 2.35 |
| 2013 | 180.24 | 77.03 | 2.34 |
| 2014 | 195.89 | 77.98 | 2.51 |
| 2015 | 229.36 | 78.95 | 2.90 |
| 2016 | 273.34 | 79.93 | 3.42 |

on mercury have not been presented since the mercury content was below the detection limit of ICP-OES in all the samples. According to the findings, the contents of cadmium, lead, zinc, nickel, copper, aluminum, lithium, arsenic, barium, cobalt, chromium, tin, vanadium, and molybdenum significantly differed in all the batteries.

According to the information in Table 5, all the batteries had a detectable cadmium level, except for the Camelion brand. The cadmium content in some labels was also extremely high, with the maximum amount (464.87 mg/kg) measured in the C.F.L and Ni-Cd batteries, as well as the rechargeable batteries made in Turkey. The Persian Power battery had a cadmium content of 2 mg/kg and ranked second in this regard, followed by Oxel, King Power, Sonika, and Osel batteries. On the other hand, the cadmium contents of the other brands were negligible. In a study in this regard, Barrett et al. evaluated the heavy metal content of 50 disposable batteries with 27 different labels, and cadmium was detectable in only 8% of the batteries [11]. In another study conducted in Japan, the cadmium content of zinc-C batteries was within the range of 86-180 mg/kg, while the cadmium content of alkaline batteries was lower than 1 mg/kg [2]. Only in the C.F.L. battery, the cadmium content has been shown to be higher than the EU batteries directive 2006/66/EC limit of 20 mg/kg [30].

In the current research, all the batteries contained lead, with a maximum level of 26.286 mg/kg in the Persian Power battery. The mean lead content of the batteries was estimated at 15.56 mg/kg, which is lower than the amount reported by Barrett et al. (127.7 mg/kg) [11]. However, none of the studied batteries violated the EU batteries directive 2006/66/EC limit of 40 mg/kg. The zinc variation in the batteries was not as high as other heavy metals, and the maximum, minimum, and mean zinc content was estimated at 7.49, 3.56, and 5.324 mg/kg, respectively.

According to the current research, nickel concentration broadly differed between the batteries. The C.F.L battery had the highest nickel content (747.028 mg/kg), followed by Maxell, Duracell, Persian Power, Sonika, Toshiba, Tianbar, and Camelion batteries. According to Karnchanawong and Limpiteeprakan, a higher amount of cadmium could be released into the leachate by Ni-Cd batteries [2]. In addition, the maximum copper and aluminum contents were calculated to be 218.539 and

**Table 4.** Comparison of per capita battery use in different countries

| Country | Population | Per Capita (Kg/Year) | Ratio to Iran | Reference |
|---|---|---|---|---|
| Iran | 80,917,422 | 3.23 | 1 | Present study |
| Australia | 22,162,863 | 5.7 | 1.75 | 30 |
| Australia | 23,622,353 | 6.2 | 1.91 | |
| EU | 727,265,060 | 1.66 | 0.51 | 18 |
| Italy | 57,147,081 | 0.5 | 0.15 | 31 |
| China | 1,351,000,000 | 0.518 | 0.15 | 9 |

**Table 5.** Heavy metal contents of the used batteries (mg/kg dry weight)

| Brand as labled | Hg | Cd | Pb | Zn | Mn | Ni | Cu | Al |
|---|---|---|---|---|---|---|---|---|
| Dorcell | <DL[*] | 0.84 | 17.9 | 6 | 1.5 | 0.16 | 0.76 | 2.3 |
| Sony | <DL | 0.04 | 10.4 | 4.1 | 1.5 | 1.2 | 0.56 | 10.2 |
| Osel | <DL | 1.08 | 20.9 | 6.9 | 1.65 | 0.94 | 0.28 | 11.4 |
| Tianbar | <DL | 0.04 | 10.3 | 7.4 | 1.3 | 4.6 | 218.5 | 2.7 |
| Panosonic | <DL | 0.04 | 11.1 | 4.7 | 1.1 | 1.6 | 1.6 | 7.6 |
| Unomat | <DL | 0.05 | 18.2 | 5.8 | 1.2 | 0.239 | 0.18 | 0.8 |
| Camelion | <DL | BDL | 4.8 | 5.9 | 1.3 | 4.6 | 179.8 | 3 |
| Duracell | <DL | 0.03 | 9.4 | 3.9 | 2 | 26.8 | 173.5 | 0.25 |
| Maxell | <DL | 35 | 9.3 | 3.5 | 2 | 47.9 | 147.2 | 0.5 |
| Sonika | <DL | 1.14 | 15.6 | 3.6 | 1 | 8.7 | 0.853 | 30.5 |
| King POWER | <DL | 1.63 | 19.7 | 5.9 | 1.3 | 0.9 | 83.2 | 3 |
| Persian POWER | <DL | 2.01 | 26.3 | 5.7 | 1.1 | 11.8 | 0.6 | 15.4 |
| Toshiba | <DL | 0.04 | 20.6 | 5.1 | 1.2 | 7.3 | 0.4 | 3.5 |
| Oxel | <DL | 1.66 | 20.8 | 5.7 | 1.2 | 3.55 | 0.96 | 22.6 |
| C.F.L | <DL | 464.8 | 17.8 | 5.1 | 0.01 | 747 | 0.57 | 0.878 |
| Min | - | 0.03 | 4.8 | 3.6 | 0.01 | 0.16 | 0.18 | 0.25 |
| Max | - | 464.8 | 26.3 | 7.49 | 2 | 747 | 218.5 | 30.5 |
| Average | - | 36.31 | 15.54 | 5.29 | 1.29 | 57.82 | 53.93 | 7.64 |

| Brand as labled | Li | As | Ba | Co | Cr | Sn | V | Mo | Sum |
|---|---|---|---|---|---|---|---|---|---|
| Dorcell | 0.002 | 0.02 | 0.5 | 0.03 | 0.3 | 4.65 | 0.02 | <DL | 34.98 |
| Sony | 0.01 | 0.1 | 0.5 | 1.8 | 0.77 | 8.36 | 0.05 | 0.013 | 39.60 |
| Osel | 0.05 | 0.03 | 0.8 | 0.46 | 0.28 | 2.1 | 0.15 | <DL | 47.02 |
| Tianbar | 0.01 | 0.2 | 0.68 | 0.03 | 0.21 | 0.17 | 0.03 | <DL | 246.17 |
| Panosonic | 0.02 | 0.3 | 2 | 0.423 | 1.64 | 10.2 | 0.05 | 0.09 | 42.46 |
| Unomat | 0.009 | 0.15 | 0.3 | 0.05 | 0.45 | 9.25 | 0.01 | <DL | 36.69 |
| Camelion | 0.01 | 0.5 | 0.04 | 0.005 | 0.13 | 0.16 | 0.01 | <DL | 200.25 |
| Duracell | 0.005 | 0.03 | 0.01 | 0.08 | 0.68 | 0.3 | 0.02 | 0.009 | 217.01 |
| Maxell | 0.002 | 0.06 | 0.01 | 0.07 | 1.15 | 1.1 | 0.02 | BDL | 247.81 |
| Sonika | 0.3 | 0.35 | 5.6 | 0.9 | 0.39 | <DL | 0.53 | 0.05 | 69.51 |
| King POWER | 0.01 | 0.02 | 0.1 | 0.02 | 0.2 | 0.65 | 0.05 | <DL | 116.68 |
| Persian POWER | 0.09 | 0.28 | 6 | 0.45 | 0.2 | <DL | 0.2 | 0.02 | 70.15 |
| Toshiba | 0.02 | 0.16 | 0.67 | 0.2 | 0.5 | 5.45 | 0.04 | 0.015 | 45.195 |
| Oxel | 0.1 | 0.2 | 5.1 | 0.667 | 0.3 | 2.65 | 0.55 | 0.05 | 66.087 |
| C.F.L | 3.1 | BDL | 6.7 | 210 | 1.2 | 0.025 | BDL | 0.02 | 1457.2 |
| Min | 0.002 | 0.02 | 0.01 | 0.005 | 0.13 | 0.025 | 0.01 | 0.013 | |
| Max | 3.1 | 0.3 | 6.7 | 210 | 1.64 | 10.2 | 0.55 | 0.09 | |
| Average | 0.25 | 0.17 | 1.93 | 14.35 | 0.56 | 3.47 | 0.12 | 0.03 | |

[*]Below detection limit.

**Table 6.** Daily analysis of municipal waste at Tabriz landfill site

| Day | Solid Waste Entering Recycling Process (ton) | Battery Weight (g) | Battery Ratio to Total Recycled Waste (%) | Ratio of AA and AAA to Total Batteries (%) | Ratio of Cellphone Battery to the Whole Battery |
|---|---|---|---|---|---|
| 1 | 231.560 | 216 | 0.000093 | 90.74 | 9.26 |
| 2 | 205.160 | 214 | 0.0001 | 71 | 29 |
| 3 | 243.28 | 386 | 0.00015 | 76.2 | 23.8 |
| 4 | 231.28 | 452 | 0.00019 | 31.86 | 68.14 |
| 5 | 197.72 | 629 | 0.00034 | 43.64 | 56.36 |
| 6 | 183.5 | 502 | 0.00027 | 80.48 | 19.52 |
| 7 | 246.04 | 552 | 0.00022 | 83.88 | 16.12 |
| 8 | 234.02 | 528 | 0.00022 | 62.5 | 37.5 |
| 9 | 179.42 | 440 | 0.00024 | 83.2 | 16.8 |
| 10 | 112.68 | 698 | 0.0006 | 81 | 19 |
| 11 | 223.96 | 626 | 0.00027 | 70.6 | 29.3 |
| 12 | 278.88 | 698 | 0.00025 | 81 | 19 |
| 13 | 140.08 | 574 | 0.0004 | 81.9 | 18.1 |
| 14 | 195.26 | 698 | 0.00035 | 67.6 | 32.4 |
| 15 | 109.74 | 392 | 0.00035 | 82.15 | 17.85 |
| 16 | 237.98 | 793 | 0.00028 | 85.12 | 14.88 |
| 17 | 288.26 | 858 | 0.00029 | 78 | 22 |
| 18 | 152.88 | 712 | 0.00046 | 85.5 | 14.5 |
| 19 | 111.06 | 758 | 0.00068 | 82.85 | 17.15 |
| 20 | 232.66 | 976 | 0.00041 | 78 | 22 |
| 21 | 163.22 | 493 | 0.000302 | 86.2 | 13.8 |
| Total | 4198.64 | 12195 | 0.00029 | - | - |
| Average | 199.9352 | 580.7143 | 0.000308 | 75.40095 | 24.59429 |
| SD | 51.55451 | 191.1679 | 0.000142 | 13.97494 | 13.97332 |

30.575 mg/kg in Tianbar and King Power batteries, respectively. Arsenic was also detected in 87.5% of the studied batteries, and the content was below the detection limit only in Oxel and C.F.L batteries, while Sonika had the highest arsenic content (0.352 mg/kg), followed by Panasonic (0.312 mg/kg). The minimum arsenic content was measured in the Durucell battery (~0.02 mg/kg).

Barium and cobalt were detected in all the battery samples, and C.F.L demonstrated the highest barium and cobalt contents (6.74 and 210.118 mg/kg, respectively). In three out of 16 studied batteries (Panasonic, Maxell, and C.F.L), the chromium content was estimated at 1.645, 1.150, and 1.189 mg/kg, respectively. In other batteries, this value was less than 1 mg/kg. Tin, vanadium, and molybdenum were also detected in 87.5%, 93.75%, and 50% of the battery samples, respectively.

Table 5 shows the comparison of the heavy metal content of the used batteries in the present study and other

**Table 7.** Summary of the current condition of used batteries' management in Tabriz and Ardabil

| | The Surveyed Subject | Results | |
|---|---|---|---|
| | | Tabriz | Ardabil |
| 1 | There is an approved definition for used batteries. | No | No |
| 2 | The quantity of used batteries is documented. | No | No |
| 3 | An organization\office has the management responsibility of used batteries. | No | No |
| 4 | Municipal staffs\authorities are educated for the management of used batteries. | No | No |
| 5 | Used batteries are collected separately. | Yes\No* | Yes\No* |
| 6 | The separate collection is legally implemented. | No | No |
| 7 | The current collection and disposal conditions of used batteries are in accordance with environmental and health principles. | No | No |
| 8 | Workers who are collecting comingled municipal waste including used batteries are familiar with safety aspects such as putting boots, gloves, guns, and other safety instruments. | No | No |
| 9 | The workers who are collecting used batteries are educated about health and environmental issues. | No | No |
| 10 | Recovery of used batteries is implemented. | Yes\No* | Yes\No* |
| 11 | Used batteries recovery is implemented legally. | Yes\No* | Yes\No* |
| 12 | Which method is used for the final disposal of used batteries? | Sanitary landfilling | Sanitary landfilling |
| 13 | How is the final disposal method from a health and technical point of view? | Inappropriate | Inappropriate |
| 14 | Re-recovery of used batteries at the final disposal location. | No | No |
| 15 | Producers are paying for management\disposal of used batteries. | No | No |
| 16 | There is planning for the management of used batteries in the future. | No | No |
| 17 | Public people were educated about the environmental risk of used batteries. | No | No |
| 18 | Private and governmental companies have requested permission for the collection and recovery of used batteries. | No | No |

*Industrial and automobile batteries collected separately by a system same as EPR.

similar reports. In the study by Barret et al., the contents of mercury, lead, copper, arsenic, barium, chromium, antimony, and vanadium were reported to be higher than the values obtained in the current research, while the levels of all the heavy metals in our study (except mercury) were higher than the values reported by the mentioned authors [2, 10, 11]. In addition, the levels of lead, manganese, zinc, nickel, iron, copper, and chromium were observed to be lower in the current research compared with the values reported in previous studies [15, 31]. On the other hand, the cadmium content of the Ni-Cd battery (i.e., C.F.L.) was significantly higher in the present study compared with the previous findings [2, 10, 15, 27, 31].

## Amount of used batteries in Tabriz landfill site

Prior to the study, no documented data were available on the quantity and weight percentage of the used batteries in the municipalities and landfill sites of Iran. As mentioned earlier, all the used batteries entering the Tabriz landfill site were analyzed in the present study during a 21-day period, and the results are shown in Table 6. Because industrial and automobile batteries were not included in the municipal solid waste stream, only household batteries were sent to the landfill site, which are often collected by buyback centers and sent to recycling and recovery facilities. Household batteries are classified as household hazardous waste. Although the ratio of these hazardous materials is relatively low (0.1%), they are considered important due to their potential toxicity to humans and the environment [31].

Used batteries must be recycled, and it is illegal to send these wastes to landfill sites. Moreover, according to the label of some batteries, they should be collected and processed separately, while due to the lack of an integrated management and collection system in Iran, used batteries are sent to landfill sites along with other non-hazardous wastes. In China, which is one of the largest battery producers and consumers in the world, used batteries are not commonly recycled and are delivered to a municipal landfill [32].

Considering the per capita value of used batteries and the Tabriz population in 2016 (Table 3), it was estimated that 273.34 kt of the battery was delivered to the landfill site in 2016. In the current research, the used batteries delivered to the landfill site were analyzed within a period of 21 days. As only 11% of all the municipal wastes entered the recovery facility located in the landfill site and portable batteries constituted 12% of the available batteries on the market, it was expected that 38,264 kg of the used batteries would enter the landfill site.

According to the information in Table 7, out of 4,198.64 t of recycled waste, used batteries constituted only 12.195 kg (0.00029%). Notably, industrial batteries are recycled by special sectors in the country, and it has been estimated that 4,592 kg of the used battery should be delivered to landfill sites. On the other hand, some families store their used batteries at home, and the separate recovery and recycling of automobile and industrial batteries might be another reason. Our findings are consistent with the previous studies.

The European Union produces more than one million batteries each year, which contain chemically hazardous materials. In 2002, 45% of all sold batteries entered the municipal solid waste stream, followed by incineration or landfilling, and only 17% were collected separately [2]. In Portugal, from 2004 to 2006, approximately 13% of used batteries were recycled, while a large amount entered the municipal waste stream. During 2005, 65% of commingled collected wastes were landfilled, while 20% were incinerated, indicating the final destination of used batteries in Portugal [33]. In addition, AA and AAA batteries were reported to constitute 75.5% of all the batteries separated at landfill sites, and the remaining 24.5% belonged to the mobile phone, wireless phones, and other batteries.

## Current status of used battery waste management

The waste management legislation in Iran was proposed by the government and approved by the Parliament in 2004. According to Clause 12 of the executive instruction of waste management legislation, all the manufacturers and importers of all electronic and electrical equipment (including batteries) must actively participate in the waste management action. Accordingly, producers should recycle their wastes or 0.005% of the value of the produced/imported goods must be paid to a special fund, and the money will be used for waste recycling. Furthermore, Clause 12 of the executive instruction states that the companies that do not take the responsibility must be financially penalized, while the manufacturers who recycle materials in their production processes as well as those voluntarily taking back the products at the end of their useful lifespan or export their products are exempted from fines. The Ministry of Health and the Department of Environmental Protection Agency are responsible for the proper implementation of this legislation [34].

As mentioned earlier, the quantity and quality of used batteries in Iran were unclear before the present study. Considering the size of the Iranian population (~80 million) in 2016 and the per capita generation rate of batteries (3.41 kg/year), and since then, it is estimated that 272,800 t of battery waste has been produced throughout the country. Table 7 presents the checklist that surveyed different items of used battery waste management in Tabriz and Ardabil. Accordingly, no organization was responsible for the recycling of household batteries, and no integrated management action was implemented in these cities. The only management action was the collection and recycling of used automobile and industrial batteries. Because household batteries are classified as hazardous wastes, the method used for the disposal of used batteries may cause severe health and environmental damages, such as soil and groundwater pollution and even economic losses. Moreover, no Extended Producer Responsibility (EPR), take-back programs, or recycling/recovery facilities have been implemented for recovering batteries, with the exception of automotive and industrial batteries. Other cities and provinces in Iran mostly have the same status in terms of the collection and disposal of used batteries.

EPR is a mechanism that has been primarily emphasized by the EU waste framework directive to reduce waste production and enhance management performance. EPR covers a wide variety of wastes, including packaging, end-of-life vehicles, electrical wastes, electronic equipment, and used batteries [35]. In compliance with EPR, some countries (e.g. EU, Korea, and Japan) have urged legislation mandating batteries manufacturers and importers to take back used batteries at their end-of-life stage [36-38]. In Poland, obligatory collection has also been imposed on the manufacturers, importers, and end-users of batteries. The successful implementation of EPR may improve health conditions and yield environmental and economic benefits, as well. Besides, in the concentrations of heavy metals in municipal wastes in reported in some studies has been compared with current research (Table S1).

## 4. Conclusion

Contrary to other countries, there is no common management action for used batteries in Iran. In the heavy metal analysis, the levels of elements, such as lead, arsenic, cobalt, copper, chromium, nickel, zinc, tin, barium, and vanadium were measured in the studied batteries, and the mercury content was observed to be below the detection level of the instrument in all the samples. Approximately 40% of the battery brands contained considerable levels of heavy metals, while in 60% of the batteries, the values were lower than 100 mg/kg. However, the heavy metal content in all the batteries was above 35 mg/kg. The heavy metal content of the only analyzed rechargeable battery was also 10-fold higher than the other batteries.

The per capita of spent battery waste generation in 2016 was estimated at 3.41 kg/year in Iran, while the number of battery wastes entering the landfill site was significantly lower than expected. Industrialized and automobile batteries have been completely separated and recycled throughout the country, while only small parts of spent household batteries have entered landfill sites with no source separation or recycling actions implemented. The current management condition of used batteries is expected to lead to severe environmental damages (e.g. heavy metal leaching into groundwater and soil) and harmful health outcomes. According to our findings, AA batteries were the only battery types analyzed for their heavy metal content, and the heavy metal content of other battery types and brands (especially rechargeable batteries) must be addressed in further investigations.

## Ethical Considerations

### Compliance with ethical guidelines

All ethical principles are considered in this article.

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### Authors' contributions

All authors equally contributed to preparing this article.

### Conflict of interest

The authors declared no conflict of interest.

### References

[1] Qu J, Feng Y, Zhang Q, Cong Q, Luo Ch, Yuan X. A new insight of recycling of spent Zn-Mn alkaline batteries: Synthesis of $Zn_xMn_{1-x}O$ nanoparticles and solar light driven photocatalytic degradation of bisphenol A using them. J Alloys Compd. 2015; 622:703-7. [DOI:10.1016/j.jallcom.2014.10.166]

[2] Terazono A, Oguchi M, Iino Sh, Mogi S. Battery collection in municipal waste management in Japan: Challenges for hazardous substance control and safety. Waste Manag. 2015; 39:246-57. [DOI:10.1016/j.wasman.2015.01.038] [PMID]

[3] Song J, Yan W, Cao H, Song Q, Ding H, Lv Zh, et al. Material flow analysis on critical raw materials of lithium-ion batteries in China. J Clean Prod. 2019; 215:570-81. [DOI:10.1016/j.jclepro.2019.01.081]

[4] Badawy SM, Nayl AA, El Khashab RA, El-Khateeb MA. Cobalt separation from waste mobile phone batteries using selective precipitation and chelating resin. J Mater Cycles Waste Manag. 2014; 16(4):739-46. [DOI:10.1007/s10163-013-0213-y]

[5] Ebin B, Petranikova M, Ekberg Ch. Physical separation, mechanical enrichment and recycling-oriented characterization of spent NiMH batteries. J Mater Cycles Waste Manag. 2018; 20(4):2018-27. [DOI:10.1007/s10163-018-0751-4]

[6] Zueva SB, Macolino P, Manciulea AL, Vegliò F. Polyamine flocculation applied to household batteries recycling. J Mater Cycles Waste Manag. 2015; 17(3):504-12. [DOI:10.1007/s10163-014-0265-7]

[7] Mantuano DP, Dorella G, Elias RCA, Mansur MB. Analysis of a hydrometallurgical route to recover base metals from spent rechargeable batteries by liquid-liquid extraction with Cyanex 272. J Power Sources. 2006; 159(2):1510-18. [DOI:10.1016/j.jpowsour.2005.12.056]

[8] Kim MJ, Seo JY, Choi YS, Kim GH. Bioleaching of spent Zn-Mn or Ni-Cd batteries by Aspergillus species. Waste Manag. 2016; 51:168-73. [DOI:10.1016/j.wasman.2015.11.001] [PMID]

[9] Song X, Hu Sh, Chen D, Zhu B. Estimation of waste battery generation and analysis of the waste battery recycling system in China. J Ind Ecol. 2017; 21(1):57-69. [DOI:10.1111/jiec.12407]

[10] Karnchanawong S, Limpiteeprakan P. Evaluation of heavy metal leaching from spent household batteries disposed in municipal solid waste. Waste Manag. 2009; 29(2):550-8. [DOI:10.1016/j.wasman.2008.03.018] [PMID]

[11] Barrett HA, Ferraro A, Burnette Ch, Meyer A, Krekeler MPS. An investigation of heavy metal content from disposable batteries of non-U.S. origin from Butler County, Ohio: An environmental assessment of a segment of a waste stream. J Power Sources. 2012; 206:414-20. [DOI:10.1016/j.jpowsour.2012.01.008]

[12] Provazi K, Campos BA, Espinosa DCR, Tenório JAS. Metal separation from mixed types of batteries using selective precipitation and liquid-liquid extraction techniques. Waste Manag. 2011; 31(1):59-64. [DOI:10.1016/j.wasman.2010.08.021] [PMID]

[13] Gallegos MV, Falco LR, Peluso MA, Sambeth JE, Thomas HJ. Recovery of manganese oxides from spent alkaline and zinc-carbon batteries. An application as catalysts for VOCs elimination. Waste Manag. 2013; 33(6):1483-90. [DOI:10.1016/j.wasman.2013.03.006] [PMID]

[14] Xi G, Yang L, Lu M. Study on preparation of nanocrystalline ferrites using spent alkaline Zn-Mn batteries. Mater Lett. 2006; 60(29-30):3582-5. [DOI:10.1016/j.matlet.2006.03.064]

[15] Guevara-García JA, Montiel-Corona V. Used battery collection in central Mexico: Metal content, legislative/management situation and statistical analysis. J Environ Manage. 2012; 95 Suppl:S154-7. [DOI:10.1016/j.jenvman.2010.09.019] [PMID]

[16] Huang Ch, Zeng G, Huang D, Lai C, Xu P, Zhang Ch, et al. Effect of Phanerochaete chrysosporium inoculation on bacterial community and metal stabilization in lead-contaminated agricultural waste composting. Bioresour Technol. 2017; 243:294-303. [DOI:10.1016/j.biortech.2017.06.124] [PMID]

[17] European Commission. Batteries and accumulators [Internet]. 2016 [Updated 2016]. Available from: http://ec.europa.eu/environment/waste/batteries/

[18] Sayilgan E, Kukrer T, Civelekoglu G, Ferella F, Akcil A, Veglio F, et al. A review of technologies for the recovery of metals from spent alkaline and zinc-carbon batteries. Hydrometallurgy. 2009; 97(3-4):158-66. [DOI:10.1016/j.hydromet.2009.02.008]

[19] Sun Zh, Cao H, Zhang X, Lin X, Zheng W, Cao G, et al. Spent lead-acid battery recycling in China - A review and sustainable analyses on mass flow of lead. Waste Manag. 2017; 64:190-201. [DOI:10.1016/j.wasman.2017.03.007] [PMID]

[20] Zhang X, Xie Y, Lin X, Li H, Cao H. An overview on the processes and technologies for recycling cathodic active materials from spent lithium-ion batteries. J Mater Cycles Waste Manag. 2013; 15(4):420-30. [DOI:10.1007/s10163-013-0140-y]

[21] Aharoni I, Siebner H, Dahan O. Application of vadose-zone monitoring system for real-time characterization of leachate percolation in and under a municipal landfill. Waste Manag. 2017; 67:203-13. [DOI:10.1016/j.wasman.2017.05.012] [PMID]

[22] Li Zh, Ma Z, van der Kuijp TJ, Yuan Z, Huang L. A review of soil heavy metal pollution from mines in China: Pollution and health risk assessment. Sci Total Environ. 2014; 468-469:843-53. [DOI:10.1016/j.scitotenv.2013.08.090] [PMID]

[23] Huang D, Deng R, Wan J, Zeng G, Xue W, Wen X, et al. Remediation of lead-contaminated sediment by biochar-supported nano-chlorapatite: Accompanied with the change of available phosphorus and organic matters. J Hazard Mater. 2018; 348:109-16. [DOI:10.1016/j.jhazmat.2018.01.024] [PMID]

[24] Li YL, Wang J, Yue ZB, Tao W, Yang HB, Zhou YF, et al. Simultaneous chemical oxygen demand removal, methane production and heavy metal precipitation in the biological treatment of landfill leachate using acid mine drainage as sulfate resource. J Biosci Bioeng. 2017; 124(1):71-5. [DOI:10.1016/j.jbiosc.2017.02.009] [PMID]

[25] Mishra H, Karmakar S, Kumar R, Kadambala P. A long-term comparative assessment of human health risk to leachate-contaminated groundwater from heavy metal with different liner systems. Environ Sci Pollut Res Int. 2018; 25(3):2911-23. [DOI:10.1007/s11356-017-0717-4] [PMID]

[26] Slack RJ, Gronow JR, Voulvoulis N. Household hazardous waste in municipal landfills: Contaminants in leachate. Sci Total Environ. 2005; 337(1-3):119-37. [DOI:10.1016/j.scitotenv.2004.07.002] [PMID]

[27] Taghipour H, Amjad Z, Asghari Jafarabadi M, Gholampour A, Nowrouz P. Determining heavy metals in spent Compact Fluorescent Lamps (CFLs) and their waste management challenges: Some strategies for improving current conditions. Waste Manag. 2014; 34(7):1251-6. [DOI:10.1016/j.wasman.2014.03.010] [PMID]

[28] United States Environmental Protection Agency. Method 3050B: Acid digestion of sediments, sludges, and soils [Internet]. 1996 [Updated 1996 December]. Available from: https://www.epa.gov/sites/default/files/2015-06/documents/epa-3050b.pdf

[29] Almeida MF, Xará SM, Delgado J, Costa CA. Characterization of spent AA household alkaline batteries. Waste Manag. 2006; 26(5):466-76. [DOI:10.1016/j.wasman.2005.04.005] [PMID]

[30] European Union EUR-Lex & Legal Information Unit. Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC [Internet]. 2006 [Updated 2006 September 26]. Available from: https://eur-lex.europa.eu/eli/dir/2006/66/oj

[31] Ruffino B, Zanetti MC, Marini P. A mechanical pre-treatment process for the valorization of useful fractions from spent batteries. Resour Conserv Recycl. 2011; 55(3):309-15. [DOI:10.1016/j.resconrec.2010.10.002]

[32] Komilis D, Bandi D, Kakaronis G, Zouppouris G. The influence of spent household batteries to the organic fraction of municipal solid wastes during composting. Sci Total Environ. 2011; 409(13):2555-66. [DOI:10.1016/j.scitotenv.2011.02.044] [PMID]

[33] Frank K, Tchobanoglous G. Handbook of solid waste management. New York: McGraw Hill Inc; 1994.

[34] Niza S, Santos E, Costa I, Ribeiro P, Ferrão P. Extended producer responsibility policy in Portugal: A strategy towards improving waste management performance. J Clean Prod. 2014; 64:277-87. [DOI:10.1016/j.jclepro.2013.07.037]

[35] Taghipour H, Nowrouz P, Asghari Jafarabadi M, Nazari J, Asl Hashemi A, Mosaferi M, et al. E-waste management challenges in Iran: Presenting some strategies for improvement of current conditions. Waste Manag Res. 2012; 30(11):1138-44. [DOI:10.1177/0734242X11420328] [PMID]

[36] Zhao W. A study on the environmental policies of waste batteries in China [MSc. thesis]. Lund: Lund University; 2003. https://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=1325150&fileOId=1325151

[37] Kim H, Jang YC, Hwang Y, Ko Y, Yun H. End-of-life batteries management and material flow analysis in South Korea. Front Environ Sci Eng. 2018; 12(3):3. [DOI:10.1007/s11783-018-1019-x]

[38] Rogulski Z, Czerwiński A. Used batteries collection and recycling in Poland. J Power Sources. 2006; 159(1):454-8. [DOI:10.1016/j.jpowsour.2006.02.034]

## Appendix

**Table S1.** Comparison of heavy metal contents with other studies (mg Kg-1)

| No | Hg | Cd | Pb | Mn | Zn | Ni |
|---|---|---|---|---|---|---|
| 1 | BDL | 0.03-464 | 4.8-26.3 | 15-2000 | 246-7490 | 0.163-747 |
| 2 | 0.1-31.5 | 1.7-85.2 | 0.1-739 | - | - | 0.4-152 |
| 3 | BDL | 0.0019-46.9 | 0.0015-0.0674 | 0.12-53.6 | 207-568 | 0.03-9.15 |
| 4 | - | 0.441-66 | 6.41-1400 | 86600-157000 | 170000-251000 | 22.2-2230 |
| 5 | 0.16-4900 | <1- 180 | 3-1000 | 150000-240000 | - | 84-4700 |
| 6 | 0.16 | 2.6 | 51 | 229000 | 145000 | 2800 |

| No | Cu | Li | As | Co | Cr | Mo | V | Reference |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.18-218 | 0.002-3.1 | <0.005-0.352 | 0.005-210 | 0.13-1.64 | <0.001-0.092 | <0.003- 0.554 | This study |
| 2 | 1.6-1312 | - | 1.2- 41.4 | 0.1-142 | 0.1-16.3 | - | 0.1-43.9 | 11 |
| 3 | - | - | <0.005-0.006 | - | - | - | - | 9 |
| 4 | 20-12800 | - | - | 7.4-242 | 8.2-21.2 | - | - | 33 |
| 5 | 11-18000 | - | - | 4-23 | 9-88 | - | - | 2 |
| 6 | 12000 | - | 0.89 | 36 | 400 | - | - | 29 |