A Regional Approach For Health Risk Assessment of Toxicants in Plastic Food Containers

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Abstract

Plastic food containers are being used popularly, generating a waste of about 115 million tons in Vietnam. Such waste is causing environmental and health issues. This study conducted a field survey with 309 local people and selected 59 samples out of 135 plastic food containers collected in Go Vap district, Vietnam. Collected plastic samples identified compositions were PET 13.6 %, PP 28.8 %, PS 16.9 %, and 40.7 % X. Although most people are aware of the toxicity of plastics, plastics are still widely used due to their convenience and price with easy use and purchase. Collected plastic samples were classified based on the plastic type using recycling code and quantitatively analyzed with X-ray fluorescence spectroscopy method to assess concentrations of Cd, Sb, Pb, Hg, Sn, Cr, Br, Cl, and S. Most of these collected plastic samples (91.5 %) were found to contain 8/9 hazardous substances and most elements contained in these plastics were below their standard thresholds. However, elements Cl and Sb exceeded their safe thresholds, reached the highest concentrations of 1990.3 ppm and 469.2 ppm, respectively. Thus, additional health risks need to be assessed using the USEtox model. Finally, this study proposed a screening process to assess the risk of toxicity of elements contained in plastic food containers through ISO 31000:2018.

1. Introduction

Plastic is being used commonly in the world, having a total production of 368 million tons in 2019. The biggest end-use market is packaging plastic, accounting for 39.6% of total European plastic demand (Plastics Europe 2020). In fact, compared to metal and glass containers, plastic packaging, including hard and flexibles plastic materials, are preferred because of they are lighter and more durable. Therefore, various additives or low molecular weight chemical compounds are applied and mixed in the manufacturing processes of plastic food containers so that the resulting material is more durable with improved functional properties (Bhunia et al. 2013). Currently, there are many concerns about the migration of chemicals from food packaging or plastic containers into food due to close contacts between containers and food. Therefore, humans are easily exposed to these chemicals that can have toxic and harmful effects on human health (Thompson and Darwish 2019; Muncke et al. 2020).

Plasticizers, stabilizers, flame retardants, antioxidants, anti-microbial agents, and colorants are main additives in plastic materials, particularly food packaging materials (Hauser and Calafat 2005; Singh et al. 2012; Cherif Lahimer et al. 2017; Hahladakis et al. 2018; Claudia Pivonello et al. 2020). Metallic elements contained in these additives can also migrate from the packaging material to food or beverage over the exposure or contact time, prticularly when there is an increase in temperature or mechanical stress (Bhunia et al. 2013). Colorants and stabilizers containing cadmium and lead are often used in colored polymers. Chromium is mainly used for polymers such as polyvinyl chloride (PVC), polyethylene (PE), and polypropylene (PP). Although synthetic polymers are generally resistant to microbial attack, some microorganisms can use certain additives as an energy source in the presence of water. This phenomenon can be prevented by adding biocides such as As, Sb, and Sn during polymer production (Campanale et al. 2020). Additives such as compounds S, Br, and Cl are added to create fire resistance for polystyrene (PS) materials (Alekseev et al. 2001; Ketov et al. 2013; Braun et al. 2015). Antimony is commonly used as a flame retardant additive. It is also a catalyst involved in polymerization of polyethylene terephthalate (PET) (Snedeker 2014).

To prevent or minimize the risk of affecting consumers' health due to accumulation of substances contained in packaging plastic products and food containers, government authorities in charge of health and environmental markets in the world including Vietnam have established environmental regulations and requirements for plastic products used in contact with food before products are put into circulation on the market.

Directive 94/62/EC on packaging and packaging waste limits toxic metals such as Hg, Pb, Cr^{6+}, and Cd in plastic materials with a maximum concentration of 100 mg/kg (European Parliament and the Council of the European Union 1995). The RoHS Directive (Restriction of hazardous substances directive in electrical and electronic equipment 2002/95/EC) is a directive on the restriction of hazardous substances in electrical and electronic equipment. The RoHS directive stipulates a maximum of 0.1% for Pb, Hg, Cr^{6+}, PBB, and PBDE and a maximum of 0.01% for Cd by weight of packaging plastics (UK Office for Product Safety and Standards 2021). The EU food safety standard specifies that the maximum Sb concentration is 350 ppm (Snedeker 2014). National technical regulation QCVN 12-1:2011/BYT stipulates that the maximum concentration allowed for Cd and Pb is at 100 µg/g and the maximum migration concentration allowed of Sb is 0.05 µg/ml (Vietnam Ministry of Health 2011).

The aim of the present study was to analyze concentrations of hazardous substances contained in food-grade plastic and provide modeling results of a life cycle impact assessment (LCIA) to determine the impact of hazardous substances on human health and the ecosystem. LCIA is a tool of product life cycle assessment to understand and estimate the magnitude and significance of potential environmental impacts added in a product system throughout its life cycle (Jolliet et al. 2015). Several LCIA impact assessment methods have been developed with different approaches to resolve issues related to environmental and human impacts. There are several LCIA methods for determining effects of hazardous substances on human health, including classical impact assessment methods or problem-oriented methods [such as CML (Centrum voor Milieukunde Leiden), EDIP (Environmental Design of Industrial Products), and TRACI (the Tool for the Reduction and Assessment of Chemical and other environmental Impacts)], damage-oriented methods (such as Eco-indicator 99, EPS 2000, and EI99 methods), and other research-based LCA methodologies including the USEtox model (Menoufi 2011; Acero et al. 2017). The main purpose of this study was to perform a preliminary screening for concentrations of hazardous additives with possible adverse health effects containd in plastic food containers samples. For this study, the authors collected different plastic container products for food and characterized hazardous substances released from them after proper processing. Obtained data were then applied to LCIA's USEtox model to determine impacts on human health and ecosystems. Finally, this study proposed a risk assessment screening process according to ISO 31000:2018.

2. Materials And Methods

2.1. Survey methodology and sample collection

A survey was conducted in order to evaluate people's reactions and attitudes to the use of plastic packaging for food. Data were obtained through face-to-face surveys of 250 participants who lived in Go Vap District, Ho Chi Minh City, Vietnam. The questionnaire included the following: (1) socio-demographic characteristics such as gender, age, and occupation of participants, (2) habits of using food container materials, (3) habits of reusing plastic food containers, and (4) perceptions, awareness, and attitudes about toxic components in plastic food containers and their use.

Sample collection of plastic food containers was conducted with the survey in parallel. Plastic samples were collected mostly from households and fast food restaurants at markets, and roadsides in Go Vap District, Ho Chi Minh City, Vietnam. A total of 135 plastic samples were collected, including plastic food containers after being used by customers or owners of facilities. After the preliminary assessment, duplicate samples of their origin and shapes of collected plastic food containers were removed. The remaining 59 plastic samples were selected for next experiments (See Table S1).

2.2. Determination of hazardous components by X-ray fluorescence spectroscopy

To analyze hazardous elements contained in plastic food containers, this study used energy-dispersive X-ray spectroscopy (EDX) due to its several advantages over other methods of measuring elemental content (Adel Ismael Chaqmaqchee 2017; Goodlaxson 2017). EDX measurement is simple, fast, safe, cost-effective, and less time-consuming for daily calibration than other methods such as atomic absorption (AA). After being collected, food plastic container samples were classified by recycling code for plastic (Resin identification code, Figure S1) (ASTM - American Society for Testing and Materials 2013) and watering for cleaning grease and food residue. Elemental concentrations of nine selected hazardous substances, including cadmium (Cd), antimony (Sb), lead (Pb), mercury (Hg), tin (Sn), chromium (Cr), bromine (Br), chlorine (Cl) and sulfur (S), were determined using an EDX-7000 (Shimadzu, Japan). Elemental concentrations of selected substances of each plastic sample were analyzed three times to ensure sample precision. Concentration results of selected hazardous elements were collated according to RoSH standard, Directive 95/62/EC, and EU Food Safety Standards and then classified into three different hazard groups:

- High-hazard group: a group of hazardous substances with concentrations exceeding their safety standards;
- Medium-hazard group: a group of hazardous substances with their concentrations ranging from 50–90% of the prescribed concentration based on safety standards;
- Low-hazard group: a group of hazardous substances with concentrations lower than 20% of the prescribed concentration.

2.3. Migration test

For plastic food containers containing elements of the high-hazard group, their safety levels were evaluated with the migration test method according to Vietnam national technical regulations QCVN 12-1:2011/BYT (Vietnam Ministry of Health 2011).

2.4. Life cycle impact assessment by USEtox

USEtox is a well-known scientific consensus model developed by the USEtox Team and endorsed by the United Nations Environment Program (UNEP) and the Society for Environmental Toxicology and Chemistry (SETACT) Life Cycle Initiative to characterize "human toxicological and ecotoxicological impacts of chemical emissions and of chemicals in consumer products" in life cycle assessment (http://www.usetox.org). The potential impact of hazardous substances on human health and the environment was calculated using the following formula with USEtox model factors (1) (Westh et al. 2015; Singh et al. 2019, 2020).

$IS_x = C_x \cdot M \cdot CF_x$ (1)

where IS_x was the impact point of element X in plastic food containers, C_x was the concentration of element X in the plastic food containers, M (kg) was the mass of each plastic sample, and CF_x was the characterization factor (CF) or total cause for the corresponding element X. CFx characteristic factors were quantified through the model, resulting in migration data. The output of the USEtox model included a database of recommended and interim characterization factors, including human exposure parameters such as cancerous and noncancerous incidence and ecotoxicological impacts of chemicals. The unit is $PAF \cdot m^3 \cdot day/kg_{emitted}$ for ecotoxicity specific factor and $cases/kg_{emitted}$ for human toxicity. In this study, input data of the USEtox model are clearly described in Table 1.

Table 1
Input description of USEtox model used in the study

Factors	Factor description	Factors in the study
Mx	The quantity of each sample of waste plastics in kg	0.0025 kg
Cx	The amount of metal x in the waste plastic	Analytical data of substances performed by the method of migration specified in the national technical regulation QVCN 12-1:2011/BYT
Landscape data	Landscape- and human-exposure relevant environmental characteristics	Southeast Asia
Substance data	The substance data describes the physical-chemical characteristics, degradation rates, toxicity, ecotoxicity, bioaccumulation factors and biotransfer factors of a substance	Substance data of elements Sb (III), Cr (III), Cr (VI) and Hg

3. Results And Discussion

3.1. Results of the questionnaire

A total of 250 survey questionnaires including 104 men and 146 women were used for analyzing the use or consumption behaviors of food containers, especially plastic materials. Survey participants who aged 20 - 29 years old had the highest proportion (41.2%), followed by those aged over 40 years old (22%), under 20 years old (20%), and 30 - 39 years old (16.9%). Thus, the surveyed age range from 18 – 54 years old mainly falls representing the age group that determines most of the products consumed in the family. People of this age range has a lot of exposure to general knowledge and information exchange, reflecting an interest in products that pose a risk to health and the environment, specifically plastic food containers.

According to the survey, plastic is the most chosen material for food containers by both women and men, with 62.4% of participants choosing plastic, while only 23.2% and 13.3% of participants chose glass and stainless steel products, respectively (Fig. 1a). On a per-gender basis, 61.6% (90 out of 146) of women and 65.4% (68 out of 104) of men chose plastic food containers rather than food containers made of glass, stainless steel, or ceramic. Percentages of those choosing food containers made of glass, stainless steel, and ceramic were not significantly different between women and men. However, by age, the age group of 20 - 29 years old who chose plastic materials accounted for 40%, which was the highest percentage among age groups. This is because people in this age group are mostly students or office workers. Thus, the use of plastic food containers is more common for food products, particularly street food. The selection rate for plastic products as food containers was 22 - 23 % for age groups of 30 - 39 or over 40 years old. The age group of under 20 years old had the lowest selection rate of 15% for plastic food containers. Regarding plastic types of food containers, PP had the highest proportion (31%), followed by PET (24%), PS (16%), and HDPE (12 %). The rest of plastic food containers were LDPE and PVC types, accounting for a low percentage (< 10%) (Fig. 1b). The survey also showed that 52 % of respondents preferred plastic food containers to other types of food containers such as glass and stainless steel products due to convenience of plastic food containers. Moreover, using plastic containers does not take time to clean or wash dishes. After using them, they could be just collected and thrown away as trash. Plus, it is easier to store take-away food instead of using expensive glass or steel containers or cups that could be easily broken and dented. This selection of plastic food containers was predominant in age groups of under 20 years and 20-29 years old. Other reasons such as low-cost and light properties of plastic food containers accounted for 24.8% and 13.6%, respectively. They were evenly distributed in surveyed age groups (Fig. 1c and Fig. 1d). With high mechanical strength and relative temperature resistance, plastic containers can hold almost any type of food. Plastic food containers just need to be carried in a bag, taking up very little space and effort to carry.

Figure 2a shows opinions about the reuse of plastic food containers. About half (49.2%) of respondents did not try to reuse plastic food containers because these containers were used on-site, at school, or work place and often thrown away after using. Some boxes of PS foam or thin plastic are easily damaged, making it difficult to reuse them. According to Chi-square test results (sig. ¼ 0.045 < 0.05), only the relationship between gender and plastic recycling habits was established in the three tested relationships between plastic recycling habits and gender, age, or occupation (See Table S2). Contrary to traditional thinking, males tended to reuse plastic containers more than females (43.7% vs. 38.1% for answer sometimes or always) (Table 2).

Table 2
Chi-square test results and significance response in the study

Hypothesis	Chi-square test result	Response
There is no significant relationship between age and plastic recycling habits	0.269	Yes
There is a significant relationship between age and plastic recycling habits		No
There is no significant relationship between gender and plastic recycling habits	0.045	No
There is a significant relationship between gender and plastic recycling habits		Yes
There is no significant relationship between occupation and plastic recycling habits	0.912	Yes
There is a significant relationship between occupation and plastic recycling habits		No

Most interviewees had heard that some plastic food containers might contain toxic or hazardous ingredients. In addition, the same respondents mentioned harmful effects of such toxic or hazardous substances with the potential to cause cancer, neurological diseases, respiratory diseases, and brain damage with health and environmental impacts. Regarding attitude using plastic food containers, 51.4% of the respondents were concerned. They wanted to get more information about the toxicity and adverse health effects of hazardous susbtances in plastic products. When asked if they would continue using products containing toxic or hazardous elements that are harmful to health, 25.6% of respondents said they would consider carefully about plastic component information before buying and 16.5% of respondents said they they were ready to tell others about unsafe plastic (Fig. 3a). However, 6% of participants said that they would not worry about plastic components or their toxicity information and 0.5% of participants said that they would continue to use these products. To minimize or prevent adverse human toxicological and ecotoxicological impacts from exposure to toxic or hazardous substances released from food plastic food containers, proper activities and regulations banning non-biodegradable single-use plastic products should be established in the near future, especially in Vietnam (Fig. 3b).

3.2. Concentrations of substances in food containers

The selected samples for concentration analysis of hazardous substances contained in the collected plastic food containers were 59 food-grade plastic samples, including those containing PET (n = 8), PP (n = 17), and PS (n = 10). The large fraction of these 59 samples was X plastic (n = 24), which was defined as a plastic with plastic classification number and code not known or not easily identified from its appearance in this study. From EDX analysis of the 59 collected food plastic samples, Hg, Cr, Br, Sb, Cl, and S elements were detected, whereas Cd, Pb, and Sn were not detected. Fig. 4 and Table S3 show concentration distribution of detected substances. Concentrations of Cl, S, and Sb were much higher than those of the remaining components. High chlorine concentrations were detected from 38 samples, including 3 PET, 12 PP, 9 PS, and 14 X plastic samples. In particular, chlorine in 8 samples showed significantly higher concentrations (above 300 ppm) than other elements, with the highest chlorine level of 1361.87 ppm (M28). Exposure to or contact with compressed liquid chlorine may cause frostbite of the skin and eyes. It can easily produce hypochlorous acid which is corrosive. Such acid can damage cells in the body on contact. According to WHO (World Health Qrganization), the guideline value for free chlorine in drinking-water derived from a NOAEL (no-observed-adverse-effect level) is 15 mg/kg of body weight per day. Its TDI (tolerable daily intake) is 150 µg/kg of bodyweight with the application of an uncertainty factor of 100. Its guideline value in drinking-water is 55 mg/liter with an allocation of 100% of the TDI to drinking-water (World Health Organization 1996). Released fractions or levels might vary depending on plastic food container, food packaging process, and various conditions such as food contact time, food composition, and food temperature in plastic containers. Currently, an allowable concentration limit of chlorine has not yet been set or regulated for food plastic packaging or container. Results about these high chlorine contents in the present study call for attention to chlorine regulation issue to minimize or prevent from adverse health effects caused by the use of plastic food containers.

The second finding of interest is chromium (Cr). It was detected in 28 of 59 plastic samples, including 8 PP, 8 PS, and 11 X plastic samples: 8 PP samples of M1-1, M3-1, M4 (plastic cup), M5-1, M7-1, M9-1, M13-1, and M36-1 (plastic bowl); 8 PS samples of M27, M28, M29, M30, M31, M33, M34-1, and M34-2 featured in foam food containers; and 11X samples of plastic cups and plastic boxes. Chromium concentration mainly fluctuated in the range of 4.45 - 8,53 ppm on PP and PS, except for M22-1 and M23-1 with concentrations of 9.47 ppm and 10.27 ppm in X plastic, respectively. However, Cr concentrations in all investigated plastic samples used for food containing purposes in this study were detected within the regulated safe limit of 100 ppm specified in the directive 94/62/EC.

Sulfur (S) concentrations in 18 out of 59 samples exceeded 300 ppm. Sulfur was detected in 2 PET samples (M21-2 and M36-2 of plastic lids), 3 PP samples (M12-2, M13-2, and M14 of lunch boxes), 3 X plastic samples (M19-1, M24-1, and M25-2), and 10 PS samples. PS in most samples had high concentrations above 400 ppm. In particular, M31 had the highest concentration of 830,83 ppm. PP and X plastic samples showed average concentrations of sulfur, ranging from 356.65 to 592.07 ppm. However, PET samples had the lowest S concentrations among different plastic groups tested.

Bromine (Br) was detected in 11 plastic samples, with concentrations ranging from 1.58 to 117.37 ppm. Among these 11 samples with Br detected, 10 were PS samples. This is because PS is considered to have a very high fire hazard. Thus, bromine compounds are mostly added as flame retardants into PS (Ketov et al. 2013). Currently, Vietnam does not have proper regulations about the concentration of Br in plastic. Considering that the RoHS standard of Br is 1000 ppm, detected bromine concentrations seemed to be lower than the standard. However, caution still should be exercised in the use of these materials.

Only three samples showed mercury (Hg) detection, including two PET samples of M12-1 and M36-2 (food container lids) and one X sample (plastic container). The RoHS standard and Directive 94/62/EC of Hg both stipulate a safety threshold of < 100 ppm for Hg. Detected Hg concentrations (with the highest of 7.34 ppm) were within the safe limit. However, mercury also needs to be paid more attention, particularly considering that Vietnam currently does not have a legal standard regulating the concentration of mercury in food plastic materials.

Antimony (Sb) was detected in all 8 PET samples and 3 X plastic samples (M17-2, M37 and M38). Antimony is often used as a flame retardant additive and a catalyst involved in the polymerization reaction in PET plastic. Previous studies have also shown the presence of Sb in PET resins, with concentrations ranging from 150 to 300 ppm (Shotyk and Krachler 2007; Haldimann et al. 2013; Franz and Welle 2020). Compared with EU food safety standards (EFSA EU), 9 out of 11 samples containing Sb exceeded the safety standard of 350 ppm. In particular, M11-1 (PS) showed the highest Sb concentration of 433.3 ppm, which was 1238 times higher than the standard (Fig. 5a). It may cause a potential risk to human health. Many studies have proven that antimony can migrate from materials to food under the influence of temperature and storage time. Antimony migration may lead to adverse health impacts such as cancer, cardiovascular, immune response, and endocrine disorder in human (Haldimann et al. 2013).

Based on results described above, substance groups contained in plastic food containers investigated in this study can be classified into three main hazard groups:

- High hazard group, including Sb, Cl, and S elements, which can be classified as a group with high-value screen-measured concentrations by EDX. In particular, Sb element in 9 samples out of 11 exceeded its EU safety standard of 350 ppm. Although their detected concentrations of Cl and S substances were quite high, currently there are no specific regulations on their safe concentrations.
- Medium hazard group, including Hg, Cr, and Br substances, with their concentrations ranging from 50–90% of the prescribed level by the corresponding standard specified on the Directive 95/2/EC and the RoHS standards, 100 ppm for Hg and Cr and 1000 ppm for Br. Currently, measured concentrations of the substances Hg, Cr, and Br in the plastic food containers investigated in this study were much lower than their prescribed levels.
- Low hazard group, including substances Cd, Pb, and Sn not detected in the investigated plastic food containers of the current study using the EDX-7000 screening for element detection.

3.3. Migration test

The migration test was used to assess the potential for toxicity accumulation from food resins into the human body. Although concentrations of Cl and S are quite high, there are currently no regulations about their safe thresholds. Thus, the current study tried a migration test for these two substances to assess their potential toxicity. Sb element was assessed for its migration in a group of substances with high levels of risk in this study.

Nine out of 11 samples of plastic food containers samples showed Sb exceeding its EU safety standard of 350 ppm. Therefore, Sb was classified into the high hazard group with a high level of risk in this study. It was also assessed with the migration test. Most of the plastic food containers with Sb detected were PET plastic, a widely used plastic for single-use water and beverage bottles. Many studies have shown that element Sb can migrate from plastic to food under the influence of temperature and storage time (Haldimann et al. 2013; Hansen et al. 2013; Bhunia et al. 2013; Guerreiro et al. 2018; Franz and Welle 2020). Concentration of Sb is currently regulated as QCVN 12-1: 2011/BYT in Vietnam, which specifies the maximum concentration of Sb migration. The allowed maximum limit of Sb specified in QCVN 12-1:2011/BYT is 0.05 μg/mL. As shown in Fig. 5b, all samples containing Sb exceeded its allowable limit. For example, all tested PET samples exceeded its level, ranging from 1.18 to 3.16 times higher than the allowable limit, with concentrations ranging from 0.059 to 5.67 μg/mL. All tested X plastic samples also exceeded its allowable limit, with concentrations ranging from 0.056 to 0.07 μg/mL.

3.4. Life cycle impact assessment by USEtox

The resulting migration information of Sb was included in the LCIA model using USETox to assess risks of hazardous substances contained in plastic food containers. However, substances such as S, Br, Cl, Hg, and Cr do not currently have migration regulations. Therefore, it was assumed that these substances' concentrations measured by EDX analysis were completely migrated to food for risk assessment. Sb, Hg, and Cr components are known to be very toxic or carcinogenic (Snedeker 2014; Wang et al. 2017; Rodrigues et al. 2019). Therefore, they were focused on in this study to evaluate their risk using the USEtox model. Chromium applied in the USEtox the model included both Cr (III) and Cr (VI) species.

Figure 6 shows the impact of hazardous substances (Hg, Cr and Sb) identified in plastic food containers using the USEtox LCIA model. Detailed calculations for each metal in terms of emission concentration in air, water, and soil are shown in Fig. S2 and S3. It was found that Hg was the most ecotoxic element, followed by Cr (VI), Cr(III), and Sb (Fig. 6a). These results indicate that Hg element tends to become a significant carcinogen in the PET plastic group (Fig. 6b). Element Cr (VI) can affect human health due to its carcinogenicity (Wang et al. 2017). It was detected in most food plastic samples, especially in the X plastic group. Sb and Cr (III) are not classified as Group 1 (known human carcinogen) or Group 2A (probable human carcinogen) carcinogenic agents. Fig. 6c shows that element Hg has a risk of causing non-cancerous diseases. It tends to be show a risk of cancer when both PET samples have high levels of mercury. Cr (VI) also has a significant risk of causing non-cancerous diseases. Results also indicate that elements Sb and Cr (III) are causative agents of non-cancerous diseases at low levels.

3.5 An operational framework of risk assessment process by ISO 31000:2018 on plastic food containers

The object of a risk assessment (RA) was determined to be food-grade plastic and additives contained in the plastic by the method of collecting assets related to the object. The first step of RA is to survey and collect survey method for determining the context and scope of the research. Achieved survey results included the collection and identification of process information on plastic food containers and information related to food container problems surrounding people whom are often in contact with plastic. Through the survey, this study found that the use of plastic products for food packaging or containers was very frequently chosen and the reuse of plastic was quite high at 49.2%. The use rate of plastic containers for hot food was also high at 44%. These data indicate that plastic food containers have great potential to cause health risks if they are regularly used and reused for hot food for a long time.

In this study, the identification of potential hazards was conducted through screening of hazardous substances contained in plastic food containers measured by Energy Dispersive X-ray fluorescence spectrometer (EDX -7000). This method is simple and safe because samples are measured directly without needing a digestion step. It is also more cost-effective than other analytical methods. Through the screening processes of element information (concentration and toxicity) obtained after analysis by EDX-7000 with a comparison with plastic-related legal standards, including RoHS standards, Directive 94/62 EC, and Food Safety standards, study results indicate that elements in plastic samples can be divided into three hazard groups: (1) High hazard group (Sb, Cl, and S); (2) Medium hazard group (Cr, Br and Hg); and (3) Low hazard groups (Cd, Pb and Sn).

For substances classified into the high hazard group after the screening process, their risks were analyzed through the exposure method (concentration investigation by EDX and migration test in this study for example) to assess their ability to accumulate toxic substances in the human body. In this study, among substances in the high hazard group, element Sb was assessed for its migration. It was chosen because in the sample screening process, almost all plastic samples containing Sb exceeded its safety threshold prescribed for PET plastic, a type of plastic widely used in food containers.

However, in the high hazard group of substance classified in the above step, only Sb is regulated in Vietnam in QCVN 12-1: 2011/BYT. Thus, the maximum concentration of Sb contamination was chosen as the basis to assess its ability to accumulate toxicity from plastic food containers into the human body. Substances of Cl, S, Cr, Br, and Hg do not have regulations related to the method of decontamination. Thus, these substances were only subjected to screening analysis using EDX-7000. However, it is difficult to identify or estimate their safety level.

Through the USEtox model, Hg and Cr (VI) were found to be highly toxic substances, while Sb and Cr (III) substances were found to have a relatively low potential for ecological toxicity and human health compared to Hg and Cr (VI). However, this model is mainly applicable to the problem of assessing the toxicity of E-waste plastics because e-plastics are mainly exposed to humans through pathways in the USEtox LCIA model (Singh et al. 2019, 2020). The limitation of this model was that data on temperature conditions, food contact time, and physicochemical issues were not directly applied in the model. Thus, evaluation through this model needs more data on temperature and storage time to ensure high accuracy of the model.

The final step of the process is to propose a risk management option. Although hazardous substances Cd, Pb, and Sn were not detected in plastic food containers during EDX screening, they should be investigated using more appropriate methods. These substances were considered to have a low risk. However, they might have a high risk in other studies.

In this study, only Sb can be decontaminated. Other substances also need to be decontaminated, regardless whether they are in the high, medium, or low risk group. This is because these substances have potential risk to human health. All possible emitted substances in food plastics (such as 9 hazardous substances, including cadmium (Cd), antimony (Sb), lead (Pb), mercury (Hg), tin (Sn), chromium (Cr), bromine (Br), chlorine (Cl) and sulfur (S) in this study) need to have an impact assessment process with LCIA models, especially the USEtox model. This is because toxicity research about plastic food containers using this model has not been established yet. In addition, the USEtox model is still limited in the application of data on migration conditions, such as temperature, storage time, and physicochemical environment of hazardous substances contained in plastic food containers. Fig. 7 summarizes the risk assessment screening process of plastic food containers according to ISO 31000:2018.

4. Conclusions

This study analyzed screening results for hazardous substances including Sb, Hg, Cr, halogen group (Br, Cl), and non-metallic S contained in plastic food containers and detected in component analysis by Energy Dispersive X-ray fluorescence spectroscopy. All these elements analyzed were within their safe limits specified by EFSA except for Sb which exceeded its limit. Food container plastic samples containing Sb were mainly PET containers with a few X plastic containers. Their Sb concentrations exceeded the allowable limit specified by QCVN 12-1: 2011/BYT in Vietnam. This result indicates that Sb in plastic food containers can leach into food while packaging and storing food, particularly hot food for long time. Thus, it is necessary to be wary of reusing these types of plastic food containers. For Cl and S elements, their measured concentrations were also high. However, there is no regulation on their safe limits in food plastics. Thus, it is necessary to conduct further studies to evaluate their toxicity. Also, many interviewed people still use plastic food containers, even though they know there is a risk of poisoning from contaminated ingredients from them, because of the convenience and price. Results from screening and removal were used to assess potential human health risks of substances through the USEtox LCIA model. USEtox model results showed that three substances could be applied in the model, including Sb, Hg, and Cr. This study also proposed a screening process to assess health risks for plastic food containers through the ISO 31000:2018 standard.

Declarations

- Ethics approval and consent to participate: Not applicable
- Consent for publication: Not applicable
- Competing interests: The authors declare that they have no competing interests.

- Authors' contributions: Nguyen Thi Lan Binh and Nguyen Thi Thanh Truc analyzed and interpreted the main data and was a major contributor in writing the manuscript. Nguyen Thi Ngoc Tran and Vu Dinh Khang were responsible for data curation. Byeoung-Kyu Lee took responsibility for writing - reviewing the manuscript. All authors read and approved the final manuscript.
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Figures

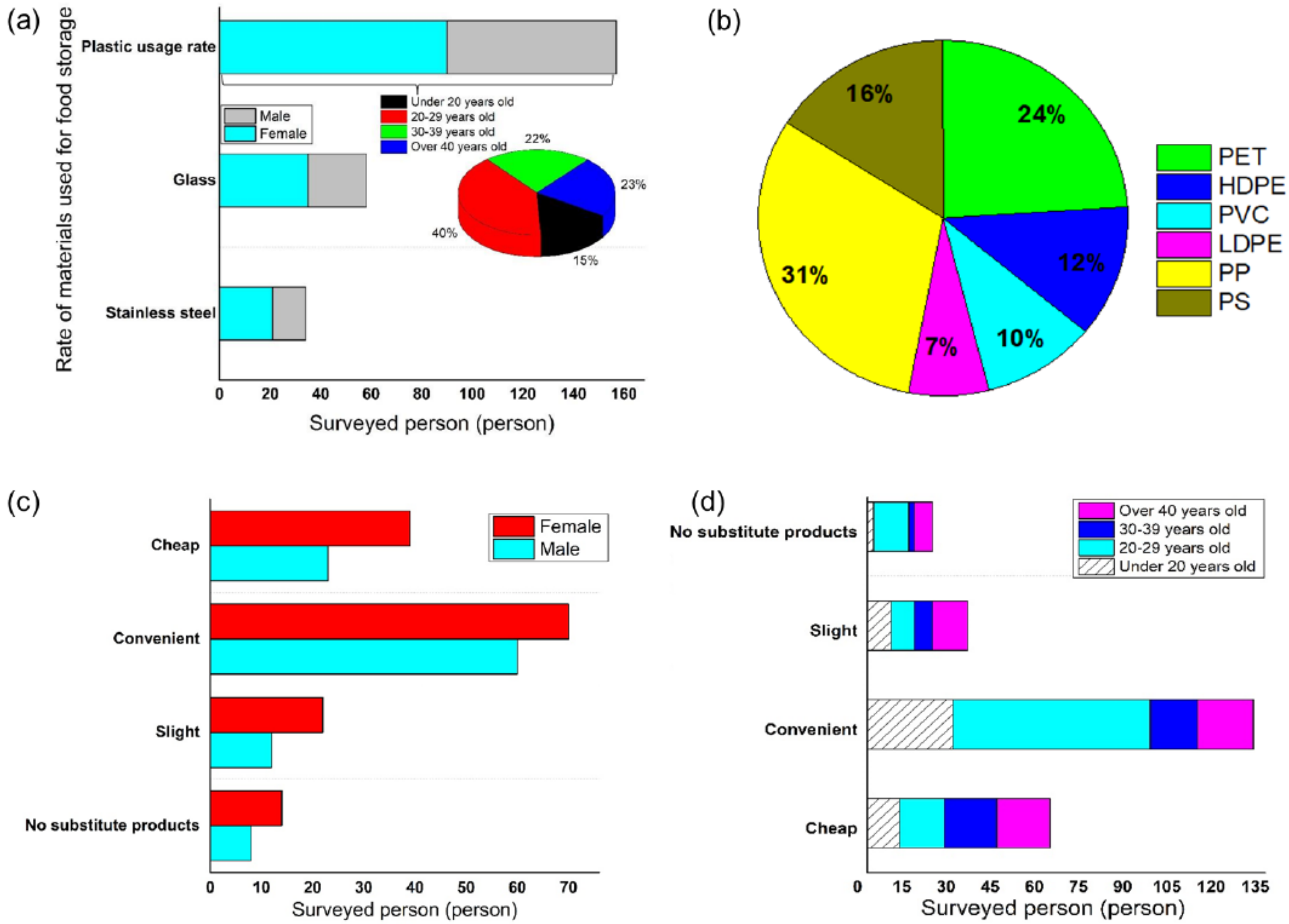

Figure 1

Survey of using food container materials by gender and age group (a), percentage of food containers according to plastic type (b), and reason of choosing plastic food container by gender and age (c, d).

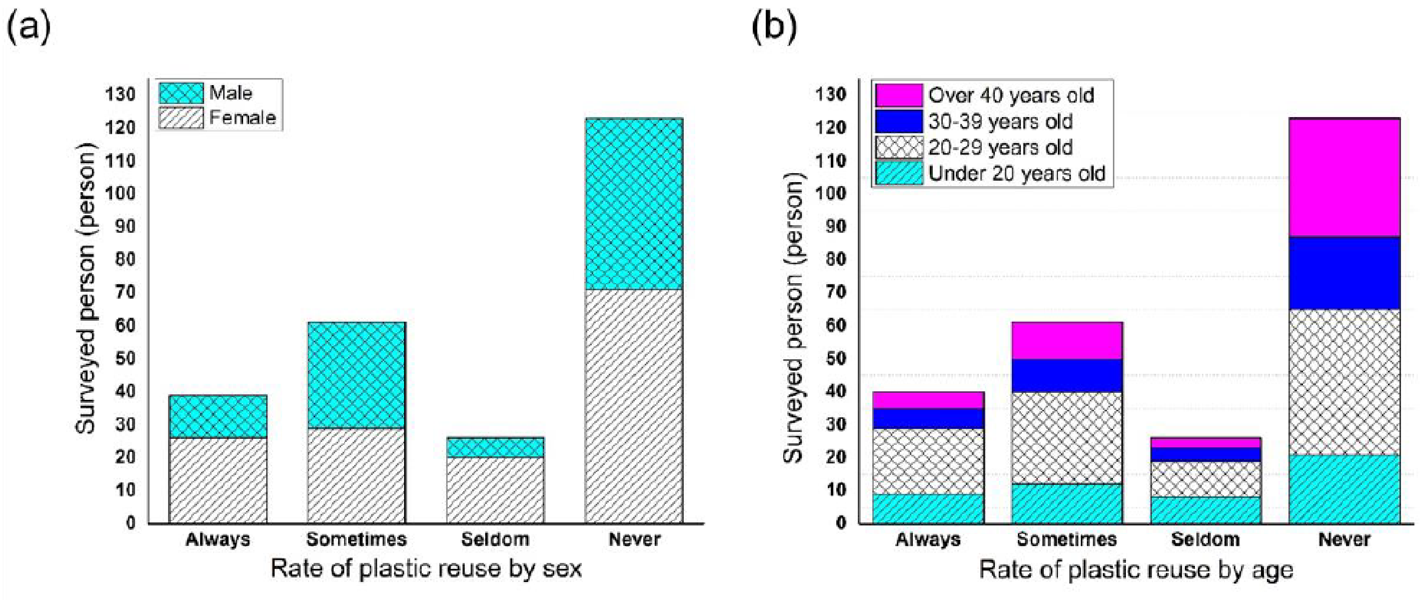

Figure 2

Survey on the level of reuse of plastic food containers by gender (a) and by age group (b).

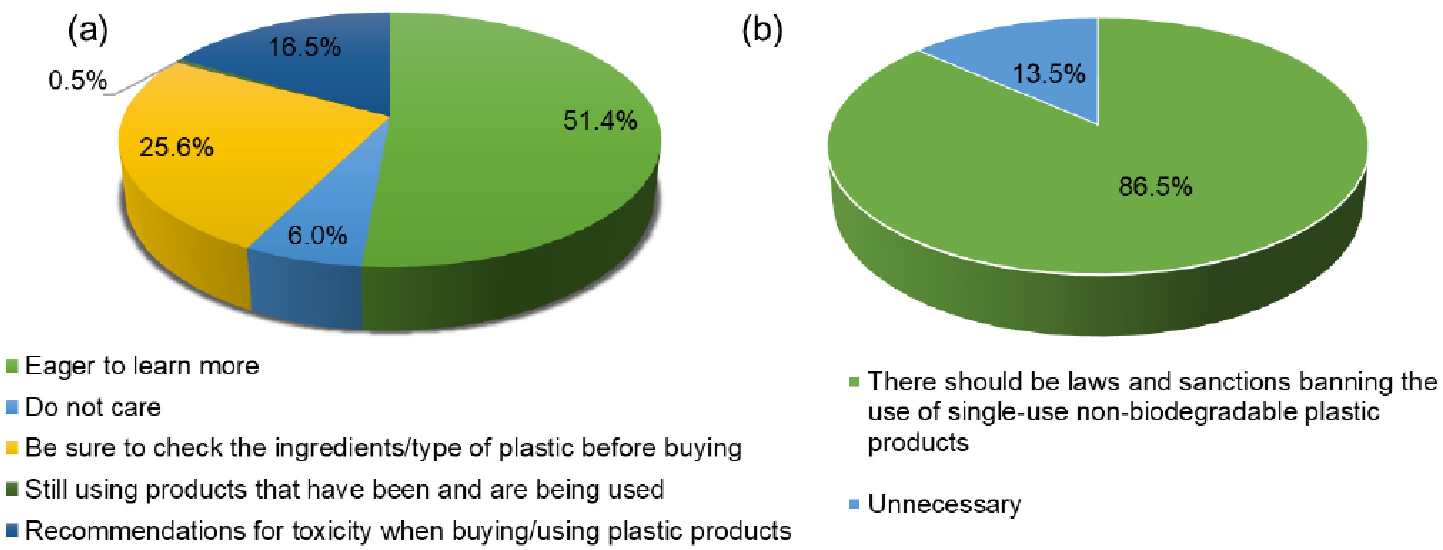

Figure 3

Consumer attitudes and perceptions about the use of these products (a) and requirements for developing laws/regulations about the use of single-use plastic containers (b).

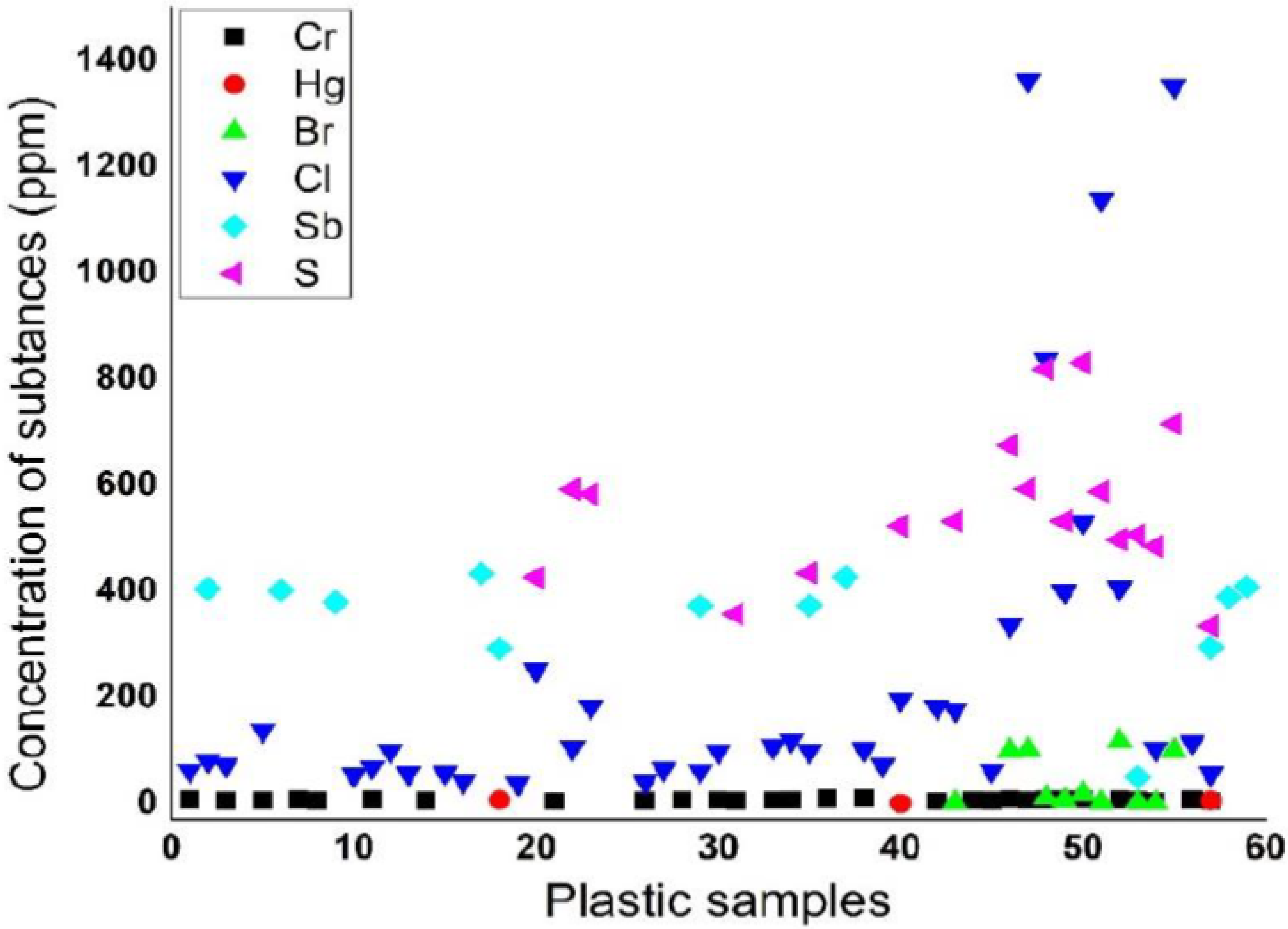

Figure 4

Distribution of toxic elements in collected plastic samples of food containers.

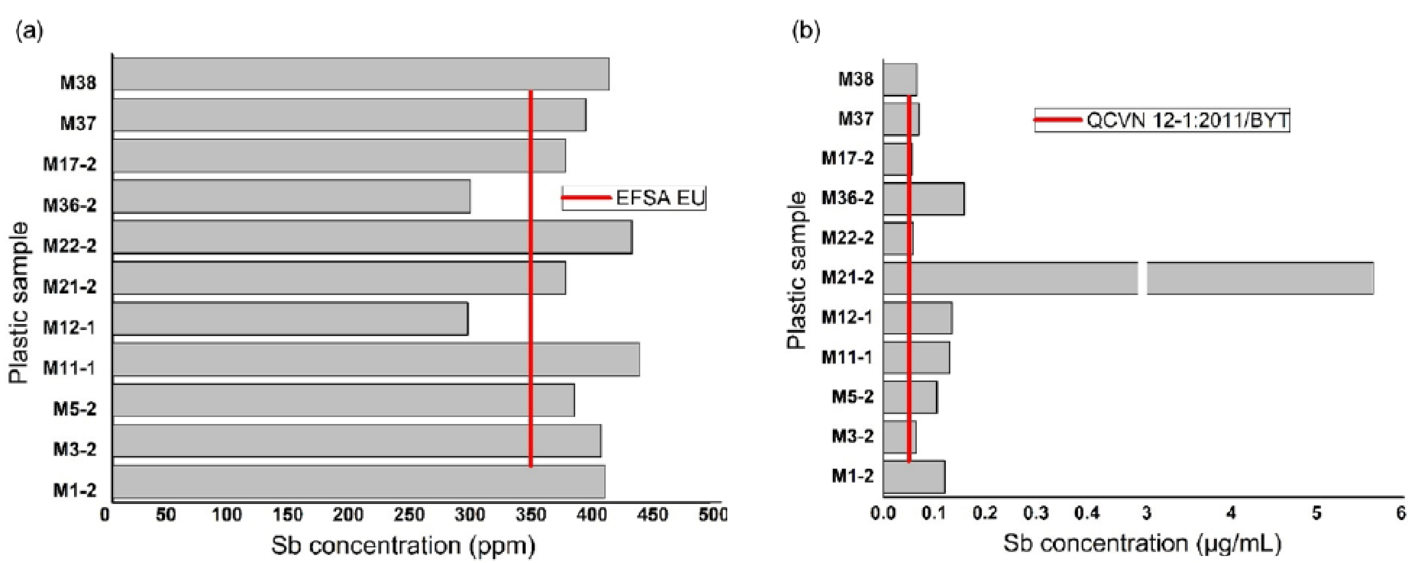

Figure 5

Antimony (Sb) concentrations detected in some obtained plastic samples by EDX (a) and by migration test (b).

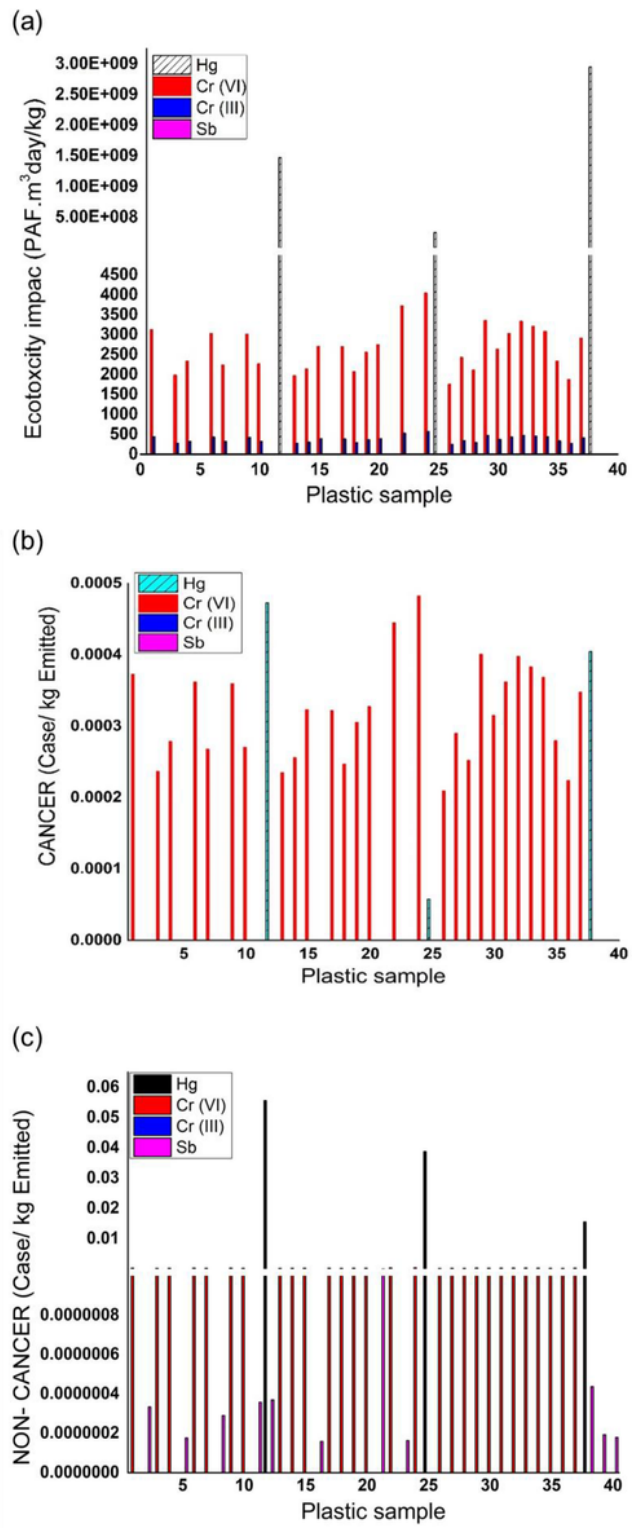

Figure 6

Results of USEtox LCIA model showing average impacts of Hg, Cr, and Sb identified in food plastic containers - related to emission concentrations in air, water and soil with (a) Ecotoxicological impacts, (b) Human cancer and, (c) Non-cancerous diseases.

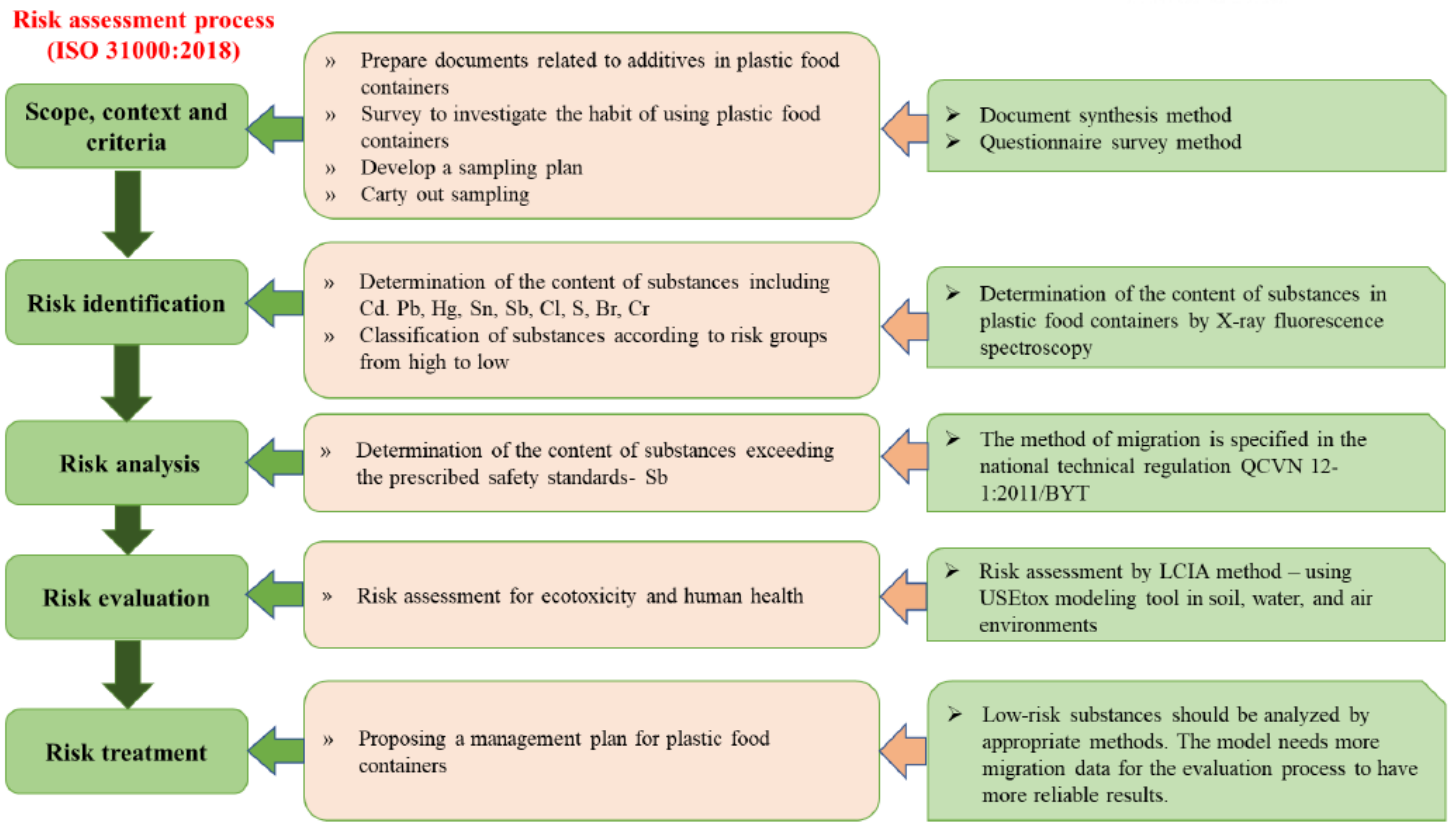

Figure 7

Summary of the risk assessment screening process of plastic food containers according to ISO 31000:2018.

Supplementary Files

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- SupplementaryMaterial.docx