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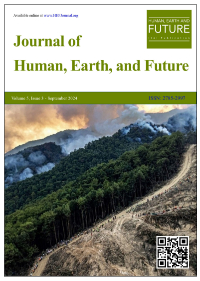

Evaluating Household Hazardous Waste Generation, Composition, and Health Risks in an Urban Municipality

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Abstract

This study aimed to assess the generation rate and composition of household hazardous waste (HHW) in Nakhon Si Thammarat Municipality, Thailand. A questionnaire survey was conducted to collect data on HHW generation and disposal practices from households in the municipality. Soil samples were collected and analyzed for heavy metals (cadmium, chromium, mercury, nickel, and lead) and PCBs contamination. The potential health risks from ingestion exposure associated with heavy metals and polychlorinated biphenyls (PCBs) contamination in the soil were evaluated. The result revealed that in 2023, the HHW generation rate was 11.95 kg/household/year, with the highest percentages occurring of electronic waste (17.40%), fluorescent lamps (16.98%), spray cans (12.38%), cleaning products (11.30%), and engine oil and lubricant oil products (9.87%). The majority of residents (92.90%) disposed of hazardous waste and general waste together in public waste containers. However, the health risk assessment indicated that the levels of heavy metals and PCBs in the soil were within the safe acceptable range for residents, with a total lifetime cancer risk from ingestion exposure of less than 1E-06 for both adults and children. The findings highlight the need for improved waste separation practices and the implementation of effective hazardous waste management strategies to minimize potential health risks and environmental impacts. This study serves as a basis for developing targeted interventions and policies to enhance household hazardous waste management in the municipalities and similar urban areas in Thailand.

Keywords: Household Hazardous Waste; Heavy Metals; Polychlorinated Biphenyls; Health Risk Assessment.

1. Introduction

Solid and hazardous waste management is a significant challenge for authorities in developing countries. Population growth has resulted in an increase in solid and hazardous waste generation. Large quantities of solid and hazardous waste also increase management costs [1]. Many studies have reported that developing countries mismanage waste due to improper disposal methods such as open dumping, uncontrolled landfills, and burning. The lack of appropriate solid and hazardous waste management can cause environmental contamination and social problems, particularly with organic, inorganic, and hazardous substances that are released into the air, soil, and water surrounding them. Additionally, people, as waste generators, lack awareness and understanding of proper waste management. This is an important factor in ineffective waste management [2-6]. The worldwide municipal solid waste (MSW) generation rate is estimated to reach 2.59 billion tons by 2030 and 3.40 billion tons by 2050. In addition, municipal solid waste typically includes hazardous waste and electronic waste [7]. The households in communities contribute to more than two-thirds of the total MSW generated worldwide, with a significant portion ending up in

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landfills. Household hazardous waste (HHW) represents a small fraction, typically approximately 1% by weight [8]. Hazardous wastes are classified by their properties: flammable, corrosive, reactive, and toxic [9]. The HHW subcategory includes a variety of waste items. The various household products, especially those used for cleaning, disinfection, polishing, painting, descaling, lubrication, fuels, fertilizers, and pesticides, often contain harmful substances, including heavy metal-containing products, pharmaceuticals, and personal care. Containers that still contain residual chemicals are categorized as household hazardous waste [10, 11].

In Thailand, HHW generation is also increasing every year. According to the Pollution Control Department, a total of 669,518 tons of HHW were generated in 2021. This included 435,187 tons (65%) of waste from electrical and electronic equipment (WEEE) or electronic waste (e-waste) and 234,331 tons (35%) of other hazardous community waste, such as batteries, fluorescent lamps, light bulbs, chemical containers, and spray paint [12]. There was a noticeable upward trend in hazardous community waste, particularly electronic appliances and electronic waste, with an average annual increase of 1.60% since 2019. The government implemented policies to support the establishment of a HHW management system. This initiative delegated responsibilities to local government organizations, which collaborate with relevant agencies, private sector entities, and the public. Collection drop points for hazardous waste were set up within communities, and centralized collection centers were established at the provincial level. These efforts aimed to enhance the proper sorting and management of hazardous waste. The total hazardous waste was correctly managed at 147,293 tons (22%), which was divided by the utilization of 100,316 tons and the safe landfill disposal of 46,977 tons. However, these results were lower than the targets outlined in the National Solid Waste Management Master Plan for the years 2016-2021, which aimed for a 30% disposal rate [12].

The primary reason for inadequate management of HHW is the low participation of the majority of the population in segregating hazardous waste from general waste. This situation is evidenced by a lack of awareness among the public. Furthermore, the authorities have not enforced regulations to support the proper management of community hazardous waste. Moreover, there is also a lack of legislation governing the disposal of electronic waste [13]. To address these issues, there is a need to establish more community-level hazardous waste drop points and provincial collection centers. Collaboration networks between the government, the private sector, and the public should be strengthened to manage community hazardous waste effectively. The previous study revealed the best model for a hazardous waste management system for Thailand’s local administrative organizations in 2022. The findings indicated that fifteen hubs of hazardous waste collection should be established and distributed in the North, Central region, Northeast, and East of Thailand. Then, hazardous waste would be transported and disposed of at the plant in Phitsanulok province. Remarkably, there were no hubs in the Southern region, as this area was not included in the research scope. Consequently, there is a lack of data related to the appropriate management of hazardous waste in this region [14].

Nakhon Si Thammarat is a southern province with residual solid waste problems, ranking among the top 5 in the country [12]. The Nakhon Si Thammarat municipality generates approximately 368,388 tons of municipal solid waste annually. In particular, the municipality of Nakhon Si Thammarat has a municipal waste disposal site (Thung Tha Lat). At the disposal site, more than two million tons of waste accumulated. According to data on waste management, the average quantity of municipal solid waste was 260 tons per day, of which 120–140 tons per day were collected within the municipality in 2020. Approximately 3% of hazardous waste will be mixed with general waste. The estimated amount of hazardous waste stored in municipal facilities was approximately 3.6 tons per day [15]. Similarly, a study on the quantity of household hazardous waste at the source by all local administrations in Nakhon Nayok Province revealed 2.90 tons per day, which constitutes 2.53% of the total household waste [16]. As mentioned above, HHW mixed with general waste is disposed of in landfills. Residual hazardous substances leach into the environment, including heavy metals (e.g., Cd, Cr, Hg, Pb, and Ni) and organic compounds, some of which are carcinogenic [13, 17-20]. This leads to health risks and environmental pollution. In addition, emerging pollutants such as microplastics, phthalates, bisphenol-A, dioxins, and antibiotics further contribute to contamination. According to previous research, improper management of HHW leads to the accumulation of heavy metals and organic compounds in the environment. This can consequently contaminate the food chain, which can be detrimental to humans [9, 21, 22]. However, there is currently no study in the area that provides insights into the types and quantities of hazardous waste, as well as the actual management methods. This information is crucial for planning effective hazardous waste management, as it can reduce the amount of hazardous waste mixed with general waste, thereby ensuring the long-term safety of the waste disposal system.

This research aimed to investigate the quantity and components of household hazardous waste generated at its source. Additionally, this study aimed to examine heavy metals and polychlorinated biphenyls (PCBs) contamination in soil and assess the associated health risks. This study provides a better understanding of household hazardous waste management in the Nakhon Si Thammarat Municipality.

2. Material and Methods

2.1. Study Area and Design

The study area included 67 communities in five subdistricts of Nakhon Si Thammarat Municipality, which is in central Nakhon Si Thammarat Province in southern Thailand. There were 46,145 households with a residential population of 102,152 people in an area of 22.56 km^2. The average population density is 4,528 people/km^2. The study was carried out in two phases: a questionnaire survey and a soil sampling investigation. A questionnaire survey was used to gather data on hazardous waste management in households. Then the soil in the area was examined for contaminants due to improper management.

2.2. Questionnaire Survey

A descriptive cross-sectional study was carried out among people in the Nakhon Si Thammarat Municipality, Thailand. A field survey was conducted between February and April 2023. The quantitative and qualitative data were collected via a face-to-face questionnaire. The sample size was estimated using Taro Yamane's equation with a 5% margin of error. Based on this formula, 396 households in 67 communities were initially involved in the fieldwork, and the sample size increased to 419. The respondents were recruited using a random sampling technique (Figure 1).

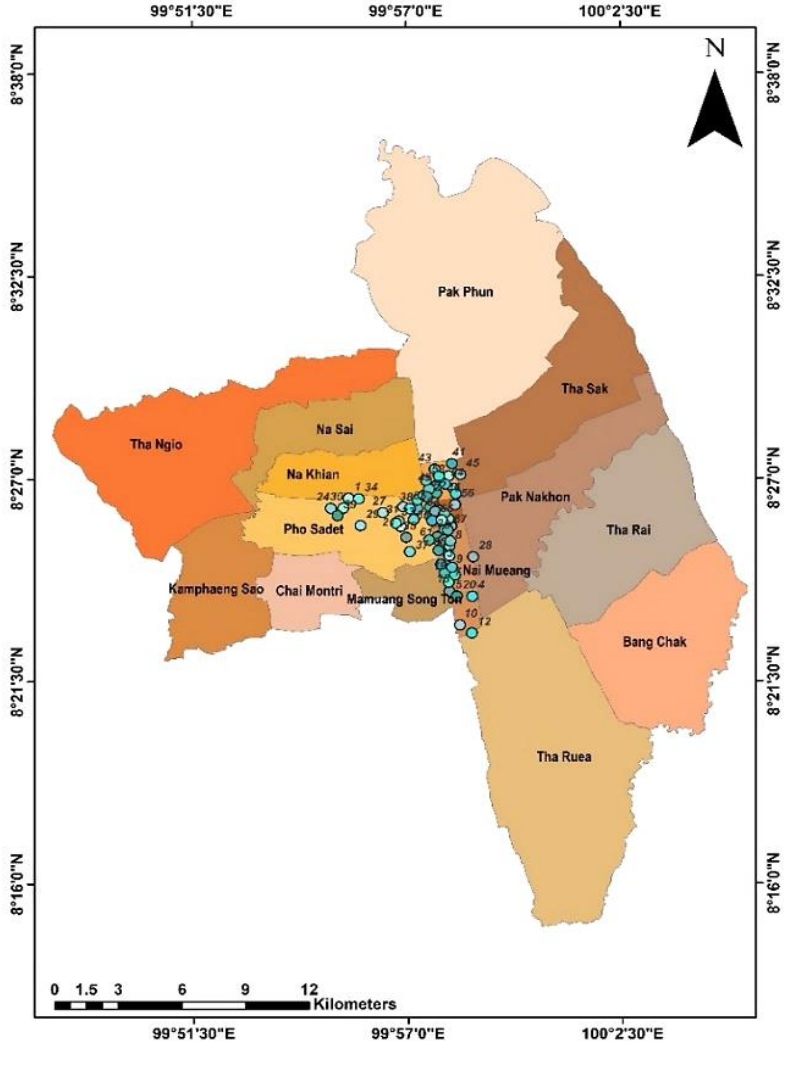

Figure 1. Study area in the Nakhon Si Thammarat Municipality, Thailand

2.3. Soil Investigation

Soil samples were collected to examine heavy metals and PCBs. Sampling points were randomly collected from 18 locations (P1–P18) within five subdistrict areas in the surrounding communities of the municipality, as shown in Figure 2. A soil sample of approximately 1 kg was taken from a depth of 0–30 cm. of soil on sites and homogenized. All the samples were air-dried, and stones and debris were removed. Then the samples were crushed into powder, sieved through a 2-mm stainless steel sieve, stored in polyethylene bags, and kept at 4 °C until analysis.

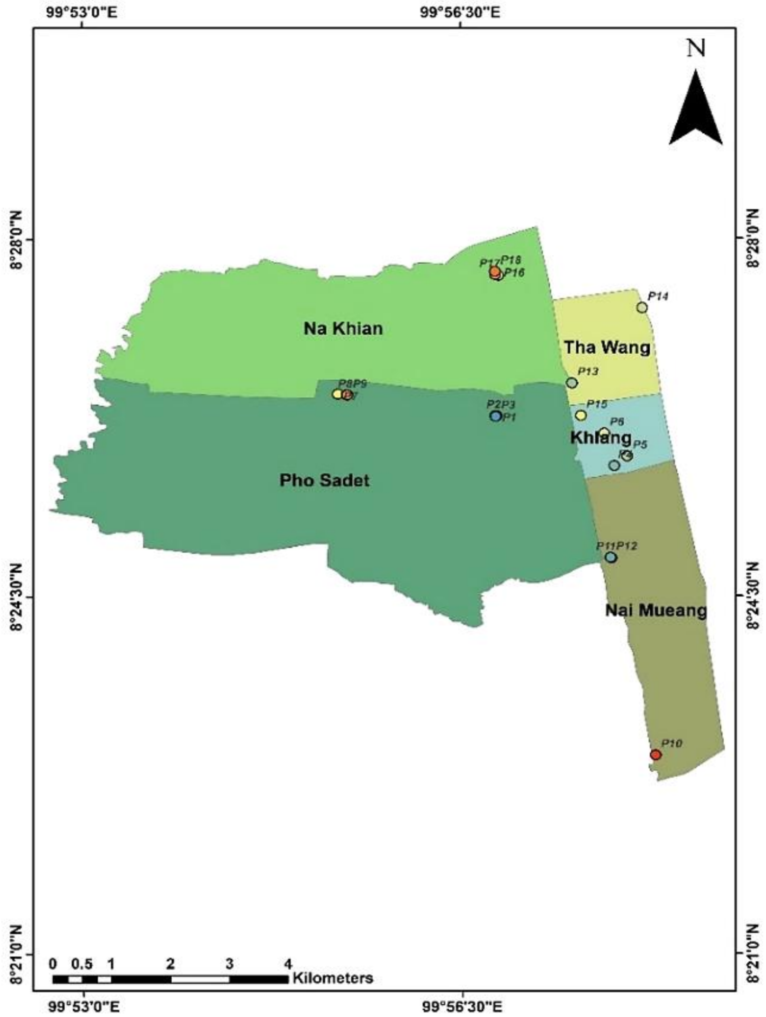

Figure 2. Soil sampling points in the study area (P1 – P18)

2.4. Heavy Metals and Polychlorinated Biphenyls Analysis

Heavy metals were extracted using the acid digestion method according to the U.S. Environmental Protection Agency (U.S. EPA) Method 3050 [23]. The concentrations of cadmium (Cd), chromium (Cr), mercury (Hg), nickel (Ni), and lead (Pb) in the soil samples were determined using inductively coupled plasma optical emission spectrometry (ICP-OES, Perkin Elmer-3000 DV). During the investigation, quality assurance and quality control, standard samples, duplicate samples, and blank samples were added.

Chemical analysis of polychlorinated biphenyls (PCBs) was performed following method 3550C for PCBs ultrasonic extraction by the U.S. EPA and adapted from previous research [18, 24-28]. All soil samples were spiked with 2-, 4-, 5-, and 6-tetrachloro-m-xylene (TMX) and PCB209 as surrogate standards of PCBs before extraction. A mixture of acetone and n-hexane (1:1, v/v) was added to 100 ml of soil sample and extracted for 2 hours. The PCBs concentrations were quantified using a gas chromatography mass spectrometer (GC-MS, Agilent 7890A-5975C) with a DB-XLB column of 30 m × 250 μm × 0.25 μm (Agilent J&W) that was used for selected ion monitoring (SIM). Fourteen PCB congeners, including PCB 18, 28, 31, 44, 52, 101, 118, 138, 149, 153, 170, 180, 194, and 209, were analyzed. Contamination was measured in the blank samples during sampling and analysis.

2.5. Health Risk Assessment

The lifetime cancer risks of residents exposed to heavy metals and PCBs through ingestion were estimated following EPA guidelines [29-32]. The health risk assessment models and assumptions were based on real-life situations and activities in the study area. Improper waste disposal in communities can lead to the ingestion of hazardous substances released from HHW. Unintentional ingestion exposure may occur when the contaminated hand comes into contact with the mouth or surrounding area [33]. The ingestion exposure concentrations of residents were calculated as chronic daily intake (CDI) (mg/kg-d), which was applied for quantifying lifetime cancer risk (LCR), as presented in Equations 1 and 2.

$$\mathrm{CDI} = (\mathrm{C} \times \mathrm{IRing} \times \mathrm{EF} \times \mathrm{ED})/(\mathrm{BW} \times \mathrm{AT}) \quad (1)$$

$$\mathrm{LCR} = \mathrm{CDI} \times \mathrm{CSF} \quad (2)$$

All variables in the equations are described in Table 1. Exposure variables recommended by the U.S. EPA [32, 34], including the ingestion rate (IRing), exposure frequency (EF), exposure duration (ED), body weight (BW), averaging time (AT), and cancer slope factor (CSF), were used for the calculations. For interpretation, an LCR greater than 1E-06 was regarded as an unacceptable risk, as it represented a potential carcinogenic health effect [34]. The range of carcinogenic risk was assessed and reported with a 95% confidence interval (CI).

Table 1. Variables for exposure equation of residents

Variable	Definition (unit)	References
C	Concentration of heavy metal (mg/kg)	Data from this study
C	Concentration of PCBs (mg/kg)	Data from this study
IRing	Ingestion rate	U.S. EPA (2011) [34]
EF	Exposure frequency (day/year)	U.S. EPA (1991) [35]
ED	Exposure duration (year)	U.S. EPA (2011) [34]
BW	Bodyweight (kg)	U.S. EPA (2011) [34]
AT	Average time (365 d/y × 70 y)	U.S. EPA (1997) [32]
CSF	***Cancer slope factor (mg/kg-d)***	
	Cd= 0.38	U.S. EPA (2011) [36]
	Cr= 0.50	U.S. EPA (2011) [36]
	Ni= 0.91	U.S. EPA (2011) [36]
	Pb= 0.042	U.S. EPA (2011) [36]
	PCBs= 2.00	U.S. EPA (2015) [37]

Figure 3 shows the flowchart of the research methodology through which the objectives of this study were achieved.

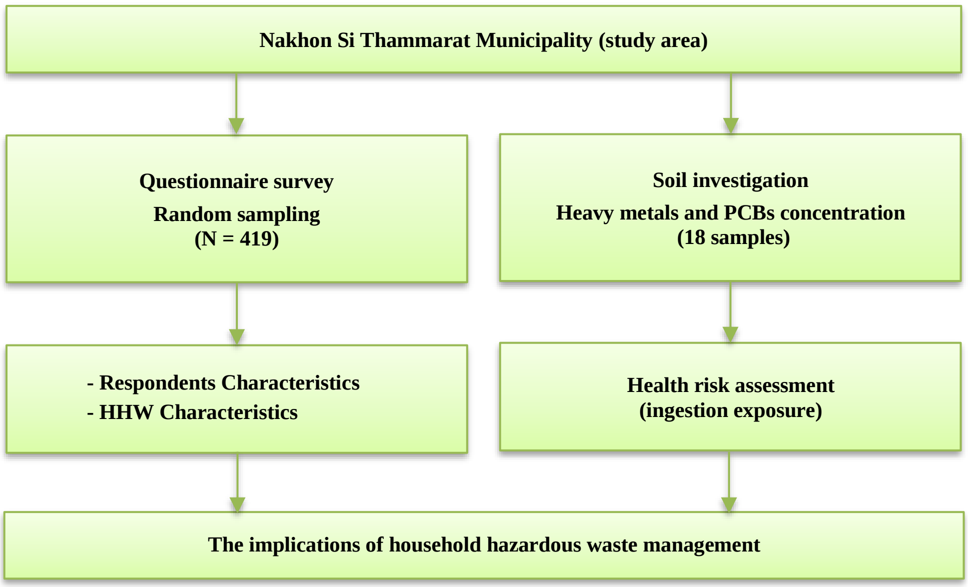

Figure 3. Flowchart of the research methodology

3. Results and Discussion

3.1. Characteristics of the Respondents

Table 2. shows the descriptive data of the respondents in this study. This study provided an explanation of household hazardous waste management practices. The sample group of 419 participants who responded to the questionnaire revealed that the majority were females (73.75%), with an average age of 52.12±13.10 years. Approximately 46.97% of the respondents held the position of household head. Regarding occupation, the respondents were self-employed (49.40%). In terms of education, 41.29% of the respondents had completed their diploma and undergraduate degrees. The average length of stay in the community was 34.93±17.85 years. Regarding hazardous waste management in households, hazardous waste was mainly managed by disposal of general waste in municipal

bins, which was collected by relevant authorities, and accounted for 92.90% of the total waste. This sample was then sorted and sold at 6.15%. However, 0.95% of the respondents burned or dumped waste on their own land. According to a questionnaire survey, most residents dispose of hazardous waste together with general waste due to a lack of intention toward waste separation. They are unaware of which wastes are hazardous, and some residents believe that separating waste is ineffective for waste disposal.

Table 2. Sociodemographic characteristics of the respondents

Variable	Description	Frequency (N)	Percentage (%)
Gender	Female	309	73.25
	Male	110	26.25
Education	None	4	0.96
	Primary	96	22.91
	Secondary	146	34.84
	Tertiary (Diploma/ Degree)	173	41.29
Occupation	Self-employed	223	53.22
	Private sector	76	18.14
	Housewife	57	13.60
	Civil servant	30	7.16
	Retiree	15	3.58
	Student	4	0.96
	Others	14	3.34

3.2. Household Hazardous Waste Characteristics

The properties of flammability, reactivity, explosiveness, and toxicity are defined as hazardous wastes. Household hazardous wastes (HHW) include fertilizers, paints, obsolete solvents, pharmaceuticals, wood preservatives, pesticides containing heavy metals, products used in vehicle and home maintenance, personal care items, household cleaning products, biologically infectious waste, and batteries [10, 11]. In this study area, the total HHW from 419 households was 5,021 kg, or 2.02% of the total municipal solid waste. It was estimated that the total HHW generation was 11.95 kg/household/year. The results indicated that the generation rate of HHW was 0.014 kg/person/day. Thus, the total households in the study area generated approximately 551 tons of HHW per year. The residents managed 7.1% of the HHW at the source, while the remaining 92.9% was collected with general waste and disposed of at a landfill. On the other hand, in the previous study, the quantity of HHW at the sources in all local administrations in Nakhon Nayok province, Thailand was 1,059 tons/year, which represented 2.53% of total household waste in 2017 [16]. This study revealed that the HHW generation rate was lower than previous research estimates in the Asian region, where HHW generation at 0.038 kg/person/day in upper-middle-income countries and 0.028 kg/person/day in lower-middle-income countries [38]. However, this HHW generation rate was higher than that in China and Tehran, which were 0.0062 and 0.0063–0.0083 kg/person/day, respectively [8, 39].

This study included all types of HHW in communities. There were no categories of HHW excluded. This study classified HHW into 14 categories: spray can, oil and solvent product, paint product, pesticide product, herbicide product, pharmaceutical and personal care product, cosmetics, battery, fluorescent lamp, cleaning solution product, engine oil and lubricant oil product, infectious waste, electronic waste, and others. The top three categories of HHW were electronic waste (872.52 kg), fluorescent lamps (851.64 kg), and spray cans (620.58 kg). The types and quantities of HHW are presented in Table 3. and Figure 4. The Nakhon Si Thammarat municipality generated a total of 551 tons of HHW that required appropriate and proper management. The percentage of HHW in the study area indicated that electronic waste contributed the most (17.40%), followed by fluorescent lamps (16.98%), spray cans (12.38%), cleaning products (11.30%), and engine oil and lubricant oil products (9.87%). In this case, electronic waste contributed the most (17.40%) because it has become an integral part of life. The growth and demand for electrical and electronic equipment have led to a significant increase in the volume of e-waste. According to a previous report, 62.0 Mt of e-waste was generated globally in 2022; of this, 22.3% was formally gathered and recycled environmentally and sustainably [40]. The HHW distribution for this area was similar to those reported in China, Mexico, and Thailand, whereas it differed from that of Tehran, which found home cleaning products to be the largest hazardous waste group. [8, 16, 38, 41].

Table 3. Household hazardous waste types and quantities in the Nakhon Si Thammarat Municipality

Types of HHW	Weight of HHW (kg)	Generation Rate (kg/household/year)	Total weight of HHW (tons)
Battery	106.49	0.25	11.54
Cleaning solution product	563.83	1.35	62.30
Cosmetics	62.62	0.15	6.92
Electronic waste	872.52	2.08	95.98
Engine oil and lubricant oil product	493.62	1.18	54.45
Fluorescent lamp	851.64	2.03	93.67
Herbicide product	29.3	0.07	3.23
Infectious waste	328.77	0.78	35.99
Oil and solvent product	398.81	0.95	43.84
Paint product	344.86	0.8	36.92
Pesticide product	120.29	0.29	13.38
Pharmaceutical and personal care product	205.84	0.49	22.61
Spray can	620.58	1.48	68.29
Others	22	0.05	2.40

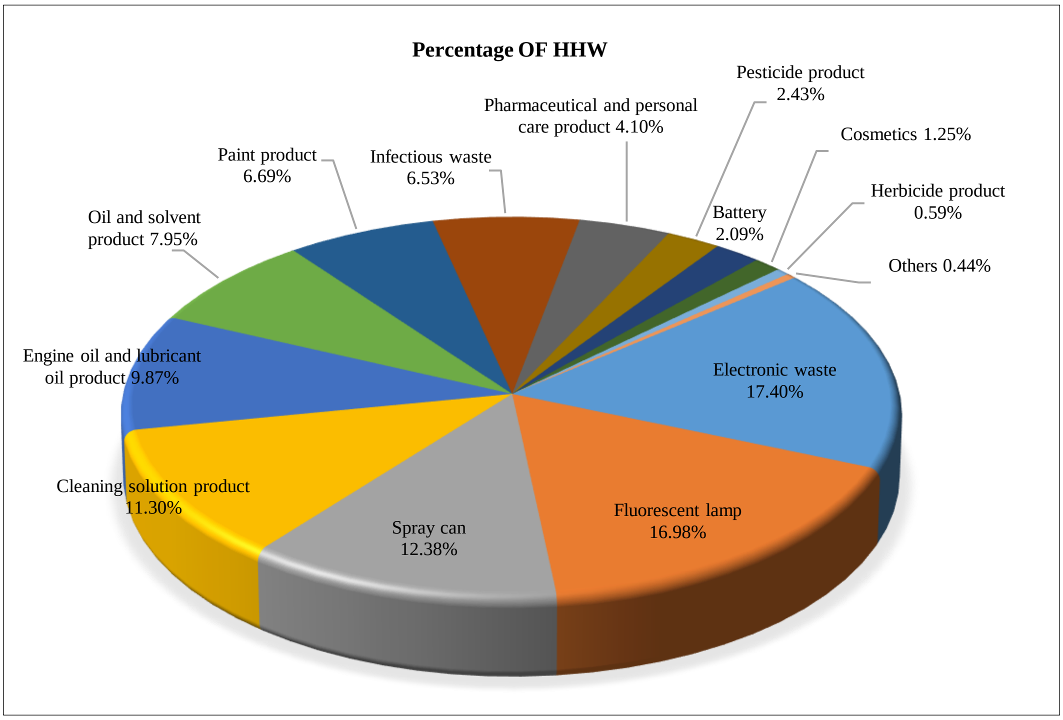

Figure 4. Percentage of household hazardous waste composition

3.3. Heavy Metals and Polychlorinated Biphenyls Concentrations

Considering the HHW management practices based on the survey data, soil samples from the environmental surroundings of the community were collected. Ninety-two percent of residents in the study area do not store HHW in their houses. Residents disposed of hazardous waste and general waste in municipal waste containers. Hazardous pollutants may be present in the soil as a result of household hazardous waste mismanagement. The 18 sampling points were spread across five subdistricts and divided into three main types of areas with different community characteristics. The urban areas with high population density include P1-P3 and P7-P9. The sampling points P4-P6 were urban areas with recycling shops. The sampling points P10-P15 were suburban areas, and P16-P18 were landfill disposal sites.

The study area revealed the following concentrations of heavy metals: Cr (0.002-0.087 mg/kg), Pb (0.028-0.817 mg/kg), and Ni (0.001-0.805 mg/kg), with no detectable levels of Cd and Hg in the soil samples. By comparing the locations of the 18 sampling points, the study revealed soil Pb contamination at 13 points (72.22%), which was significantly different from that of the other heavy metals. Soil contaminants of Cr and Ni were found at 5 points

(27.78%) and 1 point (5.55%), respectively. Household waste, including electronic appliances, cleaning products, and batteries, contains substantial quantities of heavy metals. If improperly disposed of, household waste can contribute to heavy metal pollution, such as cadmium, lead, mercury, and nickel, resulting in health and environmental hazards [42].

The soils at the P3, P6, P9, P10, and P14 sampling points (Figure 2) did not contain heavy metals. However, the concentrations of heavy metals in all soil samples did not exceed the Notification of the National Environmental Board: Soil Quality Standard guidelines for residential areas in the Royal Gazette on March 11, 2021 [43]. The presence of heavy metals is not correlated with the characteristics of community areas. This may be due to improper management of HHW, which most residents dispose of along with general waste. Consequently, the likelihood of heavy metal contamination in the soil does not vary significantly across different areas.

This result was consistent with a previous study in southwestern Nigeria, which found various heavy metals in the soil at 1 km from the municipal solid waste disposal facility. The ranges of Ni and Pb in the soil were 3.0-13.0 and 4.0-54.0 mg/kg, respectively [44]. Furthermore, researchers reported the metal concentrations in topsoil samples from the main activity areas in 18 public parks in Guangzhou, China. The heavy metal concentrations were as follows: 0.13-0.27 mg/kg for Cd, 30.26-102.70 mg/kg for Cr, 12.63-36.95 mg/kg for Ni, and 12.96-270.57 mg/kg for Pb [45]. The findings indicated that municipal solid waste management is likely to be involved in soil contamination. Remarkably, the concentration of Pb in this study was found to be greater than that of other metals due to its ability to remain in ambient air for 10 days before it settles into the ground and accumulates in soil [46]. The study area contributed the most electronic waste to the HHW composition, with 17.40% of residents disposing of municipal waste. Trace metals (Cr, Pb, and Ni) in circuit boards, batteries, and CRT monitors may spread into the surrounding environment [47]. Additionally, a previous study revealed that arsenic, cadmium, copper, and lead contaminate the soil in an e-waste dismantling area in Buriram, Thailand. This causes heavy metal contamination of surface and subsurface soils [13].

PCBs concentrations in the soil samples ranged from of 2.94–3.98 µg/kg at three sampling points (P1, P11, and P18). The results revealed the profile of PCB congeners as PCB 18, 31, 52, and 138. The concentrations of total PCBs at sampling point P1, P11, and P18 were 2.94, 6.60, and 6.92 µg/kg, respectively. The PCBs concentrations in the soil samples ranged from 2.94–3.98 µg/kg at three sampling points (P1, P11, and P18). The results revealed the profile of PCB congeners as PCB 18, 31, 52, and 138. The concentrations of total PCBs at sampling points P1, P11, and P18 were 2.94, 6.60, and 6.92 µg/kg, respectively. According to the number of chlorine atoms in the congener, the PCBs identified in this study can be classified as tri-CBs (18, 31), tetra-CB (52), and hexa-CB (138). Similarly, in this study, the sum of indicator PCBs concentrations in urban soils in Sofia, Bulgaria, ranged from 7.2-17.2 µg/kg. The soil samples contained high chlorinated indicator PCB 138, 153, and 180 [25]. In contrast to this study, the report on PCBs concentrations in the e-waste recycling areas in Taizhou, China, showed that the levels of tri-CBs, tetra-CBs, penta-CBs, and hexa-CBs were 9.01, 5.56, 12.93, and 3.13 mg/kg, respectively. These were high concentrations in the soil due to the e-waste dismantling process, which released the PCBs into the surrounding area [19, 26]. Moreover, in Lagos, Nigeria, PCBs in the soil from sites affected by different human activities ranged from 17.6 to 82.0 mg/kg [48]. These results were greater than the PCBs concentrations found in this study.

3.4. Health risk assessment

The lifetime cancer risk (LCR) of residents exposed to heavy metals and PCBs in the Nakhon Si Thammarat Municipality was evaluated. Accidental ingestion may occur when the contaminated hand touches the mouth or the surrounding area in the event that people contact the contaminated soil at the HHW collection point. The 95% confidence intervals of the LCR and total LCR are shown in Tables 4. and 5, respectively. In cases of exposure to carcinogenic substances, the assessment considered the concentrations of Cr, Ni, Pb, and PCBs. According to the results, adults exposed to Cr, Ni, Pb, and PCBs had mean LCRs of 1.68E-08, 4.54E-07, 6.55E-09, and 9.04E-09, respectively. The estimated means of the LCR for children exposed to Cr, Ni, Pb, and PCBs were 3.13E-08, 8.48E-07, 1.22E-08, and 2.11E-08, respectively. The LCRs for Cr, Ni, Pb, and PCBs in both adults and children were lower than 1E-06, indicating a safe and acceptable risk. The total lifetime cancer risk for adults and children ranged from 9.77E-10 to 4.82E-07 and from 4.99E-09 to 9.00E-07, respectively. Therefore, the total lifetime cancer risk in both adults and children shows no potential health risks. Compared with a previous study, a health risk assessment of ingestion and dermal contact exposure to PCBs in urban soils in Bulgaria was performed. The cancer risk results for both adults and children show that there is no health risk to humans [25]. Furthermore, previous studies on ingestion exposure revealed trends similar to those in which the health risk levels of Cr, Ni, Pb, and PCBs were at acceptable risk. The residents of an abandoned e-waste site in China, both adults and children, were safe. [19, 44]. In summary, the assessment showed that the risk was low because soil ingestion or hand-to-mouth exposure is less likely to occur in a real-life situation compared to other exposure pathways [33]. Despite the low risk, the residents should take caution when coming into contact with the soil that may contain hazardous substances.

Table 4. Lifetime cancer risk of heavy metals and PCBs estimated in this study

Sampling point	Lifetime cancer risk (Adult)				Lifetime cancer risk (Child)			
	Cr	Ni	Pb	PCBs	Cr	Ni	Pb	PCBs
P1	-	-	5.55E-09	1.10E-08			1.04E-08	2.57E-08
P2	2.66E-08	4.54E-07	1.26E-09	-	4.97E-08	8.48E-07	2.35E-09	-
P3	-	-	-	-	-	-	-	-
P4	2.66E-08	-	7.02E-09	-	4.97E-08	-	1.31E-08	-
P5	-	-	9.77E-10	-	-	-	1.82E-09	-
P6	-	-	-	-	-	-	-	-
P7	-	-	2.44E-09	-		-	4.56E-09	-
P8	-	-	1.46E-08	-		-	2.72E-08	-
P9	-	-	-	-	-	-	-	-
P10	-	-	-	-	-	-	-	-
P11	1.47E-08	-	9.51E-09	4.77E-09	2.74E-08	-	1.78E-08	1.112E-08
P12	6.12E-10	-	2.03E-09	-	1.14E-09	-	3.79E-09	-
P13	1.53E-08	-	7.20E-10	-	2.86E-08	-	1.34E-09	-
P14	-	-	-	-	-	-	-	-
P15	-	-	2.10E-08	-	-	-	3.92E-08	-
P16	-	-	1.03E-08	-	-	-	1.93E-08	-
P17	-	-	2.67E-09	-	-	-	4.99E-09	-
P18	-	-	6.99E-09	1.13E-08	-	-	1.31E-08	2.647E-08
Average	1.68E-08	4.54E-07	6.55E-09	9.04E-09	3.13E-08	8.48E-07	1.22E-08	2.11E-08

Table 5. Total lifetime cancer risk of residents estimated in this study

Sampling point	TLCR (Adult)	TLCR (Child)	Sampling point	TLCR (Adult)	TLCR (Child)
P1	1.66E-08	3.61E-08	P10	-	-
P2	4.82E-07	9.00E-07	P11	2.90E-08	5.63E-08
P3	-	-	P12	2.64E-09	4.93E-09
P4	3.37E-08	6.28E-08	P13	1.60E-08	2.99E-08
P5	9.77E-10	1.82E-09	P14	-	-
P6	-	-	P15	2.10E-08	3.92E-08
P7	2.44E-09	4.56E-09	P16	1.03E-08	1.93E-08
P8	1.46E-08	2.72E-08	P17	2.67E-09	4.99E-09
P9	-		P18	1.83E-08	3.95E-08

4. Conclusion

The HHW compositions of 67 communities in the Nakhon Si Thammarat Municipality were revealed. The quantity of HHW was found to be 5,021 kg. The estimated total HHW generation is 11.95 kg/household/year. The most common HHW found in the study area was electronic waste at 17.40%, fluorescent lamps at 16.98%, spray cans at 12.38%, cleaning products at 11.30%, and engine oil and lubricant products at 9.87%. Considering the HHW management in the area, 92.90% of residents do not store HHW in their houses. HHW was disposed of with general waste in the municipality's public containers. The contamination of heavy metals and PCBs in the soil indicated a safe and acceptable risk to residents. The total lifetime cancer risk for ingestion of Cr, Ni, Pb, and PCBs in adults and children was found to be lower than that for 1E-06, indicating a low potential health risk. The government should focus on strictly separating HHW and general waste at the source. The municipality should implement hazardous waste separation knowledge programs, train people, and practice hazardous waste separation. All residents should help drive better HHW management in the community. Residents should engage in strategies and specific policies in the community to improve together. Finally, the municipality may establish law enforcement to ensure that people practice proper HHW management. These findings may indicate that a municipality should consider community-based information to improve the recycling and disposal system for HHW. Additionally, a database will be used to initiate targeted interventions and policies to improve HHW management in other municipalities and similar metropolitan regions throughout Thailand.

5. Declarations

5.1. Author Contributions

Conceptualization, J.S. and T.P.; methodology, J.S., N.N., and T.P.; formal analysis, J.S., N.N., and T.P.; investigation, J.S. and T.P.; data curation, J.S., N.N., and T.P.; writing—original draft preparation, J.S., N.N., and T.P.; writing—review and editing, J.S. and T.P.; supervision, T.P.; funding acquisition, J.S. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

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5.5. Institutional Review Board Statement

The study was approved by the Ethical Review Committee for Research Subjects and received the WUEC-22-366-01 Number from the Health Science Group of Walailak University, Thailand. Respondents were recruited after giving written informed consent.

5.6. Informed Consent Statement

Not applicable.

5.7. Declaration of Competing Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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