Appraisement of PM10 Concentrations at Residential Areas Influenced by Informal E-Waste Dismantling Activity, Buriram Province, Thailand

Authors: Prueksasit, Tassanee, Chanthahong, Siriwipha, and Kanghae, Yatima

Source: Air, Soil and Water Research, 13(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/1178622120931081

Appraisement of PM_{10} Concentrations at Residential Areas Influenced by Informal E-Waste Dismantling Activity, Buriram Province, Thailand

Air, Soil and Water Research
Volume 13: 1–8

DOI: 10.1177/1178622120931081

Tassanee Prueksasit[1,2], Siriwipha Chanthahong[1] and Yatima Kanghae[1]

[1]Department of Environmental Science, Faculty of Science, Chulalongkorn University, Bangkok, Thailand. [2]Research Program of Municipal Solid Waste and Hazardous Waste Management, Center of Excellence on Hazardous Substance Management (HSM), Bangkok, Thailand.

ABSTRACT: The PM_{10} contributed in the e-waste dismantling community at Banmaichaiyaphot District, Buriram Province, was investigated due to the e-waste dismantling houses randomly located neighboring non-e-waste dismantling houses. The sampling was performed at non- and e-wastes dismantling houses and compared with the reference house in Daengyai subdistrict. The 24-hour average outdoor PM_{10} concentrations ($81.957 \pm 18.724\ \mu g/m^3$) at e-waste dismantling sites were higher than those of the non-e-waste dismantling houses ($80.943 \pm 32.740\ \mu g/m^3$) and control house ($36.717 \pm 19.516\ \mu g/m^3$). The 24-hour average indoors PM_{10} concentrations of the e-waste dismantling houses ($116.171 \pm 64.635\ \mu g/m^3$) showed higher concentrations than those of the non-e-waste dismantling ($113.637 \pm 64.641\ \mu g/m^3$) and reference house ($70.907 \pm 22.464\ \mu g/m^3$), but there were no statistically significant differences ($P > .05$). Both indoor and outdoor PM_{10} concentrations between non- and e-waste dismantling houses did not have significant differences, whereas those of non- and e-waste dismantling houses were significantly higher than that of the reference house locating approximately 5 km away. The positive correlation between indoor and outdoor concentrations of non- and e-waste dismantling houses was satisfactory significant with the r of .613 and .825, respectively. The results indicate that the existing indoor PM_{10} of either non- or e-waste dismantling houses could result from neighborhood e-waste dismantling.

KEYWORDS: E-waste dismantling, PM_{10}, residential area, indoor, outdoor, indoor-outdoor ratio

RECEIVED: April 12, 2020. **ACCEPTED:** May 11, 2020.

TYPE: Original Research

FUNDING: The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was financially supported by the Research Program of Municipal Solid Waste and Hazardous Waste Management, Center of Excellence on Hazardous Substance Management (HSM), the S&T Postgraduate Education and Research Development Office (PERDO), the Office of Higher Education Commission (OHEC) (HSM-PJ-CT-17-02).

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

CORRESPONDING AUTHOR: Tassanee Prueksasit, Department of Environmental Science, Faculty of Science, Chulalongkorn University, Wang Mai, Pathumwan District, Bangkok 10330, Thailand. Email: tassanee.c@chula.ac.th

Introduction

At present, electronic and electrical appliances are a part of our daily lives such as mobile phones, televisions, refrigerators, washing machines, and computers. When these electronics are discarded, being nonworking, and having reached the end of their useful life, they will become electronic scraps called "Electronic waste or E-waste."[1] Because of the increase in consumption of electronics, e-waste has become one of the emerging problems in developed and developing countries worldwide. In Thailand, due to the increase of electronic and electrical appliance consumption, improper handling of electrical or electronic products and no regulation to manage e-waste directly, the problem of electronic waste is increasing every year. The estimated number of electrical and electronic equipment in Thailand increased from 359 070 to 414 600 tons in 2012 to 2017.[2,3]

The northeast of Thailand is one of the largest e-waste improper dismantling areas. For example, in Daengyai subdistrict, Banmaichaiyaphot District, and Banpao subdistrict, Puthaisong District, Buriram Province, there were 130 e-waste dismantling houses in 2017. The estimated number of e-waste entry to this area in 2017, including a desktop computer, fan, refrigerator, washing machine, television (CRT), were 1.88, 5.37, 8.26, 10.06, and 12.33 tons/y/household, respectively.[4] The dismantling of these e-wastes is proceeded by informal separators or in the household in which primitive recycling techniques, such as cutting, breaking, smashing, and open burning, are used to separate the valuable parts for sale. After sorting, valuable materials such as copper, steel, aluminum, and plastic are sold, whereas the residue wastes such as debris, chips, foam, and other materials are disposed of in the dump site in the area. Inappropriate dismantling, as stated, will release the particulate matter (PM) into the air surrounding the dismantling area and also disperse into any indoor environment. Consequently, initiated air pollution can contribute to various respiratory problems.[5] The dismantling workers may be posed to have potential health risks due to the PM contained in the hazardous materials passing through the alveolus of the workers or residents and reaching parts of the body through the blood circulatory system.[6-8] Anyhow, most local people who have this occupation are not aware or are ignorant of the potential adverse health effects from dismantling of e-waste.

Contaminated outdoor air or PM could reach the indoor environment via penetration and ventilation. Opened windows and doors, as well as cracks in walls, doors, and window sealants, are the most common pathway which allows outdoor air to affect indoor air quality.[9,10] Although outdoor air could affect indoor air quality, indoor sources could also affect the air

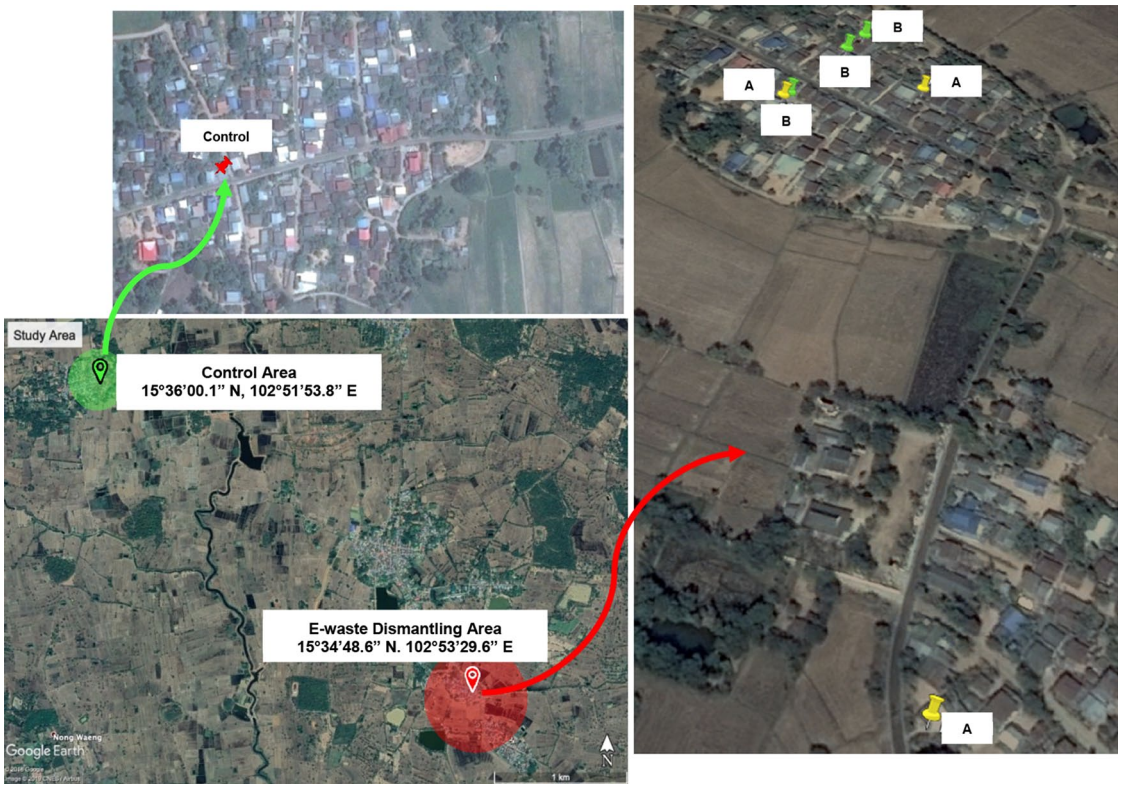

Figure 1. Location of the study site in Daengyai subdistrict, Banmaichaiyaphot District, Buriram Province.
Source: Google Earth. Assessed July 4, 2019.

quality itself. Occupants' activities and the intended use of spaces were related to indoor pollutant sources. The most significant sources of indoor air pollution are gases and dust from cooking, in particular from using a stove with coal and tobacco smoke, followed by heating systems, cleaning, resuspension due to the presence of humans, and some were contaminated from the outdoor air. Then, outdoor air or dust of e-waste dismantling houses could penetrate through opened windows and doors which must contribute to indoor concentrations of dust even higher than outdoors.[11,12] Moreover, the study of indoor/outdoor PM concentration or I/O ratio is an important indicator as the I/O ratio can portray the relationship between dust concentration indoors and outdoors, such as which one has more important sources or has more influence on the other's levels.

When contaminated PM is released into the air, it can affect the air quality. The monitoring of PM usually uses respirable dust or PM that is less than 10 μm (PM_{10}) because it is a useful indicator of the level, deposition, and distribution of contamination in the atmosphere derived from natural and anthropogenic activities and can be breathed in by people.[13,14] Earlier studies have found the indoor PM_{10} concentration in the dismantling plant for the waste of electrical and electronic equipment cities.[15] Another study detected PM_{10} around e-waste burning and industrial sites of Moradabad, India, where it was highest at industrial sites, and at e-waste burning site, it was higher than residential sites.[13] There is some evidence that particulates could cause serious harm to humans via inhalation exposure, for example, bronchial irritation, inflammation, increased reactivity, reduced mucociliary clearance, reduced macrophage response.

Furthermore, the combustion from burning e-waste creates fine PMs, which is linked to pulmonary and cardiovascular disease.[13,16] According to the above evidence of current e-waste dismantling houses widespread location in the communities in Northeastern Thailand, particularly in Daengyai, Banmaichaiyaphot District, Buriram Province, it is possible that PMs could disperse from e-waste dismantling houses to the air in the vicinity area. Consequently, the residents living in non-e-waste dismantling houses nearby might face contaminated air. Till now, the concentration and distribution of PM at non-e-waste dismantling houses in this area have not been studied. Thus, this study aims to investigate the concentration of PM_{10} in the residential area and to compare between those found in non- and e-waste dismantling houses.

Methodology

Study area description

Daengyai subdistrict, Banmaichaiyaphot District, Buriram Province, in the northeast of Thailand was considered as a study area, and the location is shown in Figure 1. In the year 2017, there were 70 to 80 informal e-waste dismantling households approximately in this area. Six houses that have similar house floor plans (ie, 3 e-waste dismantling houses: A1-A3 and 3 non-e-waste dismantling houses: B1-B3) and 1 control house

(approximately 5 km away from the e-waste dismantling region) were selected as the sampling sites for investigating the concentration of PM_{10}, and there are 2 sampling points for each house, indoor and outdoor.

Sample preparation and collection

For filter preparation, a glass fiber filter was immersed in acetone for 10 to 15 minutes, then it was placed on a watch glass for drying and stored in a desiccator at 20 C to 30 C with a humidity of 30% to 40% for at least 2 days. The gravimetric method was used to determine the weight of pre- and postsampling filters by Mettler Toledo Ultra-Microbalance (7 digits) (UMX2) with 0.001 mg sensitivity. Prior to weighing a filter 3 times, standard pendulums of 100 and 200 mg were weighed for quality control. Next, the weighed filter was put into a filter cassette and sealed with parafilm, and then kept in a ziplock plastic bag for transferring to the sampling site.

The samples of PM smaller than 10 μm (PM_{10}) were collected onto 37-mm glass fiber filters at 7 chosen sampling houses in both the dismantling and living area. Sampling points, indoors and outdoors, were set at approximately 1.0 to 1.5 m height from the ground. Before each sampling, a personal air pump connected with nylon cyclone and filter cassette was calibrated at a flow rate of 1.7 L/min, and the pump was measured again after sampling is finished. The sampling was taken 24 hours during the periods of December 22 to 28, 2017, consecutively.

After sampling, the filter cassette was sealed with parafilm and was placed in a ziplock bag for taking back to the laboratory and weighing the postsampling filter was done under the same conditions as before sampling. The total sample filters were 78 filters, 6 samples from the control house, and 36 samples each from the non- and e-waste dismantling houses. All indoor and outdoor samplings were conducted on the first floor of all sampling houses. For more additional data of the possible factor influences on PM_{10} contribution, house structure, and circumstance (closed or opened door and windows), and resident activities were also observed during the sampling. These additional data were then used to interpret the PM_{10} result.

Calculation of PM_{10} concentrations

After weighing, PM_{10} concentration was calculated using equations (1) to (3):

$$\begin{aligned}\text{Mass of } PM_{10}\,(\mu g) = {} & \text{weight of the} \\ & \text{postsampling filter}\,(\mu g) \\ & - \text{weight of the} \\ & \text{presampling filter}\,(\mu g)\end{aligned} \quad (1)$$

$$\begin{aligned}\text{Air volume}\left(m^3\right) = {} & \text{air flow rate}\left(m^3/\text{min}\right) \\ & \times \text{sampling time}\,(\text{min})\end{aligned} \quad (2)$$

$$PM_{10}\ \text{concentration}\left(\mu g/m^3\right) = \frac{\text{mass of } PM_{10}\,(\mu g)}{\text{air volume}\left(m^3\right)} \quad (3)$$

Statistical analysis

Statistical analysis of the data was performed using the SPSS program (version 22). The analysis included (1) analysis of the mean difference in concentrations of PM_{10} between non- and e-waste dismantling houses and in indoor and outdoor concentrations using the *t* test method, (2) analysis of the different concentrations of PM_{10} in all sample houses by One-way analysis of variance, and (3) Pearson correlation was applied to investigate the correlation between indoor and outdoor PM_{10} concentrations.

Results and Discussions

Comparison of PM_{10} concentrations between indoor and outdoor air environment

The average 24-hour indoor PM_{10} concentrations at the selected 3 e-waste dismantling houses (A1, A2, and A3) were 130.703 ± 36.765, 130.318 ± 95.387, and 73.153 ± 13.444 μg/m^3 as shown in Table 1, and those levels outdoors could be obtained at 91.619 ± 19.375, 80.074 ± 18.303, and 70.289 ± 13.914 μg/m^3, respectively. The mean PM_{10} concentration of indoor 3 e-waste dismantling houses (116.171 ± 64.635 μg/m^3) was higher than that measured outdoors (81.957 ± 18.724 μg/m^3). This result reveals that PM_{10} concentration in the e-waste dismantling houses of this village was generally higher than the outdoors. However, the statistical analysis of mean differences between indoor and outdoor PM_{10} concentrations could not be found.

For 3 non-e-waste dismantling houses (B1, B2, and B3), the indoor PM_{10} concentrations were at the level of 123.483 ± 56.882, 88.127 ± 16.554, and 137.133 ± 113.190 μg/m^3, respectively, which were higher than those outdoors, ie, 95.120 ± 36.640, 80.845 ± 35.478, and 59.827 ± 5.277 μg/m^3, respectively. The mean PM_{10} concentrations of 3 non-e-waste dismantling houses from the indoor and outdoor areas were 113.637 ± 64.641 and 80.943 ± 32.740 μg/m^3, respectively, which was similar to the result of the e-waste dismantling houses. Indoor and outdoor PM_{10} concentration was statistically analyzed, which showed that there were no statistically significant differences at 95% confidence level (Table 1).

At the control house, the mean of indoor PM_{10} concentrations was 70.907 ± 22.464 μg/m^3, and it was 36.717 ± 19.516 μg/m^3 for outdoor. This result shows that indoor PM_{10} concentrations were higher than outdoor. If comparing the mean concentration of 3 different houses with World Health Organization air quality guidelines (AQG) more than 24 hours (50 μg/m^3), only the mean concentration of outdoor PM_{10} at the control house was lower than AQG.[17]

This study result shows a similar trend to the study on the relationship between indoor and outdoor concentrations of

Table 1. The 24-hour average PM_{10} concentration of non-, e-waste dismantling houses, and control house.

SAMPLE HOUSES		PM_{10} CONCENTRATION, μg/m³			
		INDOOR		OUTDOOR	
		MIN-MAX	MEAN ± SD	MIN-MAX	MEAN ± SD
E-waste dismantling	A1	72.727-166.338	$130.704 \pm 36.765_{I}$	70.082-114.346	$91.619 \pm 19.375_{I}$
	A2	68.267-316.772	$130.318 \pm 95.387_{I}$	63.333-109.849	$80.074 \pm 18.303_{I}$
	A3	61.718-92.623	$73.153 \pm 13.444_{I}$	54.985-83.506	$70.289 \pm 13.914_{I}$
	Mean		$^{1}116.171 \pm 64.635^{a}{}_{A}$		$^{1}81.957 \pm 18.724^{a}{}_{A}$
Non-e-waste dismantling	B1	72.429-212.908	$123.483 \pm 56.882_{I}$	39.375-135.071	$95.120 \pm 36.640_{I}$
	B2	68.828-114.007	$88.128 \pm 16.554_{I}$	39.823-123.290	$80.845 \pm 35.478_{I}$
	B3	40.944-301.057	$137.133 \pm 113.190_{I}$	54.340-66.069	$59.827 \pm 5.277_{I}$
	Mean		$^{1}113.637 \pm 64.641^{a}{}_{A}$		$^{1}80.943 \pm 32.740^{a}{}_{A}$
Control		47.729-92.582	$70.907 \pm 22.464_{A}$	24.720-59.236	$36.717 \pm 19.516_{B}$

If the right superscripts were different alphabets, it means the PM concentrations were statistically significant differences between indoor and outdoor. If the right subscripts were different alphabets, it means the PM concentrations were statistically significant differences between non-, e-waste dismantling, and control house. If the left superscripts were a different number, it means the concentrations were statistically significant differences between e-waste and non-e-waste dismantling houses at 95% confidence level.

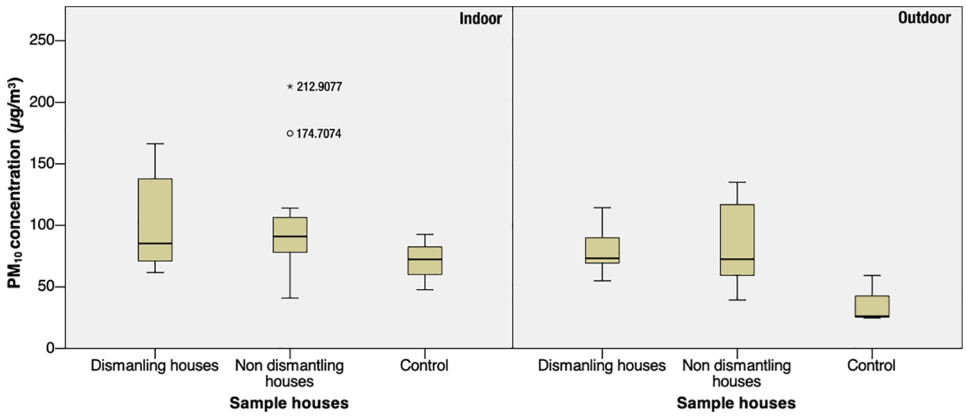

Figure 2. Comparison of the 24-hour PM_{10} concentrations between non-, e-waste dismantling houses, and control house.

PM in rural residential houses in India which also found that the mean concentration of PM_{10} indoors (217.75 ± 66.62 μg/m³) was higher than outdoors (187.86 ± 41.01 μg/m³).[18] Another study on indoor and outdoor dust around schools in Selangor, Malaysia, also found that the level of PM_{10} indoors (52.74 ± 16.90 μg/m³) mostly had higher concentration levels than outdoors (33.86 ± 17.41 μg/m³).[19] Blondenau et al have emphasized that the larger the particles are in terms of optical diameter, the heavier they are and the more easily they can be deposited on floors and furnishings. Consequently, the influence of resuspension on indoor particle concentrations increases.[20] Due to the environmental conditions at the indoors of the study was a mostly closed environment, there would be more dust precipitation than outdoors. And it is consistently influenced by resuspension, eg, house sweeping, wind pass through opened windows or doors, and household activities, especially cooking using a stove with coal. In addition, regarding the similar house characteristics of both non- and e-waste dismantling houses (mostly wooden houses) and location of the sampling houses was close to each other, all the same trends of indoor and outdoor PM_{10} concentration were observed.

Comparison of PM_{10} concentrations between non- and e-waste dismantling houses

The 24-hour average indoor PM_{10} concentrations of the non-, e-waste dismantling houses, and control house at indoor were 113.637 ± 64.641, 116.171 ± 64.635, and 70.907 ± 22.464 μg/m³, respectively, as shown in Table 1 and Figure 2, in which the levels at the e-waste dismantling houses were higher than those

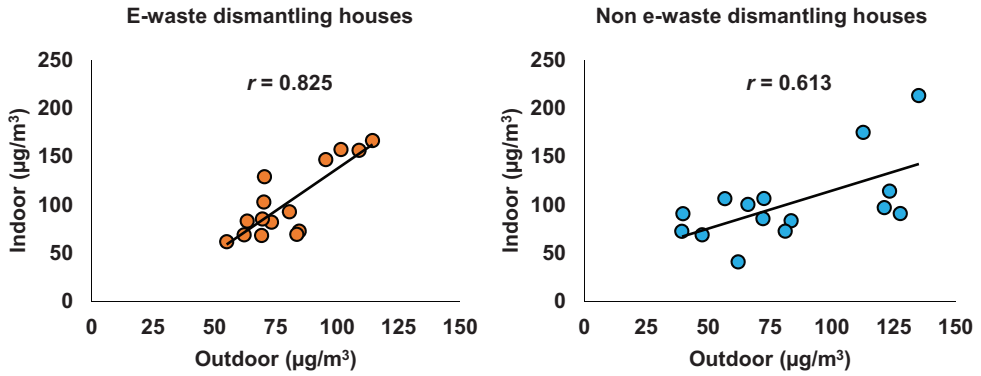

Figure 3. Pearson correlation of PM_{10} between the indoors and outdoors of non- and e-waste dismantling houses.

found at the non-e-waste dismantling houses and control house. However, there were no statistically significant differences at 95% confidence level between indoor PM_{10} concentrations of non-, e-waste dismantling houses, and the control house analyzed by ANOVA.

The average PM_{10} concentrations of the outdoor environment of the non-, e-waste dismantling houses, and control house were 80.943 ± 32.740, 81.957 ± 18.724, and $36.717 \pm 19.516\ \mu g/m^3$, respectively. Similar to the indoor environment, the outdoor PM_{10} of the e-waste dismantling house presented with a higher level than at the non-e-waste dismantling houses and control house. The statistical analysis of ANOVA was done to compare PM_{10} concentrations between non-, e-waste dismantling houses, and control house as summarized in Table 1. The result shows that the PM_{10} concentrations of non- and e-waste dismantling houses were not significantly different at 95% confidence level, whereas both were significantly higher than the control house. This analysis of no significant difference pointed out that the outdoor PM_{10} concentration in the vicinity of the e-waste dismantling community was not much different but still higher than that of non-e-waste dismantling area. When comparing the PM_{10} concentrations at the control house with concentrations at non- and e-waste dismantling houses, the result reveals that the concentrations at the control house were greatly lower than those measured at both sampling areas.

The higher PM_{10} at e-waste dismantling house could be generated from manually mechanical processes. The bulky e-waste taken for disassembly during the sampling was television, washing machine, refrigerator, desktop computer, and air conditioner. At the same time, other small appliances such as fan, rice cooker, printer, and electric jar pot were found in a lower proportion. These main types of e-wastes, in particular, the bulky e-waste gathered to this study site, were also reported by Thongkaow et al[4] and Puangprasert and Prueksasit.[21] The workers dismantled e-waste manually at their houses using primitive methods, ie, drilling, cutting and milling, and burning to separate, and recovered the saleable electrical components and precious materials. Such dismantling processes could then lead to elevate PM_{10} in their residential area and also distribute to the neighboring area. This evidence signified that the e-waste dismantling activities could contribute PM_{10} to the air and be considered the significant source of PM_{10} in this community.

There are previous studies on the PM_{10} around e-waste dismantling and burning areas and e-waste recycling industrial sites. For example, there was a study on appraisement of heavy metals in respirable dust (PM_{10}) around e-waste burning and industrial sites of Moradabad, India, in which it had been found that the highest mean concentration of PM_{10} was at the industrial sites and e-waste burning site ($200 \pm 3.05\ \mu g/m^3$) where it was significantly higher than the residential sites ($126 \pm 11.26\ \mu g/m^3$).[13] Furthermore, the study on PM_{10} distribution in a typical printed circuit boards manufacturing workshop also indicated that the concentrations of PM_{10} in the workshops ranged from 27.1 to 289.8 $\mu g/m^3$, which was higher than the level observed in the off-site area (90.0 $\mu g/m^3$).[22] As mentioned above, primitive e-waste dismantling activities such as separating electronics equipment or appliances using a hammer, chisels, and screwdrivers or the recycling process in the industry can be considered the possible contribution source of PM_{10} in the air.

Relationship of indoor and outdoor PM_{10} concentrations in e-waste dismantling community

Pearson correlation analysis was performed to examine the relationship between indoor and outdoor PM_{10} concentrations in an e-waste dismantling community. As presented in Figure 3, indoor concentrations of non-e-waste dismantling houses were correlated with outdoor concentrations ($r = .613$) and the concentrations of e-waste dismantling houses had a good correlation between indoor and outdoor ($r = .825$). As mentioned above, house characteristics between e-waste or non-e-waste house are almost the same, which most houses are 1-story wooden, but some lesser part is half wood and concrete. Each house has its own open ground space with soil cover, where it is usually used for dismantling in the case of e-waste houses. Most houses have been built no less than 20 years and have a cross-natural ventilation system through opened doors and windows. This house

Table 2. Indoor and outdoor PM_{10} concentration ratio (I/O) of non-, e-waste dismantling houses, and control house.

SAMPLING POINTS	I/O RATIO	
	MIN-MAX	MEAN ± SD
Non-e-waste dismantling houses	5.540-0.659	1.579 ± 1.153
E-waste dismantling houses	2.994-0.831	1.367 ± 0.486
Control house	2.764-1.563	2.086 ± 0.615

Table 3. Indoor and outdoor PM_{10} concentration ratio (I/O) of residential and school building.

SAMPLING POINTS	AVERAGE I/O RATIO	REFERENCES
Non-e-waste dismantling houses	1.579	This study
E-waste dismantling houses	1.367	This study
Control house	2.086	This study
Rural preschools in Korea	1.35	Yoon et al[24]
Residential buildings in Shah Alam, Malaysia	0.79	Darus et al[25]
Schools buildings at Gaza strip, Palestine	2.6	Elbayoumi et al[26]
School building located near an urban roadway in Chennai, India	2.52	Chithra and Shiva Nagendra[27]

configuration could enhance the PM_{10} blew into the inside area and might cause the significant correlations obtained from either e-waste or non-e-waste house mentioned above. The high PM_{10} presented inside the house that had e-waste dismantling could be increased from the high outdoor concentration even though the concentration indoors itself was usually high.

From the study on characterizing the indoor-outdoor relationship of fine PM in the non-heating season for urban residences in Beijing, there was a significant and strong positive correlation ($r \geqslant .90$) between indoor and ambient $PM_{2.5}$ mass concentrations over the 24-hour sampling period as well as the 4 sessions, including at morning (6:00-12:00), afternoon (12:00-18:00), evening (18:00-0:00), and night (0:00-6:00). The results indicated that the indoor and ambient $PM_{2.5}$ mass concentrations highly correlated with each other on a community basis. Even though excluding smoking families, there was still a strong correlation for all results of 4 sessions.[23]

Theoretically, indoor air particle concentrations can be influenced either by the infiltration of outdoor pollutants into the homes through opened windows and cracks or by particles from indoor sources. This may be significant for a house with poor sealing as due to these mechanisms, air pollutants from outdoors can penetrate into the indoor environment.[6]

I/O ratio of PM_{10} concentrations at non- and e-waste dismantling houses

From indoor and outdoor ratio, the result shows that PM_{10} concentrations in this area are usually higher indoors than outdoors as the average I/O ratio of non-, e-waste dismantling houses was higher than 1 (1.579 ± 1.153 and 1.367 ± 0.486, respectively), especially at the control house (2.086 ± 0.615). The mean I/O ratio of all sampling points in this study was higher than from the study on indoor air quality differences between urban and rural preschools in Korea with an I/O ratio of 1.35 in rural areas.[24] The high PM_{10} concentrations indoors might be derived from other important indoor sources, including combustion, candles, and cooking. When considered at e-waste dismantling houses, the average I/O ratio was lower than the non- and control houses, which represents that the outdoor levels of PM_{10} of the e-waste dismantling houses were increased and had an effect on the indoor environment. Outdoor PM_{10} levels of dismantling houses increasing and making the I/O ratio decrease could indicate that dismantling activities have contributed to PM_{10} concentration in this area. Although Pearson correlation results showed the strong relationship between outdoor and indoor PM_{10} concentrations, they could suggest that there were usually high concentrations of indoor PM_{10} from other indoor sources of this area as shown from the I/O ratio in Table 2. The I/O ratio of PM_{10} more than 1 obtained from the previous studies in Table 3 suggests that the building envelope of houses and schools may not inhibit the resuspension or infiltration of particles indoor,[24,26,27] whereas the I/O ratio lower than 1 indicates the absence of significant indoor sources.[25] Furthermore, some factors may directly resulting in increasing or decreasing of I/O ratio such as differences in building envelope tightness, construction materials of houses, seasonal effects, building air

exchange rates, and building design. Also, the human presence, occupancy rates and occupant activities such as walking and using chalk are the other significant factors controlling indoor/outdoor pollution ratios.[26]

Conclusions

The dismantling activities of e-waste processed by informal separators or in family-run workshops in this study could affect a noticeable contribution of PM_{10} concentrations in both indoor and outdoor environments. The PM_{10} concentration indoors being mostly higher than outdoors could be consistently influenced by resuspension and household activities. In addition, if non- and e-waste dismantling houses are located nearby each other in the same village, then existing indoor PM_{10} could result from the neighborhood e-waste dismantling house. The PM_{10} found at both non- and e-waste dismantling houses was significantly higher than at the control house, which indicates that e-waste activities could be a point source of PM_{10} emitted to the air. The strong correlation between outdoor and indoor PM_{10} levels at non- and e-waste dismantling houses is a sign of e-waste dismantling activities not only affecting the contribution of PM_{10} outdoors but also affecting indoors as well. Similar house floor plans and characteristics in this area are considerable to cause a better spread of PM_{10} between the outside and inside. However, the I/O ratio was found to be more than 1 at all sampling houses and revealed that the level of PM_{10} in the indoor environment was regularly higher in the study area. But the e-waste dismantling activities support the increase of PM_{10} concentrations in both the indoor and outdoor areas. From this overall study, e-waste dismantling activity was the main influence for increased PM_{10} concentrations in a residential area. Further studies on PM_{10} and other significant contaminants in PM_{10} as spatial and temporal distribution are required to elucidate the real effect of family-run e-waste dismantling houses.

Acknowledgements

Our thanks go to Dr Narut Sahanavin, Department of Public Health, Faculty of Physical Education, Srinakharinwirot University, for supporting air sampling equipment. We would also appreciate Interdisciplinary Program in Environmental Science, Graduate School, Chulalongkorn University for laboratory space and facilities. Moreover, we do deeply grateful to all local organizations and houses owner for their cooperation with the researchers and the involved authorities.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by SC and YK. SC wrote the first draft of the manuscript, and TP commented and corrected the manuscript finally. All authors read and approved the final manuscript.

ORCID iD

Tassanee Prueksasit https://orcid.org/0000-0001-6597-7021

REFERENCES

1. Vasanadumrongdee S, Manomaivibool P. E-waste management: part 4. http://www.hsm.chula.ac.th/website/wp-content/uploads/2020/06/e-wate-management4.pdf. Published January, 2012. Accessed November 16, 2017 (in Thai).
2. Pollution Control Department, Ministry of Natural Resources and Environment. *Thailand State of Pollution Report 2012*. Bangkok, Thailand: Wongsawang Publishing; 2013.
3. Pollution Control Department, Ministry of Natural Resources and Environment. *Thailand State of Pollution Report 2017*. Bangkok, Thailand: Wongsawang Publishing; 2018.
4. Thongkaow P, Prueksasit T, Siriwong W. Material flow of informal electronic waste dismantling in rural area of Northeastern Thailand. Proceedings of 139th The IIER International Conference, December 8-9, 2017, Osaka, Japan.
5. Siddique S, Banerjee M, Ray MR, Lahiri T. Air pollution and its impact on lung function of children in Delhi, the capital city of India. *Water Air Soil Pollut*. 2010;212:89-100.
6. Srithawirat T, Latif MT, Sulaiman FR. Indoor PM10 and its heavy metal composition at a roadside residential environment, Phitsanulok, Thailand. *Atmosfera*. 2016;29:311-322.
7. Fang W, Yang Y, Xu Z. PM10 and PM2.5 and health risk assessment for heavy metals in a typical factory for cathode ray tube television recycling. *Environ Sci Technol*. 2013;47:12469-12476.
8. Needhidasan S, Samuel M, Chidambaram R. Electronic waste—an emerging threat to the environment of urban India. *Environ Health Sci Eng*. 2014;12:36.
9. Stephens B. Infiltration of outdoor pollutants. http://built-envi.com/wp-content/uploads/stephens-2015-home-energy-magazine-infiltration-of-outdoor-pollutants.pdf. Published May-June, 2015. Accessed March 12, 2019.
10. Leung D. Outdoor-indoor air pollution in urban environment: challenges and opportunity. *Front Environ Sci*. 2015;2:1-7.
11. Dėdelė A, Miškinytė A. Seasonal variation of indoor and outdoor air quality of nitrogen dioxide in homes with gas and electric stoves. *Environ Sci Pollut Res Int*. 2016;23:17784-17792.
12. Bo M, Salizzoni P, Clerico M, Buccolieri R. Assessment of indoor-outdoor particulate matter air pollution: a review. *Atmosphere*. 2017;8:136.
13. Gangwar C, Singh A, Kumar A, Chaudhry A, Tripathi A. Appraisement of heavy metals in respirable dust (PM10) around e-waste burning and industrial sites of Moradabad: accentuation on spatial distribution, seasonal variation and potential sources of heavy metal. *IOSR J Environ Sci Toxicol Food Technol*. 2016;10:14-21.
14. Xu F, Liu Y, Wang J, et al. Characterization of heavy metals and brominated flame retardants in the indoor and outdoor dust of e-waste workshops: implication for on-site human exposure. *Environ Sci Pollut Res Int*. 2015;22:5469-5480.
15. Papaoikonomou K, Emmanouil C, Vasilatou V, et al. PM10 and elemental concentrations in a dismantling plant for waste of electrical and electronic equipment in Greece. *Aerosol Air Qual Res*. 2018;18:1457-1469.
16. World Health Organization. *Health Effects of Particulate Matter*. http://www.euro.who.int/__data/assets/pdf_file/0006/189051/Health-effects-of-particulate-matter-final-Eng.pdf. Published 2013. Accessed November 16, 2017.
17. World Health Organization. *Air Quality Guidelines Global Update 2005*. http://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf. Published 2006. Accessed September 7, 2019.
18. Massey D, Kulshrestha A, Taneja A. A Study on indoor/outdoor concentration of particulate matter in rural residential houses in India. *Environ Comput Sci*. 2009;45:218-223.
19. Latifa MT, Baharudina NH, Nora ZM, Mokhtarb MB. Lead in PM10 and in indoor dust around schools and preschools in Selangor, Malaysia. *Indoor Built Environ*. 2011;20:346-353.
20. Mainka A, Zajusz-Zubek E. Indoor air quality in urban and rural preschools in upper Silesia, Poland: particulate matter and carbon dioxide. *Int J Environ Res Public Health*. 2015;12:7697-7711.
21. Puangprasert S, Prueksasit T. Health risk assessment of airborne Cd, Cu, Ni and Pb for electronic waste dismantling workers in Buriram Province, Thailand. *J Environ Manage*. 2019;252. doi:10.1016/j.jenvman.2019.109601
22. Zhou P, Guo J, Zhou X, et al. PM2.5, PM10 and health risk assessment of heavy metals in a typical printed circuit boards manufacturing workshop. *Journal of Environmental Sciences (China)*. 2014;26:2018-2026.

23. Huang L, Pu Z, Li M, Sundell J. Characterizing the indoor-outdoor relationship of fine particulate matter in non-heating season for urban residences in Beijing. *PLoS ONE*. 2015;10:e0138559.
24. Yoon C, Lee K, Park D. Indoor air quality differences between urban and rural preschools in Korea. *Environ Sci Pollut Res Int*. 2011;18:333-345.
25. Darus FM, Zain-Ahmed A, Latif MT. Terraced residential housing indoor and outdoor air quality in Shah Alam, Malaysia. https://www.academia.edu/20920249/Terraced_residential_housing_indoor_and_outdoor_air_quality_in_Shah_Alam_Malaysia. Published June, 2011. Accessed March 15, 2019.
26. Elbayoumi M, Ramli NA, Yusof NFFM, Madhoun WA. Spatial and seasonal variation of particulate matter (PM10 and PM2.5) in Middle Eastern classrooms. *Atmosp Environ*. 2013;80:389-397.
27. Chithra VS, Shiva Nagendra SM. Indoor air quality investigations in a naturally ventilated school building located close to an urban roadway in Chennai, India. *Build Environ*. 2012;54:159-167.