

## Does Open-air Exposure to Volatile Organic Compounds near a Plastic Recycling Factory Cause Health Effects?

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**Abstract:** Does Open-air Exposure to Volatile Organic Compounds near a Plastic Recycling Factory Cause Health Effects?: Takashi YORIFUJI, *et al.* Department of Human Ecology, Okayama University Graduate School of Environmental and Life Science—**Objectives:** After a plastic reprocessing factory began to operate in August 2004, the residents around the factory in Neyagawa, Osaka, Japan, began to complain of symptoms. Therefore, we conducted an exposure assessment and a population-based epidemiological study in 2006. **Methods:** To assess exposure, volatile organic compounds (VOCs) and total VOCs were measured at two locations in the vicinity of the factory. In the population-based study, a total of 3,950 residents were targeted. A self-administered questionnaire was used to collect information about subjects' mucocutaneous or respiratory symptoms. Using logistic regression models, we compared the prevalence of symptoms in July 2006 by employing the farthest area from the factory as a reference, and prevalence odds ratios (PORs) and their 95% confidence intervals (CIs) were estimated. **Results:** The concentration of total VOCs was higher in the vicinity of the factory. The prevalence of mucocutaneous and respiratory symptoms was the highest among the residents in the closest area to the factory. Some symptoms were significantly increased among the residents within 500 m of the factory compared with residents of an area 2800 m from the factory: e.g., sore throat (POR=3.2, 95% CI: 1.3–8.0), eye itch (POR=3.0, 95% CI: 1.5–6.0), eye discharge (POR=6.0, 95% CI: 2.3–15.9), eczema

(POR=3.0, 95% CI: 1.1–7.9) and sputum (POR=2.4, 95% CI: 1.1–5.1). **Conclusions:** Despite the limitations of this study, these results imply a possible association of open-air VOCs with mucocutaneous and respiratory symptoms. Because this kind of plastic recycling factory only recently came into operation, more attention should be paid to the operation of plastic recycling factories in the environment. (J Occup Health 2012; 54: 79–87)

**Key words:** Air pollutants, Environmental health, Mucocutaneous symptoms, Respiratory symptoms, Volatile organic chemicals

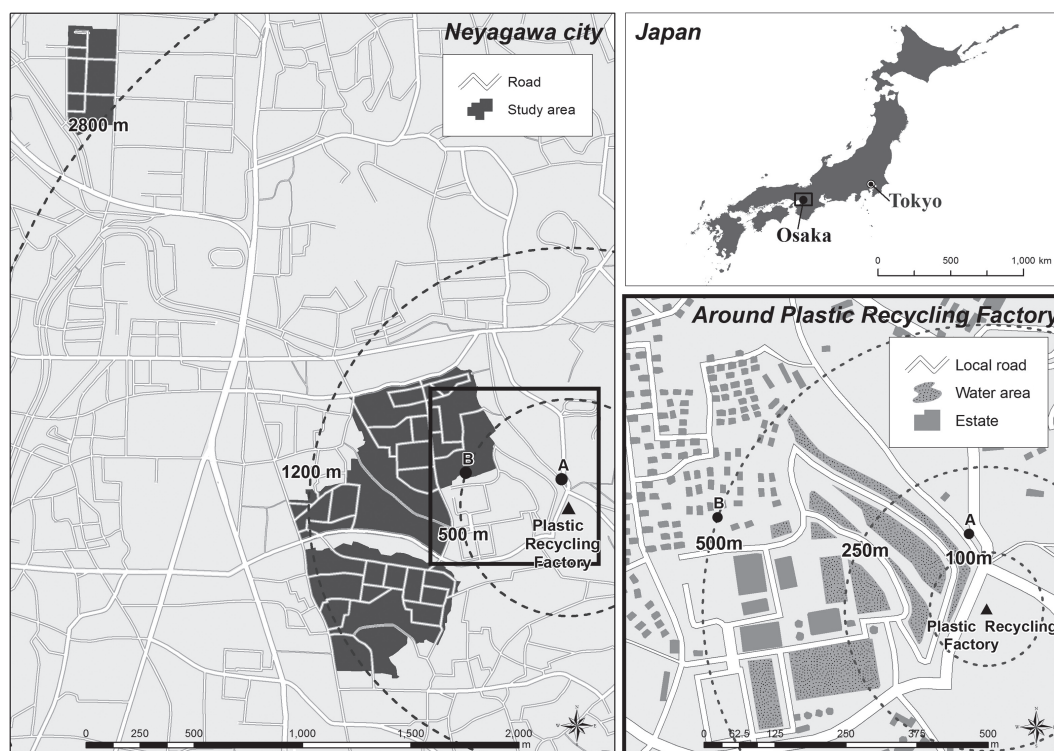
In August 2004, a plastic recycling factory was constructed and began to operate in Neyagawa, Osaka, Japan (Fig. 1). The factory's recycling process includes storage, dismantling, volume reduction, heating and melting of plastics. Subsequent to the factory opening, the residents around the factory began to complain of eye irritation, sore throat, eczema and other mucocutaneous symptoms. There were also some residents whose symptoms improved when they left the residential area but who again developed symptoms after they returned.

Although the recycling of plastic is considered to be highly desirable for resource and energy conservation<sup>1</sup>, it is also reported that recycling plastics produces various volatile organic compounds (VOCs) in the course of storage, volume reduction and other recycling processes<sup>2–6</sup>. VOCs are a category of organic chemicals with a high vapor pressure. They include gases such as benzene, chloroform, methanol, carbon tetrachloride, formaldehyde and hundreds of other compounds<sup>7</sup>. VOCs are considered to affect mucosal membranes in the eyes; nose; throat; skin on the face,

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**Fig. 1.** Map of the study areas. The map also shows the location of the plastic recycling factory and the measurement sites. The response rates among study areas were 97.5 (within 500 m from the factory), 82.6 (500–600 m), 84.5 (600–700 m), 81.2 (700–800 m), 69.8 (800–900 m), 63.1 (900–1,000 m), 63.0 (1,000–1,100 m), 50.3 (1,100–1,200 m), and 92.2% (2,800 m), respectively. The directions of the wind near the plastic recycling factory were not constant and considered to be randomly distributed (the directions were measured by the authors in January 2009).

neck, and hands; and the upper and lower airways<sup>8,9</sup>). Although the most frequent effects seem to be acute, subacute effects, such as headache, are also observed<sup>9</sup>). Since the concentration of VOCs in occupational and indoor settings is generally much higher than that in outdoor settings<sup>7</sup>), the adverse health effects of VOCs have, to date, only been studied with respect to indoor settings.

The recycling of plastics and the technology used in this factory are quite new; therefore, evidence of the associated health risks is sparse<sup>10</sup>). Furthermore, evidence is also sparse concerning the health effects of exposure to open-air VOCs. One study, conducted in Taiwan, has suggested possible effects of open-air VOC exposure on the residents near a petrochemical-polluted area<sup>11</sup>), which did not include a direct exposure assessment. Therefore, in the present study, we conducted an exposure assessment of VOCs in the vicinity of the factory. At the same time, a population-based study was conducted to assess the associations between distance from the factory as a proxy for VOC exposure and health status of residents. Although the methods and results of exposure assessment are described briefly elsewhere<sup>12</sup>), we here

expand the discussion based on the results from the population-based study.

## Materials and Methods

### Study area

The city of Neyagawa is located in the northeastern area of Osaka, Japan (Fig. 1). The plastic recycling factory is located in the southeastern part of the city.

### The factory

In August 2004, the factory was constructed and began to operate. Since April 2006, the factory has operated around the clock, at full capacity, dealing with 30 tons of plastics a day. The factory uses the recycled plastic to manufacture plastic palettes, and its recycling process includes the storage, dismantling, volume reduction, heating and melting of plastics.

### Exposure assessment

The method of exposure assessment is described elsewhere<sup>12</sup>), and we briefly introduce it here. The concentrations of VOCs were measured at two locations: point A (about 100 m from the factory) and point B (500 m from the factory) as shown in Fig. 1.

Both points were not located close to heavily trafficked roads and were not considered to be affected by VOCs emission sources other than the factory. Sampling was conducted at both points for three hours around the time when odor was detected by residents on June 23, 24 and 26, 2006. VOCs were collected in an automatic thermal desorption (ATD) tube, which was filled with Tenax TA and Carboxen, at an air flow rate of 100 ml/min and analyzed by gas chromatography-mass spectrometry (GC-MS)<sup>13)</sup>. The concentrations of total volatile organic compound (TVOC) were also obtained<sup>14)</sup>. TVOC is an indicator of pollution by VOCs<sup>15)</sup> and is known to be correlated with the symptoms of sick building syndrome<sup>16)</sup>.

#### Population-based study

##### 1) Participants

We targeted 6,294 residents living in densely populated areas in Neyagawa City. Our study area included seven residential neighborhoods within 1,200 m of the factory and one residential neighborhood located in 2,800 m from the factory. Then, we divided the former seven neighborhoods into eight areas based on distance from the factory: within 500 m, 500–600 m, 600–700 m, 700–800 m, 800–900 m, 900–1,000 m, 1,000–1,100 m and 1,100–1,200 m. The areas included 281, 436, 530, 821, 1,322, 1,329, 884 and 614 residents, respectively. Furthermore, the other neighborhood located 2,800 m from the factory included 77 residents.

##### 2) Questionnaire

The investigation was conducted in August 2006. Each residential neighborhood has its own community association (*Jichikai*). Each community association has 10–40 blocks that consist of 10–20 residents, and each block has its own block leader (*Hancho* or *Kumicho*). In the present study, the leaders of the community associations and block leaders were responsible for distributing and collecting the questionnaire. How they explained the aim of the investigation to the subjects is shown in the appendix. They distributed the self-administered questionnaire to every household in the study area by hand. The questionnaire included questions on demographic characteristics (e.g., age, sex, smoking habits and past medical history) and on subjective symptoms considered to be associated with VOCs. The queried symptoms were mucocutaneous symptoms (sore throat, eye itch, red eye, eye irritation, eye discharge and eczema) and respiratory symptoms (asthma attack, cough, sputum production and rhinorrhea). In addition, questions about other symptoms, such as muscle stiffness and constipation, were asked. The subjects were asked whether they had these symptoms more than once per

month in July 2005 and July 2006. The questions were created to be easier for the subjects to understand and answer through a pretest targeting a small group of the residents. All targeted residents were asked to answer the question by themselves, and the completed questionnaires were collected 1–2 wk later by the leaders of the community associations or block leaders by hand using an envelope.

The investigation was conducted with the participants' consent. The response rates among the study areas (in the order from the area within 500 m to the area 2,800 m from the factory) were 97.5, 82.6, 84.5, 81.2, 69.8, 63.1, 63.0, 50.3 and 92.2%, respectively. Approval for this study was obtained from the Institutional Review Board of Okayama University.

##### 3) Statistical analyses

In the statistical analyses, we excluded residents who were less than 10 yr old from the analyses because they were too young to answer the questionnaire. We compared the prevalence proportions of mucocutaneous, respiratory and other symptoms among the study areas. Subsequently, to evaluate the association between distance from the factory and symptoms in July 2006, we estimated the adjusted prevalence odds ratios (PORs) using logistic regression models. We employed the area 2,800 m from the factory as a reference and estimated PORs of each area within 1,200 m from the factory adjusting for age, sex, smoking and past history of hay fever (seasonal allergic rhinoconjunctivitis). Furthermore, we conducted an analysis of linear trends and estimated PORs per 100 m decrease in distance from the factory adjusting for the same variables.

Due to concern regarding the small number of subjects in the area 2,800 m away from the factory, instead of employing it as a reference, we collapsed the areas of 1,000–1,100 m and 1,100–1,200 m and used the area of 1,000–1,200 m as an alternative reference.

In addition, because elderly people were likely to spend more time at home and it could be inferred that influence of exposure at home was stronger among those who spent more time at home, we separated the subjects by an age category ( $\leq 60$  yr old vs.  $> 60$  yr old) and repeated the same analysis.

Finally, as a sensitivity analysis, we repeated the same analysis by assuming that the subjects did not have a symptoms if they did not answer questions for it.

All confidence intervals (CIs) were calculated at the 95% level. SPSS software version 14.0J was used for all analyses.

**Table 1.** Concentrations of volatile organic compounds at points A and B (Modified from Table 4 in ref. #12 Noguchi *et al.*)

VOCs ( $\mu\text{g}/\text{m}^3$ )	23-Jun*		24-Jun†		26-Jun‡	
	Point A	Point B	Point A	Point B	Point A	Point B
Ethylacetate	3.45	5.26	8.10	0.40	89.79	46.59
Benzene	1.71	1.10	4.16	1.80	7.78	5.93
Trichloroethylene	0.70	0.13	NA	0.75	7.04	3.21
Heptane	9.46	3.17	6.18	2.63	36.58	14.20
MIBK	0.58	0.34	0.19	0.13	1.79	1.33
Toluene	21.04	8.48	10.72	6.56	74.94	48.46
N-Buthylacetate	2.88	3.22	2.00	0.29	7.71	3.19
Octane	2.66	NA	2.77	0.44	5.97	0.97
Tetrachloroethylene	1.93	0.32	0.84	0.22	1.99	1.03
Ethylbenzene	2.62	1.16	1.89	1.16	11.31	7.42
M,p-Xylene	1.93	0.70	1.79	0.62	6.56	3.12
Styrene	0.35	0.73	0.56	0.15	1.75	0.76
o-Xylene	1.30	0.52	0.83	0.47	3.16	1.82
Nonane	4.75	NA	9.60	NA	6.39	0.26
p-Ethyltoluene	1.81	0.61	1.56	0.45	3.08	1.59
1,2,4-TMB	4.24	1.67	2.60	0.75	5.75	2.69
Decane	10.03	0.97	14.71	0.69	9.59	1.75
p-Dichlorobenzene	9.69	3.20	4.91	2.53	46.54	3.76
Undecane	8.57	0.59	8.32	0.44	9.87	1.52
Dodecane	3.93	0.42	2.74	0.46	6.03	0.98
Tridecane	3.72	1.11	3.43	0.87	5.75	1.35
TVOC (toluene conversion)	256.04	71.57	307.88	38.23	717.32	238.82
Detectable substances/TVOC(%)	45.80	50.90	37.00	69.50	44.70	53.70

VOCs, volatile organic compounds; TVOC, total volatile organic compounds; MIBK, methyl isobutyl ketone; TMB, trimethylbenzene; NA, not available.

\*Measured during the periods from 20:45 to 23:45 at point A and from 21:05 to 24:00 at point B. †Measured during the periods from 16:55 to 19:55 at point A and from 17:10 to 20:10 at point B. ‡Measured during the periods from 17:45 to 20:45 at point A and from 18:05 to 21:05 at point B.

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## Results

### Exposure assessment

The concentrations of VOCs measured in the study area are shown in Table 1. The concentrations of TVOC at Point A (about 100 m from the factory) were higher compared with those at Point B (about 500 m from the factory) on all the sampling days. Almost all of the detectable VOCs were also detected at higher concentrations at Point A compared with Point B. The fraction of detectable VOCs among TVOC ranged from 37 to 69.5%. The TVOC concentration exceeded  $200 \mu\text{g}/\text{m}^3$  even at Point B.

### Population-based study

The demographic characteristics of the population-based study are shown in Table 2. In order from the

area within 500 m to the area 2,800 m from the factory, we could include 229, 338, 395, 611, 818, 727, 500, 267, and 65 residents, respectively. The subjects in the area 2,800 m from the factory tended to be older, female and less likely to be smokers.

As shown in Table 3, the prevalence of mucocutaneous and respiratory symptoms in July 2006 was higher than that in July 2005, and trends (i.e., more prevalent in the areas closer to the factory) were not so apparent in the prevalence in July 2005. By contrast, although there were some fluctuations, mucocutaneous and respiratory symptoms in July 2006 were more prevalent in the areas closer to the factory. However, symptoms, such as muscle stiffness and constipation, were more prevalent in the residents who lived far from the factory. The lower prevalence of symptoms in July 2005 compared with that in July 2006 may be



**Table 2.** Demographic characteristics of subjects, separated by distance from the factory

	Within 500 m (n=229)	500–600 m (n=338)	600–700 m (n=395)	700–800 m (n=611)	800–900 m (n=818)	900–1,000 m (n=727)	1,000–1,100 m (n=500)	1,100–1,200 m (n=267)	2,800 m (n=65)
Age, mean (SD)	37.5 (16.1)	52.7 (19.4)	48.4 (19.7)	51 (20.3)	48.3 (20.3)	49.5 (19.3)	53 (20.0)	49.9 (19.7)	63.2 (11.3)
Interquartile range	22.0–50.5	37.0–67.0	33.0–64.0	35.0–66.0	33.0–65.0	34.0–64.0	39.0–70.0	34.0–65.0	54.5–71.0
Sex, Female (%)	53.1	57.7	55.7	50.5	54.4	55.6	57.3	54.0	59.4
Smoking, no.(%)									
Current	57 (24.9)	80 (23.7)	74 (18.7)	118 (19.3)	162 (19.8)	137 (18.8)	81 (16.2)	53 (19.9)	5 (7.7)
Ex-smoking	4 (1.7)	11 (3.3)	18 (4.6)	27 (4.4)	43 (5.3)	30 (4.1)	21 (4.2)	9 (3.4)	2 (3.1)
Never	163 (71.2)	246 (72.8)	291 (73.7)	456 (74.6)	597 (73)	552 (75.9)	395 (79.0)	200 (74.9)	58 (89.2)
Unknown	5 (2.2)	1 (0.3)	12 (3.0)	10 (1.6)	16 (2.0)	8 (1.1)	3 (0.6)	5 (1.9)	0 (0)
Hay fever (seasonal allergic rhinoconjunctivitis), no.(%)									
None	137 (59.8)	236 (69.8)	273 (69.1)	399 (65.3)	570 (69.7)	456 (62.7)	338 (67.6)	157 (58.8)	50 (76.9)
Present	91 (39.7)	92 (27.2)	105 (26.6)	189 (30.9)	221 (27.0)	239 (32.9)	143 (28.6)	93 (34.8)	11 (16.9)
Unknown	1 (0.4)	10 (3.0)	17 (4.3)	23 (3.8)	27 (3.3)	32 (4.4)	19 (3.8)	17 (6.4)	4 (6.2)

SD, standard deviation.

partly due to the fact that subjects forgot their symptoms in the past, and we focus on the symptoms in July 2006 in the following analyses.

Table 4 shows PORs for each symptom in July 2006. Compared with the subjects in the area 2,800 m from the factory, subjects living in areas closer to the factory tended to manifest mucocutaneous and respiratory symptoms more than once. In particular, the following symptoms were significantly increased among the residents within 500 m of the factory compared with the area 2800 m from the factory: sore throat (POR=3.2, 95% CI: 1.3–8.0), eye itch (POR=3.0, 95% CI: 1.5–6.0), red-eye (POR=2.7, 95% CI: 1.1–6.3), eye irritation (POR=5.2, 95% CI: 1.5–17.8), eye discharge (POR=6.0, 95% CI: 2.3–15.9), eczema (POR=3.0, 95% CI: 1.1–7.9), cough (POR=2.2, 95% CI: 1.1–4.6) and sputum (POR=2.4, 95% CI: 1.1–5.1). However, these relationships were not observed regarding muscle stiffness and constipation, and the PORs were not significantly elevated.

When we used the area of 1,000–1,200 m as an alternative reference (Table 5), although the magnitude of PORs was attenuated, we observed the same tendency; subjects living in areas closer to the factory tended to manifest mucocutaneous and respiratory symptoms more than once per month.

In the stratified analysis, PORs for the elderly group (>60 yr old) were much higher than for the younger group (≤60 yr old), especially among the residents within 500 m of the factory (data not shown); for example, the POR of eye discharge was 26.2 (95% CI: 4.1–165.9) for the elderly group and 3.0 (95% CI: 0.7–13.4) for the younger group.

Even when we assumed that the subjects did not have a symptom if they did not answer questions for it, the results did not change substantially.

## Discussion

In the present study, we conducted an exposure assessment and a population-based study to evaluate the association between open-air VOCs and health status of residents. In the exposure assessment, the concentrations of TVOC and detectable VOCs were higher in the vicinity of the factory, and the concentrations of TVOC exceeded  $200 \mu\text{g}/\text{m}^3$  even at point B in Fig. 1, where the participants in the present study lived. Furthermore, in the population-based study, mucocutaneous and respiratory symptoms in July 2006 were more prevalent in the areas closer to the factory.

In the exposure assessment, the TVOC concentration exceeded  $200 \mu\text{g}/\text{m}^3$ , even at Point B, which was located in the area “within 500 m of the factory” in the present population-based study. It has been reported that symptoms of discomfort and irritation can be felt at a TVOC concentration of  $200 \mu\text{g}/\text{m}^3$  in an indoor environment if other factors, such as temperature and other contaminant exposures, interact<sup>17)</sup>. Therefore, it is plausible for residents to manifest irritant symptoms, even at the concentrations observed in the present study. Among the VOCs detected, the concentration of benzene was sometimes higher than the Japanese guideline value for ambient benzene ( $3 \mu\text{g}/\text{m}^3$ ) and the maximum value observed throughout Japan in 2005 ( $3.7 \mu\text{g}/\text{m}^3$ )<sup>18)</sup>. In addition, the value was also higher than the reference value corresponding to an individual excess lifetime risk of cancer ( $10^{-3}$ ) of benzene (1 ppm)<sup>19)</sup>. Furthermore, it should be noted that there were a lot of nonidentifiable VOCs, which remains a great concern regarding health effects.

In the population-based study, the subjective symptoms of residents were obtained by self-administered questionnaires, and the questionnaires were collected

**Table 3.** Prevalence proportions of symptoms in July 2005 and July 2006, separated by distance from the factory (n=3,950)

Within 500 m (n=229)		500–600 m (n=338)	600–700 m (n=395)	700–800 m (n=611)	800–900 m (n=818)	900–1,000 m (n=727)	1,000–1,100 m (n=500)	1,100–1,200 m (n=267)	2,800 m (n=65)
<b>July 2005</b>									
<b>Mucocutaneous symptoms</b>									
Sore throat	12 (5.2)	24 (7.1)	27 (6.8)	48 (7.9)	52 (6.4)	61 (8.4)	38 (7.6)	23 (8.6)	4 (6.2)
Eye itch	27 (11.8)	56 (16.6)	75 (19.0)	117 (19.1)	131 (16.0)	113 (15.5)	74 (14.8)	50 (18.7)	10 (15.4)
Red-eye	20 (8.7)	33 (9.8)	38 (9.6)	55 (9.0)	52 (6.4)	60 (8.3)	41 (8.2)	23 (8.6)	4 (6.2)
Eye irritation	12 (5.2)	15 (4.4)	20 (5.1)	35 (5.7)	25 (3.1)	40 (5.5)	25 (5.0)	6 (2.2)	1 (1.5)
Eye discharge	24 (10.5)	32 (9.5)	26 (6.6)	52 (8.5)	58 (7.1)	60 (8.3)	39 (7.8)	29 (10.9)	5 (7.7)
Eczema	30 (13.1)	47 (13.9)	36 (9.1)	72 (11.8)	69 (8.4)	68 (9.4)	56 (11.2)	28 (10.5)	4 (6.2)
<b>Respiratory symptoms</b>									
Asthma attack	4 (1.7)	9 (2.7)	8 (2.0)	14 (2.3)	23 (2.8)	25 (3.4)	11 (2.2)	8 (3.0)	3 (4.6)
Cough	14 (6.1)	38 (11.2)	41 (10.4)	59 (9.7)	78 (9.5)	70 (9.6)	41 (8.2)	30 (11.2)	11 (16.9)
Sputum	21 (9.2)	43 (12.7)	50 (12.7)	75 (12.3)	91 (11.1)	84 (11.6)	47 (9.4)	39 (14.6)	10 (15.4)
Rhinorrhea	32 (14.0)	65 (19.2)	66 (16.7)	118 (19.3)	157 (19.2)	135 (18.6)	87 (17.4)	52 (19.5)	12 (18.5)
<b>Other symptoms</b>									
Muscle stiffness	6 (2.6)	18 (5.3)	21 (5.3)	35 (5.7)	27 (3.3)	31 (4.3)	36 (7.2)	16 (6.0)	6 (9.2)
Constipation	28 (12.2)	49 (14.5)	42 (10.6)	89 (14.6)	111 (13.6)	96 (13.2)	80 (16.0)	28 (10.5)	11 (16.9)
<b>July 2006</b>									
<b>Mucocutaneous symptoms</b>									
Sore throat	57 (24.9)	87 (26.5)	84 (21.9)	121 (20.2)	150 (19.2)	159 (22.6)	85 (18.0)	59 (24.1)	7 (10.9)
Eye itch	96 (41.9)	156 (46.7)	165 (43.0)	228 (37.9)	292 (37.2)	260 (36.4)	170 (35.6)	102 (40.2)	16 (25.4)
Red-eye	69 (30.1)	85 (25.8)	63 (16.6)	106 (17.7)	116 (14.9)	114 (16.4)	78 (16.6)	57 (23.2)	8 (12.9)
Eye irritation	41 (17.9)	68 (20.8)	61 (16.0)	84 (14.1)	97 (12.5)	111 (15.9)	64 (13.6)	32 (13.0)	3 (4.8)
Eye discharge	64 (27.9)	88 (26.7)	77 (20.0)	99 (16.6)	159 (20.5)	138 (19.7)	94 (19.8)	67 (27.0)	6 (9.5)
Eczema	55 (24.0)	87 (26.4)	69 (18.1)	103 (17.3)	128 (16.4)	132 (19.0)	96 (20.2)	58 (23.6)	5 (8.2)
<b>Respiratory symptoms</b>									
Asthma attack	6 (2.6)	15 (4.6)	11 (2.9)	24 (4.1)	34 (4.4)	36 (5.2)	15 (3.2)	15 (6.2)	2 (3.2)
Cough	65 (28.4)	123 (37.0)	118 (30.8)	155 (26.0)	200 (25.5)	185 (26.4)	123 (26.1)	72 (29.3)	15 (23.4)
Sputum	63 (27.5)	111 (33.8)	98 (25.7)	137 (23.4)	205 (26.1)	183 (26.1)	96 (20.4)	74 (30.2)	12 (19.0)
Rhinorrhea	81 (35.5)	157 (47.9)	147 (38.2)	216 (36.0)	284 (36.4)	262 (37.5)	163 (34.9)	103 (41.7)	19 (30.6)
<b>Other symptoms</b>									
Muscle stiffness	18 (7.9)	40 (12.2)	41 (10.8)	63 (10.6)	65 (8.4)	70 (10.1)	70 (14.8)	34 (13.8)	9 (14.5)
Constipation	31 (13.5)	69 (20.9)	64 (16.7)	113 (19.0)	142 (18.2)	116 (16.7)	98 (20.5)	38 (15.4)	11 (17.5)

**Table 4.** Adjusted prevalence odds ratios\* for symptoms in July 2006

	Within 500 m	500–600 m	600–700 m	700–800 m	800–900 m	900–1,000 m	1,000–1,100 m	1,100–1,200 m	2,800 m	Test for trend
	POR (95% CI)	POR (95% CI)	POR (95% CI)	POR (95% CI)	POR (95% CI)	POR (95% CI)	POR (95% CI)	POR (95% CI)	ref	POR <sup>†</sup>
<b>Mucocutaneous symptoms</b>										
Sore throat	3.2 (1.3–8.0)	3.3 (1.3–7.9)	2.5 (1.0–6.1)	2.4 (1–5.7)	2.2 (0.9–5.2)	2.6 (1.1–6.2)	1.7 (0.7–4.1)	2.6 (1.0–6.4)	1	1.06 (1.02–1.09)
Eye itch	3.0 (1.5–6.0)	3.4 (1.8–6.6)	3.1 (1.6–5.9)	2.4 (1.2–4.6)	2.4 (1.2–4.5)	2.1 (1.1–4.0)	2.0 (1.1–3.9)	2.3 (1.1–4.5)	1	1.06 (1.04–1.09)
Red-eye	2.7 (1.1–6.3)	2.4 (1.0–5.5)	1.3 (0.6–3.1)	1.4 (0.6–3.2)	1.1 (0.5–2.6)	1.2 (0.5–2.8)	1.3 (0.6–2.9)	1.9 (0.8–4.5)	1	1.05 (1.02–1.09)
Eye irritation	5.2 (1.5–17.8)	5.4 (1.6–18.0)	3.9 (1.2–13.2)	3.3 (1.0–10.9)	3.0 (0.9–9.9)	3.6 (1.1–11.8)	3.1 (0.9–10.2)	2.5 (0.7–8.5)	1	1.09 (1.04–1.13)
Eye discharge	6.0 (2.3–15.9)	4.4 (1.7–11.5)	3.2 (1.2–8.4)	2.5 (1.0–6.4)	3.4 (1.3–8.6)	2.9 (1.1–7.5)	2.8 (1.1–7.3)	4.3 (1.6–11.2)	1	1.06 (1.03–1.09)
Eczema	3.0 (1.1–7.9)	3.6 (1.4–9.4)	2.2 (0.8–5.7)	2.1 (0.8–5.4)	1.8 (0.7–4.7)	2.2 (0.8–5.6)	2.3 (0.9–6.0)	2.8 (1.1–7.6)	1	1.04 (1.01–1.08)
<b>Respiratory symptoms</b>										
Asthma attack	0.8 (0.1–4.0)	1.2 (0.3–5.6)	0.8 (0.2–3.7)	1.1 (0.3–5)	1.2 (0.3–5.2)	1.4 (0.3–6.2)	0.9 (0.2–4.3)	1.6 (0.3–7.4)	1	0.98 (0.94–1.03)
Cough	2.2 (1.1–4.6)	2.7 (1.3–5.4)	2.1 (1.1–4.3)	1.7 (0.8–3.3)	1.6 (0.8–3.2)	1.7 (0.8–3.3)	1.6 (0.8–3.2)	1.8 (0.9–3.8)	1	1.05 (1.02–1.08)
Sputum	2.4 (1.1–5.1)	2.5 (1.2–5.2)	1.9 (0.9–3.9)	1.6 (0.8–3.2)	1.8 (0.9–3.8)	1.8 (0.9–3.7)	1.2 (0.6–2.5)	2.1 (1.0–4.5)	1	1.04 (1.01–1.07)
Rhinorrhea	1.1 (0.6–2.1)	2.0 (1.1–3.6)	1.3 (0.7–2.3)	1.2 (0.6–2.1)	1.2 (0.7–2.1)	1.2 (0.6–2.1)	1.1 (0.6–1.9)	1.3 (0.7–2.5)	1	1.02 (1.00–1.05)
<b>Other symptoms</b>										
Muscle stiffness	1.1 (0.5–2.7)	0.9 (0.4–2)	1.0 (0.4–2.1)	0.8 (0.4–1.8)	0.7 (0.3–1.5)	0.8 (0.4–1.7)	1.1 (0.5–2.4)	1.2 (0.5–2.6)	1	0.99 (0.96–1.02)
Constipation	1.3 (0.6–3.0)	1.7 (0.8–3.7)	1.3 (0.6–2.9)	1.6 (0.8–3.4)	1.5 (0.7–3.1)	1.3 (0.6–2.8)	1.6 (0.8–3.5)	1.1 (0.5–2.4)	1	1.02 (0.99–1.05)

POR, prevalence odds ratio; CI, confidence interval; ref, reference. \*PORs were adjusted for age, sex, smoking, and past history of hay fever (seasonal allergic rhinoconjunctivitis). <sup>†</sup>POR per 100 m decrease of distance from the factory.

**Table 5.** Adjusted prevalence odds ratios\* for symptoms in July 2006 employing the area 1,000–1,200 m as a reference

	Within 500 m	500–600 m	600–700 m	700–800 m	800–900 m	900–1,000 m	1,000–1,200 m	Test for trend
	POR (95% CI)	POR (95% CI)	POR (95% CI)	POR (95% CI)	POR (95% CI)	POR (95% CI)	POR (95% CI)	POR <sup>†</sup>
<b>Mucocutaneous symptoms</b>								
Sore throat	1.6 (1.1–2.3)	1.7 (1.2–2.3)	1.3 (0.9–1.7)	1.2 (0.9–1.6)	1.1 (0.8–1.4)	1.3 (1.0–1.7)	1	1.07 (1.02–1.12)
Eye itch	1.4 (1.0–2.0)	1.6 (1.2–2.1)	1.4 (1.1–1.9)	1.1 (0.9–1.4)	1.1 (0.9–1.4)	1.0 (0.8–1.2)	1	1.09 (1.05–1.13)
Red-eye	1.8 (1.2–2.5)	1.6 (1.1–2.2)	0.9 (0.6–1.3)	0.9 (0.7–1.3)	0.8 (0.6–1.0)	0.8 (0.6–1.1)	1	1.10 (1.05–1.16)
Eye irritation	1.8 (1.2–2.8)	1.9 (1.3–2.7)	1.4 (1.0–2.0)	1.2 (0.8–1.6)	1.1 (0.8–1.5)	1.3 (0.9–1.7)	1	1.10 (1.05–1.16)
Eye discharge	1.8 (1.3–2.6)	1.4 (1.0–1.9)	1.0 (0.7–1.4)	0.8 (0.6–1.0)	1.0 (0.8–1.3)	0.9 (0.7–1.2)	1	1.07 (1.02–1.12)
Eczema	1.2 (0.8–1.7)	1.4 (1.1–2.0)	0.9 (0.6–1.2)	0.8 (0.6–1.1)	0.7 (0.6–1.0)	0.9 (0.7–1.1)	1	1.05 (1.00–1.10)
<b>Respiratory symptoms</b>								
Asthma attack	0.6 (0.3–1.6)	1.1 (0.5–2.0)	0.7 (0.3–1.4)	1.0 (0.6–1.7)	1.0 (0.6–1.7)	1.2 (0.7–2.1)	1	0.94 (0.86–1.04)
Cough	1.3 (0.9–1.9)	1.6 (1.2–2.1)	1.3 (1.0–1.7)	1.0 (0.8–1.3)	1.0 (0.8–1.2)	1.0 (0.8–1.3)	1	1.07 (1.03–1.12)
Sputum	1.6 (1.1–2.3)	1.7 (1.2–2.3)	1.3 (0.9–1.7)	1.1 (0.8–1.4)	1.2 (1.0–1.6)	1.2 (0.9–1.6)	1	1.07 (1.03–1.12)
Rhinorrhea	0.9 (0.7–1.3)	1.7 (1.3–2.3)	1.1 (0.8–1.5)	1.0 (0.8–1.3)	1.0 (0.8–1.3)	1.0 (0.8–1.3)	1	1.04 (1.00–1.09)
<b>Other symptoms</b>								
Muscle stiffness	1.0 (0.6–1.7)	0.8 (0.5–1.2)	0.9 (0.6–1.3)	0.7 (0.5–1.1)	0.6 (0.4–0.9)	0.7 (0.5–1.0)	1	0.99 (0.93–1.05)
Constipation	0.9 (0.6–1.4)	1.2 (0.8–1.7)	0.9 (0.7–1.3)	1.1 (0.8–1.5)	1.0 (0.8–1.3)	0.9 (0.7–1.2)	1	1.02 (0.97–1.07)

POR, prevalence odds ratio; CI, confidence interval; ref, reference. \*PORs were adjusted for age, sex, smoking, and past history of hay fever (seasonal allergic rhinoconjunctivitis). <sup>†</sup>POR per 100 m decrease of distance from the factory.

by the leaders of the community associations or block leaders. As pointed out by Vrijheid<sup>20)</sup>, there is a possibility that exposed subjects exaggerate their symptoms because of odor or fear. We, therefore, included in the questionnaire symptoms that would not be related to VOC exposure, and the adjusted PORs for muscle stiffness or constipation were not elevated. Furthermore, among the queried symptoms, red eye or eye discharge was considered to be more objective than sore throat, eye itch, or eye irritation. We then observed an elevated prevalence even of red eye or eye discharge, which would also strengthen our findings. Indeed, the questionnaires were collected by the leaders of the community associations or block leaders; however, we attempted to prevent the leaders of the community associations or block leaders from being able to read the contents of questionnaire by using envelopes. Although we cannot rule out a possibility of exaggerated responses among the residents fully, such differential disease misclassifications would not explain the present findings thoroughly.

Furthermore, in the present study, we used distance from the factory as a proxy for VOC exposure, assuming that VOCs are emitted from the factory and that the concentrations of VOCs diminish as the distance from the factory increases. However, there was a huge decline in TVOC or VOCs even within 500 m of the factory as shown in Table 1. Furthermore, we did not take into account elevation of residences, wind and direction from the factory. Moreover, response rates gradually diminished from the area within 500 m (97.5%) to the area 1,100–1,200 m from the factory (50.3%); thus, residents who were more concerned might have participated in the study in the areas farther from the factory. These factors might yield the fluctuating PORs (or elevated PORs in the area 1,100–1,200 m from the factory) in the present study. Therefore, we should be cautious in interpreting PORs in the areas more than 600 m far from the factory where we could not obtain actual concentrations of VOCs. However, the significantly elevated PORs in the area within 500 m could be attributed to outdoor VOCs exposure. Further studies that utilize more sophisticated exposure assessment are warranted.

When we used the alternative reference (the area of 1,000–1,200 m), we observed elevated PORs (Table 5), which could strengthen the present findings. Employing the alternative reference could increase the number of residents in the referent area and make the comparison group more comparable in demographic characteristics (Table 2). Furthermore, the finding of elevated PORs in the elderly group supports the present hypothesis. This finding may also indicate vulnerability among elderly.

Limitations of the present study are as follows:

First, as mentioned, the response rates decreased in order from the area within 500 m to the area 2,800 m from the factory; that is, the response rates were 97.5, 82.6, 84.5, 81.2, 69.8, 63.1, 63.0, 50.3 and 92.2%, respectively. Thus, this could induce selection bias, resulting in the present dose-response results. However, the selection bias would not be large enough to induce the observed elevated PORs in the area within 500 m of the factory. Second, there is a possibility that other outdoor air pollutants caused the present findings. However, all the study areas are urban areas in the same densely populated city, and large roads are closer to the reference area (2,800 m from the factory); thus, other outdoor air pollutants could not explain the present findings. Third, we could not measure indoor concentrations of VOCs in the participants' houses. However, indoor pollution could not induce such dose-response relationships. Finally, although there is a possibility of other residual confounding, since we adjusted for potential confounders and the magnitude of effect estimates were quite high, other residual confounding could not fully explain the present results.

In the present study, it was demonstrated that VOCs were higher in the vicinity of the factory, and even the concentration of TVOC in the residential area exceeded  $200 \mu\text{g}/\text{m}^3$ . Furthermore, the prevalence of mucocutaneous and respiratory symptoms was highest among the residents in the closest area to the factory. Although there are many limitations, these results imply a possible association of open-air VOCs with mucocutaneous and respiratory symptoms. Because this kind of plastic recycling factory only recently came into operation, more attention should be paid to the operation of plastic recycling factories in the environment as well as the workers in these factories. Although five years have passed since this population-based study (in 2006), the situation remains the same.

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## Appendix

### A Request for Your Cooperation and Response with a Health Survey

Community group to protect residents' health and environment from pollution due to plastic-reprocessing  
XX Community Circle

We conduct this health survey under the guidance of experts.

The purpose of this survey is to investigate the impact of the plastic-reprocessing factory operation on residents' health. The obtained results will be used for a campaign to protect our health and environment. Confidentiality of respondents is strictly maintained.

<Note>

\*Please respond to all of the questions in the survey by yourself. If a respondent has a difficulty with writing (e.g., a young child), someone else can fill the questionnaire on his or her behalf.

\*Cooperation from all of the family members is appreciated.

\*A member of the community circle will visit each residence to pick up the completed questionnaire.

Contact information: YY YY, board member of XX Community Group (phone: xxx-xxxx)