Adverse Effect of Air Pollution on Respiratory Health of Primary School Children in Taiwan

Pau-Chung Chen,1 Yu-Min Lai,1 Jung-Der Wang,1 Chun-Yuh Yang,2 Jing-Shiang Hwang,3 Hsien-Wen Kuo,4 Song-Lih Huang,3 and Chang-Chuan Chan1

1Institute of Occupational Medicine and Industrial Hygiene, College of Public Health, National Taiwan University, Taipei, Taiwan; 2School of Public Health, Kaohsiung Medical College, Kaohsiung, Taiwan; 3Institute of Statistical Science, Academia Sinica, Taipei, Taiwan; 4Institute of Environmental Health, China Medical College, Taichung, Taiwan; 5Institute of Public Health/Department of Social Medicine, National Yang Ming University, Taipei, Taiwan

This study is a part of the Study On Air Pollution and Health In Taiwan (SOAP&HIT), an ongoing research project involving cooperation of several universities in Taiwan. In this study, the objective was to evaluate the effects of ambient air pollution on respiratory symptoms and diseases of school children, in addition to considering indoor air pollution. Six communities were selected: one community located in a rural area (Taihsi), two in urban areas (Keelung and Sanchung), and the other three in petrochemical industrial areas (Toufen, Jenwu, and Linyuan). We sampled 5,072 primary school students in six communities from the main study population of SOAP&HIT. Respiratory health was assessed by evaluation of the children’s respiratory symptoms and diseases using a parent-completed questionnaire. Data were analyzed using logistic regression analysis to compute odds ratios of adverse effect. The school children in the urban communities had significantly more respiratory symptoms (day or night cough, chronic cough, shortness of breath, and nasal symptoms) and diseases (sinusitis, wheezing or asthma, allergic rhinitis, and bronchitis) when compared with those living in the rural community. However, only nasal symptoms of children living in the petrochemical communities were more prevalent than in those living in the rural community. Although the association with ambient air pollution is suggestive, the cross-sectional study cannot confirm a causal relationship; thus further studies are needed. Key words: air pollution, cross-sectional study, home dampness, respiratory health, school children. Environ Health Perspect 106:331–335 (1998). [Online 11 May 1998] http://ehpnet1.niehs.nih.gov/docs/1998/106p331-335chen/abstract.html

In the last few years, several studies have reported significant associations between air pollution and daily mortality and various markers for acute respiratory morbidity, including hospital admissions, hospital emergency and outpatient clinic visits, exacerbation of respiratory symptoms, lung functions changes, and school absenteeism in Europe and America (1–9). However, there are still many issues to be clarified before we know the real causal relationship between air pollution and health effects. Specific air pollutants have not been identified as causes of health effects, and effects of short-term peak air pollution exposures are not sufficiently evident. Also, there is no agreement on the economic impact of air pollution-related health effects. To develop the exposure–effect relationship between air pollution and health indices, we cooperated in an ongoing research project, The Study On Air Pollution and Health In Taiwan (SOAP&HIT).

This is the first multicenter (five research institutes), multidisciplinary (health, exposure assessments, statistics, and economics), and multiyear (1994–1997) cross-sectional air pollution study in Taiwan. The SOAP&HIT seeks to address three critical hypotheses: 1) What are the exposure–effect relationships between air pollutant mixtures and various adverse respiratory effects based on population and individualized air pollution exposure data? 2) What are the economic costs for air pollution-related health effects based on the dose–response relationship found in our research? and 3) Is there a subpopulation that is particularly susceptible to air pollution in Taiwan?

To conduct SOAP&HIT efficiently, our disciplinary integrated study design was further classified into four components: exposure assessments, health effects, biological markers, and economic analysis. For efficiency of study design, we decided to use concentrations of three major air pollutants, SO2, O3, and particulate matter ≤10 μm (PM10), in the year before this study as indicators to select study sites. A total of eight (25) communities were preliminarily selected based on these three pollutants using a factorial design. However, we only selected six out of these communities due to financial constraints. These six sites included different pollution patterns representing rural, urban, and industrial areas in Taiwan.

The objective of the present study was to determine whether there was an adverse effect of air pollution on respiratory health in primary school children. This paper characterizes the respiratory symptoms and diseases of school children in urban and petrochemical communities and in a reference community, which is in a rural area and not in the immediate proximity of any petrochemical or other industrial emissions during the study period.

Materials and Methods

Study design. A cross-sectional survey was designed to determine the prevalence of respiratory symptoms and diseases of primary school children residing in two urban communities exposed to pollution caused by traffic (Keelung and Sanchung), and three petrochemical communities (Toufen, Jenwu, and Linyuan), which serve as the exposed group of stationary sources by petrochemical industries. These communities were compared to a rural community, Taihsi, which serves as the reference group in Taiwan (Table 1). According to population characteristics and air pollution patterns (6), the three petrochemical communities were classified further: both Toufen and Jenwu also had traffic pollution, the populations are ethnically Hakka in Toufen and Taiwanese in Jenwu, and Linyuan represents typical petrochemical pollution.

Subjects. Among 5,072 primary school students selected from the six communities, a total of 4,860 returned the questionnaire, for a response rate of 95.8%. Of this group of children, 81.6% had resided in their current houses for at least 3 years. Questionnaires with incomplete data (136) were excluded for the purpose of consistency throughout the analyses. A total of 4,697 valid questionnaires are presented in this study (Table 2).

Air monitoring. The hourly concentrations of nine air pollutants including PM10, SO2, NOx, NO, NO2, O3, total hydrocarbons (THC), nonmethane hydrocarbons (NMHC), and CO are continuously monitored and carried out by the Environmental...
Protection Administration air quality monitoring stations located in the campus of the selected primary school in each community. The instrumentation used in the fixed-site monitoring stations are β-gauge for PM10; UV fluorescence for SO2; chemiluminescence for NOx, NO, and NO2; flame ionization for THC and NMHC; non-disperse infrared absorption for CO; and UV absorption for O3. The air quality was measured by comparing the air pollution levels with appropriate National Ambient Air Quality Standards (NAAQS) for each air pollutant. Two-year monitoring data from 1994 to 1995 are included in this study. In the preliminary analysis, the six public schools were similar with respect to indoor environment and timetable for teaching activity.

**Table 1. The design structure of the Study On Air Pollution and Health In Taiwan**

| Site         | Rural area | Urban areas | Petrochemical industrial areas |
|--------------|------------|-------------|---------------------------------|
|              | Taishi     | Keelung     | Sanchung                        | Toufen | Jenwu | Linyuan |
| Population density (persons/km²) | 568       | 13,670      | 23,115                          | 1,568  | 2,174 | 1,238   |
| Study population | Taishi primary school children (705) | Jenai primary school children (954) | Shuder primary school children (1,386) | Luiho primary school children (796) | Bakua primary school children (701) | Sanwei primary school children (530) |
| Air monitoring | Nine air pollutants excluding HC | Nine air pollutants excluding HC | Nine air pollutants excluding CO and O3 | Nine air pollutants | Nine air pollutants | Nine air pollutants |
| Exposure assessment | IAQ questionnaire | IAQ questionnaire | IAQ questionnaire | IAQ questionnaire | IAQ questionnaire | IAQ questionnaire |
| Health effect | Symptoms (637) | Symptoms (917) | Symptoms (1,326) | Symptoms (771) | Symptoms (668) | Symptoms (500) |

**Table 2. Study population by gender, grade, and father's education**

| Study population | Rural areas | Urban areas | Petrochemical industrial areas |
|------------------|-------------|-------------|---------------------------------|
|                  | Taishi      | Keelung     | Sanchung                        | Toufen | Jenwu | Linyuan |
| Total responses  | 705         | 954         | 1,386                           | 796    | 701   | 530    |
| Valid responses  | 657 (95.3)  | 917 (96.1)  | 1,326 (95.9)                    | 771 (99.1) | 689 (98.4) | 500 (94.2) |
| Sex Male         | 292 (47.8)  | 464 (51.8)  | 663 (51.1)                      | 356 (47.6) | 351 (52.0) | 245 (52.1) |
|       Female     | 319 (52.2)  | 431 (48.2)  | 605 (48.9)                      | 392 (52.4) | 324 (48.0) | 225 (47.9) |
| School grade Low | 170 (27.8)  | 254 (28.4)  | 399 (30.7)                      | 228 (30.5) | 206 (30.5) | 130 (27.7) |
|       Middle     | 221 (36.2)  | 315 (35.2)  | 381 (29.4)                      | 231 (30.9) | 215 (31.9) | 131 (27.9) |
|       High      | 220 (36.0)  | 326 (36.4)  | 518 (39.9)                      | 289 (38.6) | 254 (37.6) | 209 (44.5) |
| Father's education Primary school | 194 (31.8)  | 57 (6.4)    | 328 (25.3)                      | 75 (10.0) | 180 (26.7) | 251 (53.4) |
|       Junior school | 228 (37.2)  | 120 (13.4)  | 354 (27.3)                      | 199 (26.6) | 211 (31.3) | 121 (25.7) |
|       High school | 130 (22.3)  | 415 (46.4)  | 424 (32.7)                      | 344 (46.0) | 219 (32.4) | 71 (15.4) |
|       University | 30 (6.2)    | 296 (32.0)  | 188 (12.9)                      | 177 (15.8) | 48 (7.1)   | 17 (3.6) |
| Unknown          | 15 (2.5)    | 17 (1.9)    | 21 (1.8)                        | 13 (1.7) | 17 (2.5) | 10 (2.1) |
| Mother's education Primary school | 320 (52.4)  | 95 (10.8)   | 407 (31.4)                      | 113 (15.1) | 230 (34.1) | 290 (61.7) |
|       Junior school | 160 (26.2)  | 135 (15.1)  | 377 (29.0)                      | 326 (43.6) | 237 (35.1) | 123 (26.2) |
|       High school | 91 (14.9)   | 490 (54.7)  | 401 (30.9)                      | 273 (36.5) | 183 (27.1) | 41 (8.7) |
| Unknown          | 22 (4.4)    | 166 (18.5)  | 86 (6.6)                        | 28 (5.5) | 13 (1.9) | 5 (1.1) |

**Table 3. Average concentrations (AC) and days of exceedance (DE) for five criteria air pollutants during 1994–1995**

| Pollutant | Rural area | Urban areas | Petrochemical industrial areas |
|-----------|------------|-------------|---------------------------------|
|           | Taishi     | Keelung     | Sanchung                        | Toufen | Jenwu | Linyuan |
|           | AC         | DE          | AC | DE | AC | DE | AC | DE | AC | DE |
| SO2 (ppb) | 3.27       | 0           | 8.68   | 0 | 8.77 | 0 | 45.79 | 108 | 17.20 | 0 | 16.04 | 0 |
| CO (ppm)  | 0.40       | 0           | 0.93   | 0 | 1.35 | 0 | NM | NM | 0.76 | 0 | 0.66 | 0 |
| O3 (ppb)  | 52.96      | 2           | 41.90  | 0 | 38.34 | 0 | NM | NM | 52.12 | 2 | 60.64 | 26 |
| PM10 (μg/m³) | 72.20    | 57          | 53.42  | 6 | 42.42 | 44 | 64.31 | 19 | 35.67 | 197 | 109.97 | 294 |
| NO2 (ppb) | 10.00      | 0           | 25.41  | 0 | 31.84 | 0 | 25.63 | 0 | 29.32 | 0 | 28.16 | 0 |

**Abbreviations:** NM, not measured; PM10, particulate matter ≤10 μm.

1. Daily SO2 average >100 ppb.
2. Daily CO average >100 ppm.
3. Daily PM10 average >120 ppb.
4. Daily PM2.5 average >125 μg/m³.

**Values in parentheses are percent.**
or night cough as cough usually in the rest of the day or at night, and chronic cough as the previous symptoms on most days for 3 consecutive months or more during the year. We defined shortness of breath as breathlessness when hurrying on the level or walking up a slight hill and wheezing as a wheezy or whistling sound in the chest at any time. Nasal symptoms were defined as stuffy and running nose or sneezing in the morning or before sleeping, apart from colds for 2 or 3 consecutive days or more. Self-reported respiratory diseases such as sinusitis, wheezing or asthma, allergic rhinitis, bronchitis, and pneumonia were included in a history of respiratory disease diagnosed by medical doctors.

**Statistics.** We analyzed data concerning the prevalence of respiratory symptoms and diseases according to place of residence. To explore the relationship between respiratory symptoms and diseases and the exposure areas, multiple logistic regression models were used in which the potential confounding factors were controlled. The adjusted odds ratios (aORs) and their 95% confidence intervals (CIs) were computed. All statistical analyses were performed using the SPSS for Windows, Release 6.1. (8, 9).

**Results**

As indicated in Table 3, both mean concentrations and exceedance frequencies were significantly different for most air pollutants among the three community types. For two mixed-type communities (Toufen and Jenwu) and the typical petrochemical community (Linyuan), their average SO₂ concentrations (16–46 ppb) were significantly higher than rural (3 ppb) and urban (9 ppb) communities. As expected, the average concentrations of CO in two urban communities (0.9–1.4 ppm) were significantly higher than the concentrations in both the rural (0.4 ppm) and the typical petrochemical (0.7 ppm) communities. For NO₂, the average concentrations in rural communities (10 ppb) were significantly lower than those in typical petrochemical (20 ppb), urban (25–32 ppb), and mixed-type (26–29 ppb) communities. The concentrations of O₃ and PM₁₀ also showed interesting comparisons among these six communities. The lowest concentrations for both air pollutants were found in the two urban communities of Keelung and Sanchung (38–42 ppb for O₃ and 53–67 µg/m³ for PM₁₀), while the highest concentrations were in the two petrochemical communities of Jenwu and Linyuan (52–60 ppb for O₃ and 96–110 µg/m³ for PM₁₀).

The basic information of the study population is shown in Table 2. With regard to the children's sex, there was no significant difference among those living in different communities. The proportion of children (44.5%) who were in high grades (grades 5 and 6) in the typical petrochemical industrial community (Linyuan) was slightly higher than proportions in the other communities. However, there were apparent differences in education of the children's parents. For example, education of fathers in Linyuan community was the lowest level on average of those in the six communities.

The prevalence of respiratory symptoms and diseases are summarized in Table 4. Children living in the urban area (Keelung and Sanchung) had consistently higher rates of respiratory symptoms and diseases (with the exception of pneumonia) than did those living in the rural community (Taihsi). However, nasal symptoms were more prevalent in children living in the petrochemical communities (Toufen, Jenwu, and Linyuan) than in the rural community. For morning cough and day or night cough, there was a steady rise with the Hakka (Toufen), mixed (Jenwu), and typical (Linyuan) petrochemical industrial communities.

**Table 4. Prevalence of respiratory symptoms and diseases**

| Symptom                  | Rural area | Urban areas | Petrochemical industrial areas |
|--------------------------|------------|-------------|---------------------------------|
|                          | Taihsi     | Keelung     | Sanchung                        |
|                          | Toufen     | Jenwu       | Linyuan                         |
|                          | Total      |             |                                 |
| **Symptoms**             |            |             |                                 |
| Morning cough            | 70 (11.5)  | 122 (13.6)  | 175 (13.5)                      |
| Day or night cough       | 61 (10.0)  | 116 (13.0)  | 188 (14.5)                      |
| Chronic cough            | 17 (2.8)   | 42 (4.7)    | 72 (5.5)                        |
| Shortness of breath      | 69 (11.3)  | 114 (12.7)  | 196 (15.1)                      |
| Nasal symptoms           | 121 (19.8) | 292 (32.6)  | 404 (31.1)                      |
|                          |            |             | 166 (22.2)                      |
|                          |            |             | 182 (27.0)                      |
|                          |            |             | 131 (27.9)                      |
|                          |            |             | 1,296 (27.6)                    |
| **Diseases**             |            |             |                                 |
| Sinusitis                | 38 (6.2)   | 104 (11.6)  | 103 (7.9)                       |
| Wheezing or asthma       | 34 (5.6)   | 89 (9.9)    | 109 (8.4)                       |
| Allergic rhinitis        | 53 (8.7)   | 175 (19.6)  | 200 (15.4)                      |
| Bronchitis               | 98 (16.0)  | 269 (30.1)  | 342 (26.3)                      |
| Pneumonia                | 21 (3.4)   | 31 (3.5)    | 40 (3.1)                        |
| Family's respiratory     | 73 (11.9)  | 153 (17.1)  | 206 (15.9)                      |
| diseases                 |            |             | 87 (11.6)                       |
|                          |            |             | 84 (12.4)                       |
| Total subjects (n)       | 611        | 895         | 1,298                           |
|                          | 748        | 675         | 470                             |
|                          | 4,697      |             |                                 |

**Table 5. Indicators of indoor environment**

| Indoor condition         | Rural area | Urban areas | Petrochemical industrial areas |
|--------------------------|------------|-------------|---------------------------------|
|                          | Taihsi     | Keelung     | Sanchung                        |
|                          | Toufen     | Jenwu       | Linyuan                         |
|                          | Total      |             |                                 |
| **Crowning index**       |            |             |                                 |
| Low (≥10 m²/person)      | 437 (71.5) | 830 (92.7)  | 1,119 (86.2)                    |
| High (<10 m²/person)     | 98 (16.0)  | 40 (4.5)    | 128 (9.9)                       |
| Unknown                  | 76 (12.4)  | 25 (2.8)    | 51 (3.9)                        |
| Household smoking        |            |             |                                 |
| None                     | 161 (26.4) | 357 (38.9)  | 468 (36.1)                      |
| Low (≤1 pack/day)        | 380 (62.2) | 500 (55.9)  | 766 (59.0)                      |
| High (1+ pack/day)       | 36 (5.9)   | 19 (2.1)    | 35 (2.7)                        |
| Unknown amount           | 34 (5.6)   | 19 (2.1)    | 29 (2.2)                        |
| Pets                     | 149 (24.4) | 178 (19.3)  | 287 (22.1)                      |
| Coal stove used          | 186 (30.4) | 66 (7.4)    | 117 (9.0)                       |
| Tea gas-cooker used      | 205 (33.6) | 65 (7.7)    | 134 (10.3)                      |
| Incense burning          | 34 (5.6)   | 21 (2.3)    | 41 (3.2)                        |
| Mosquito repellent       | 269 (44.0) | 213 (23.8)  | 280 (21.1)                      |
| Indoor plants            | 200 (32.7) | 237 (26.5)  | 439 (33.8)                      |
| Home dampness            |            |             | 284 (380)                       |
| None                     | 402 (65.8) | 390 (43.6)  | 802 (61.8)                      |
| In rainy season           | 142 (23.2) | 350 (39.1)  | 328 (25.3)                      |
| When continuously raining| 49 (8.0)   | 129 (14.4)  | 151 (11.6)                      |
| On most days             | 18 (2.9)   | 26 (2.9)    | 17 (1.3)                        |
| Total subjects (n)       | 611        | 895         | 1,298                           |

Values in parentheses are percent.
regard to the level of crowding, the amount of household smoking in the dwelling, the presence of feathered or hairy pets, fowls kept in the home, the use of a coal stove, the use of a tea gas-cooker in the home, the burning of incense the whole day, the burning of a mosquito repellent, plants inside the home, and self-reported home dampness. Children in Taishí, Jenwu, and Linyuan lived in more crowded households than did those in the other communities.

The amount of household smoking in Taishí and Linyuan was higher than in the other communities. Home dampness was reported more frequently in Keelung.

The results of the logistic regression analysis are shown in Table 6. The school children in the urban communities (Keelung and Linyuan) had higher risks of having respiratory symptoms (day or night cough, chronic cough, shortness of breath, and nasal symptoms) or diseases (sinusitis, wheezing or asthma, allergic rhinitis, and bronchitis) when compared with those living in the rural community (Taishí). For example, compared to children in the rural community, children in the urban communities had a higher risk of having day or night cough (aOR = 1.67; CI, 1.21–2.29), chronic cough (aOR = 1.88; CI, 1.07–3.31), shortness of breath (aOR = 1.40; CI, 1.04–1.91), and nasal symptoms (aOR = 1.96; 95% CI, 1.54–2.48). On the other hand, children living in the petrochemical communities (Jenwu and Linyuan) had higher odds of having nasal symptoms than did those living in the rural community. Compared to children in the rural community, children in the petrochemical industrial communities had a higher risk of having nasal symptoms (mixed type: aOR = 1.59; CI, 1.21–2.09 and typical: aOR = 1.59; CI, 1.19–2.14).

Among indicators of indoor environment, home dampness was the most significant factor in relation to children's respiratory health. The crowding index, household smoking, pets, fowls, use of a coal stove, use of a tea gas-cooker, incense burning the whole day, mosquito repellent burning, and indoor plants are also significantly associated with some of respiratory symptoms and diseases. There were dose–response relationships between home dampness and most of the respiratory symptoms and diseases after controlling for the potential confounders mentioned above (see Table 7). For example, compared to children whose parent did not report any sign of dampness in the home, children with reported home dampness had a higher risk of having reported cough, which increased with an increase in dampness (dampness in rainy season: aOR = 1.62; CI, 1.32–1.98; dampness with continuous rain: aOR = 2.22; CI, 1.74–2.84; and dampness on most days: aOR = 3.30; 95% CI, 2.09–5.19).

Discussion

The school children in the urban communities had significantly more respiratory symptoms (day or night cough, chronic cough, shortness of breath, and nasal symptoms) and diseases (sinusitis, wheezing or asthma, allergic rhinitis, and bronchitis) when compared with those living in the rural community. On the other hand, nasal symptoms were more prevalent in children living in the petrochemical communities than in those living in the rural community.

When evaluating the effects of individual sources of pollution, an epidemiologic approach best eliminates the effects of other variables (10). Unfortunately, such an approach is impossible in this cross-sectional survey. In this study, we evaluated the health effects in six communities with different pollution patterns, based on community monitoring (6). We used a spatial approach in which multivariate statistical analyses were performed to control for possible confounding factors.

Because there are several types of health care in Taiwan, including Western, Chinese, and herbal medicine and self-medication bought from drug stores, we could not use medical records from general practice only. Thus, we selected respiratory symptoms of primary school children as indices of health effects resulting from air pollution. Parents of the subjects completed questionnaires concerning the status of the children's respiratory health. The limitations of this type of research tool have been reviewed (11), and reporting errors may have occurred in this study. All questions concerning respiratory health were selected from a standardized questionnaire (7).

This cross-sectional study offers weak evidence for causality because one cannot be confident that exposure preceded the disease. Most of the children in this study had lived in their current houses for at least 3 years, although the etiologically meaningful time between exposure and occurrence of respiratory symptoms and disease is still a matter of debate. The overall high response rate achieved in the present study increases confidence in the data and makes an important selection bias unlikely. Also, we collected the data in the same month in order to avoid differential inclusion of study subjects into the survey according to season, which can bias the results.

The study communities included rural, urban, and petrochemical industrial areas and therefore may have shown apparent differences in socioeconomic status. In this study, the father's education at a primary school level gave lower odds for chronic cough, allergic rhinitis, and bronchitis (more severe respiratory conditions) than those at higher educational levels. We concluded that these respiratory conditions in questionnaires were underestimated by parents or guardians at low levels of education. The father's education was a surrogate included in the final models to control for differences of health-seeking behavior and disease perception. Hakka people (Toufen) are known for their hard work and high tolerance to difficult and hazardous environments. They may be less likely to express their complaints of bodily discomfort or they may have a higher threshold of discomfort to consider it a symptom. Our results in Tables 4 and 6 show this trend before and after controlling for indoor air pollution, compared to the
Table 7. Adjusted odds ratios (95% confidence intervals) for respiratory symptoms and diseases by home dampness

| Respiratory condition | In raining season | When continuously raining | On most days |
|-----------------------|-------------------|----------------------------|-------------|
| Symptoms              |                   |                            |             |
| Morning cough         | 1.62 (1.32–1.98)**| 2.22 (1.74–2.84)**        | 3.30 (2.09–5.19)** |
| Day or night cough    | 1.62 (1.32–1.98)**| 2.13 (1.67–2.73)**        | 2.92 (1.82–4.88)** |
| Chronic cough         | 2.72 (1.93–3.83)**| 2.75 (1.80–4.19)**        | 2.33 (0.97–5.62)  |
| Shortness of breath   | 1.90 (1.56–2.29)**| 2.08 (1.62–2.69)**        | 3.35 (2.10–5.34)** |
| Nasal symptoms        | 1.33 (1.15–1.55)* | 1.74 (1.44–2.12)**        | 2.58 (1.72–3.86)** |
| Diseases              |                   |                            |             |
| Sinusitis             | 1.12 (0.88–1.45)  |                            |             |
| Wheezing or asthma    | 1.56 (1.20–2.01)* | 1.90 (1.41–2.55)**        | 2.26 (1.26–4.04)** |
| Allergic rhinitis     | 1.13 (0.92–1.38)  | 1.90 (1.41–2.55)**        | 2.26 (1.26–4.04)** |
| Bronchitis            | 1.79 (1.52–2.10)**| 2.48 (2.02–3.05)**        | 1.74 (1.10–2.76)** |
| Pneumonia             | 1.36 (0.91–2.05)  | 1.96 (1.22–3.13)**        | 2.77 (1.21–6.32)** |
| Family’s respiratory diseases | 1.60 (1.31–1.94)** | 2.39 (1.88–3.03)** | 2.06 (1.24–3.42)** |

*Adjusted for gender, school grade, father’s education, crowding index, household smoking, pets, fowls, coal stove used, tea gas-cooker used, incense burning the whole day, mosquito repellent burning, indoor plants, and air pollution patterns using logistic models.

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