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*Asia Pac J Public Health* published online 20 December 2011

DOI: 10.1177/1010539511428488

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# A GIS-Based Assessment of Environmental Influences on Allergy Development in Children

Asia-Pacific Journal of Public Health  
XX(X) 1-13  
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DOI: 10.1177/1010539511428488  
<http://aph.sagepub.com>  


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## Abstract

**Objective.** This study aims to assess potential environmental influences on allergy development in children. **Methods.** Based on a parent-completed questionnaire survey administered in Hong Kong in 2003 in accordance with the International Study of Asthma and Allergies in Childhood protocol, the prevalence and incidence of asthma and rhinoconjunctivitis of 508 preschool children aged 4 to 6 years in Yuen Long District were determined and a range of indoor and outdoor environmental factors were assessed. **Results.** Exposure to moisture and mold in the first year of life increased the risk of asthma (adjusted odds ratio [aOR] = 2.56; 95% confidence interval [CI] = 1.40-4.68) and rhinoconjunctivitis (aOR = 2.09; 95% CI = 1.15-3.80). Current maternal smoking was also associated with a higher prevalence of asthma (aOR = 2.00; 95% CI = 1.04-3.84). No association was observed between outdoor traffic-related air pollutants and the prevalence of the allergic conditions. **Conclusion.** Indoor home environments had a stronger influence on allergy development, whereas exposure to traffic-related external environment gave a variable effect, the significance of which would be difficult to be substantiated.

## Keywords

asthma, rhinoconjunctivitis, indoor environment, outdoor environment, maternal smoking, moisture and mold, risk factors, preschool children

## Introduction

Allergic diseases, as exemplified by asthma and rhinoconjunctivitis, constitute a health problem of increasing importance in children worldwide,<sup>1</sup> particularly in countries beginning to adopt modern lifestyles and becoming urbanized. The cause of allergy in human society is multifactorial. It has been shown that a history of respiratory disease during childhood is associated with an increased risk of pathologic changes in respiratory function and chronic obstructive pulmonary disease during adulthood.<sup>2,3</sup> Genetic predisposition is important but nonmodifiable. To

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protect our children from the potential risk of allergy, a clear understanding of modifiable environmental determinants, no matter how small, may help inform preventive strategies.

In reviewing the roles of environmental determinants, numerous studies have shown that exposure to outdoor air pollutants, specifically traffic-related pollutants, is associated with a higher risk of asthma and allergic diseases.<sup>4-7</sup> In a cohort study, it was reported that infants living near “stop-and-go traffic” (residence within 100 m of a bus route and/or 100 m of a state route with less than 50 mi/h speed limit) had a 2.5-fold increased risk of wheeze without cold compared with subjects living farther away (>400 m from an interstate route and >100 m from state and bus routes).<sup>4</sup> In another cross-sectional study, exposure to high traffic, that is,  $>8 \times 10^6$  vm (vehicle meters) was associated with a 2.8-fold increased risk of asthma compared with children exposed to low traffic ( $<4 \times 10^6$  vm).<sup>5</sup>

On the other hand, increases in allergic diseases have been attributed to adverse indoor environments. For instance, in a cross-sectional study of 16 789 Chinese children, the presence of pets at home was associated with an increased risk of doctor-diagnosed asthma and asthma-related respiratory symptoms.<sup>8</sup> A population-based study comprising 5019 children in Taiwan demonstrated that prenatal and household environmental tobacco smoke (ETS) exposure had significant adverse effects on respiratory health in children.<sup>9</sup> A population-based, 6-year prospective cohort study of 1984 children aged 1 to 7 years suggested that exposure to mold was independently associated with the development of asthma.<sup>10</sup> Other significant indoor air pollution determinants of asthma morbidity include particulate matter, nitrogen dioxide, ozone, volatile organic compounds, and allergens from house-dust mites, cat, cockroach, and rodents.<sup>11-15</sup>

To determine the relative importance of indoor and outdoor environmental factors on the development of allergy, we set out to assess their impacts on 2 allergic conditions, asthma and rhinoconjunctivitis, in preschool children from 1 district in Hong Kong. Located in Southeastern coast of China, Hong Kong is an urbanized city of 1000 km<sup>2</sup> with a high population of about 7 million. With a predominantly Chinese population, results in our study may be of useful reference for other cities in Mainland China and other locations with similar environmental backgrounds.

## Methods

This is a cross-sectional study examining the environmental influences on the development of allergy in preschool children in a district in Hong Kong. Data on exposure to pollutants and allergens as well as prevalence and incidence of allergic conditions were retrieved from a territory-wide questionnaire survey. Exposure to outdoor traffic-related pollutants was inferred by using geographic information system (GIS).

### Study Population

In 1991, the International Study of Asthma and Allergies in Childhood (ISAAC), a worldwide epidemiological research program, was established to investigate the patterns of asthma, rhinitis, and eczema in children across countries and cities including Hong Kong. Survey data from preschool children aged 4 to 6 years collected in 2003 in Hong Kong during phase III of ISAAC was used in this study.<sup>16</sup> Details of the phase III study protocol have been published elsewhere.<sup>17</sup> The original data set consisted of 1929 preschool children scattered unevenly in 18 districts in Hong Kong. To minimize the potential impacts of geographic variations, we focused on preschool children living in one large district, Yuen Long District, which has an area of 138 km<sup>2</sup> and a population of 534 192, as documented at the by-census in 2006. Institutional approval was

obtained from the Joint Chinese University of Hong Kong–New Territories East Cluster Clinical Research Ethics Committee.

### *Definition of Asthma and Rhinoconjunctivitis*

In this study, 2 allergic conditions—namely, asthma and rhinoconjunctivitis—were evaluated. Prevalent asthma was defined as the presence of one or more of the following: (a) ever had wheeze, (b) asthma or “bronchus sensitivity” diagnosed by a doctor, (c) exercise-induced wheezing in the past 12 months, and (d) dry cough in the evening excluding flu in the preceding 12 months. Incident asthma was defined as either wheeze in the past 12 months or (c) or (d). Prevalent rhinoconjunctivitis was defined as the presence of one or more of the following: (e) frequent sneezing, runny nose, or congestion and (f) hay fever or allergic rhinitis. Incident rhinoconjunctivitis was defined as sneezing, runny nose, or congestion in the preceding 12 months.

### *Assessment of Indoor Exposure to Pollutants or Allergens*

The ISAAC questionnaires included built-in questions on home environments that were answered by parents or caregivers. The items evaluated for this study were as follows: (a) pet keeping currently (at the time of the survey) and before 1 year of age; (b) exposure to moisture and mold currently and before 1 year of age; (c) exposure to secondhand tobacco smoke from mother currently, before 1 year of age, and during pregnancy or from other family members currently; and (d) current air-conditioning situations.

### *Assessment of Outdoor Exposure to Traffic-related Pollutants*

A GIS-based approach was used. The residential addresses of the participants were geocoded manually to obtain the coordinates at building level. Digital maps were purchased from the Lands Department of the Hong Kong Special Administrative Region Government. Mapping of the 2 conditions was made, using District Council Constituency Areas (DCCA) as the geographic unit. There were 29 DCCA in the District of Yuen Long, each with a population of about 17 000. The distances of each participant’s residence to the (a) nearest major traffic roads and (b) nearest high-traffic flow roads (annual average daily traffic >30 000, data obtained from The Annual Traffic Census 2003 from the Transport Department of the Hong Kong Special Administrative Region Government) were calculated. Classification of exposure by distances to the nearest major traffic roads or nearest high-traffic flow roads was made, taking reference from previous studies that suggested that residence within 75 m of a major road was associated with an increased risk of lifetime asthma and allergic diseases and that the concentration of traffic-related pollutants declined markedly within at a distance of 150 to 300 m.<sup>6</sup> The distances between residence and the nearest traffic roads or high-traffic flow roads were stratified into 4 levels, that is, <75 m, 75 to 150 m, 150 to 300 m, and >300 m. In addition, the total length of vehicle roads within 75-m buffer zone of the residential locations was calculated and further stratified by quartiles. Exposure to traffic-related pollutants when travelling between residence and school was studied by using the distance between residence and school as surrogate.

### *Statistical Analysis*

Chi-square tests were used to analyze the relationships between prevalence and incidence of asthma and rhinoconjunctivitis, and their relationships with each risk factor. Crude odds ratios

**Table 1.** Demographic and Household Characteristics of Preschool Children (N = 508)

| Category                              | Number | Percentage        |
|---------------------------------------|--------|-------------------|
| Gender                                |        |                   |
| Male                                  | 259    | 51.0              |
| Female                                | 249    | 49.0              |
| Age (years)                           |        |                   |
| 4                                     | 172    | 33.7              |
| 5                                     | 291    | 57.3              |
| 6                                     | 46     | 9.1               |
| Place of birth                        |        |                   |
| Hong Kong                             | 404    | 79.5              |
| Mainland China                        | 96     | 18.9              |
| Other countries                       | 8      | 1.6               |
| Breastfeeding                         | 212    | 41.7              |
| Day care attendance                   | 53     | 10.4              |
| Parental allergy                      |        |                   |
| Paternal asthma                       | 11     | 2.2               |
| Maternal asthma                       | 19     | 3.7               |
| Paternal rhinoconjunctivitis          | 84     | 16.5              |
| Maternal rhinoconjunctivitis          | 89     | 17.5              |
| Potential sources of indoor allergens |        |                   |
| Pet ownership                         | 74     | 14.6              |
| Secondhand smoke                      | 224    | 44.8 <sup>a</sup> |
| Air-conditioning                      | 490    | 97.8 <sup>a</sup> |

<sup>a</sup>Expressed as a percentage of responders only, which is <508.

for individual risk factors were calculated. Factors found to be significantly associated with each disease condition were analyzed by bivariate logistic regression. Statistical significance was 2 sided and a threshold of  $P < .05$  was considered to be significant for all analyses. Statistical Package for the Social Sciences (SPSS) version 18.0 was used in performing statistical analyses. ArcGIS 9.2 was used in implementing the spatial studies.

## Results

A total of 508 preschool children of age 4 to 6 years with geocodable addresses in Yuen Long District were included in the study. They came from 5 randomly selected kindergartens: 259 (51.0%) of which were male, whereas 249 (49.0%) were female. A majority of children were born in Hong Kong (404, 79.5%). About half of the children (44.8%) had been exposed to secondhand tobacco smoke at home, and 9.6% were from their mothers. Almost all children (490, 97.8%) were living in places with air-conditioning. Other characteristics of the children, their parents, and households are shown in Table 1.

Table 2 shows the distribution, with gender and age, of the prevalence and incidence of asthma and rhinoconjunctivitis. Overall, the prevalence and incidence of asthma was highly correlated with each other ( $r = .79$ ,  $P < .0001$ ), reported as 41.9% (213 cases) and 30.9% (157 cases), respectively. Compared with asthma, rhinoconjunctivitis was less prevalent (189, 37.2%) and had a lower incidence (133, 26.2%) in the study population. Again, the prevalence and incidence of rhinoconjunctivitis was highly correlated with each other ( $r = .77$ ,  $P < .0001$ ). In view

**Table 2.** Distribution of Asthma and Rhinoconjunctivitis Cases in Preschool Children by Age and Gender

| Age (Years)               | Number | Asthma |            | Rhinoconjunctivitis |            |
|---------------------------|--------|--------|------------|---------------------|------------|
|                           |        | Number | Percentage | Number              | Percentage |
| Male preschool children   |        |        |            |                     |            |
| Prevalence                |        |        |            |                     |            |
| 4                         | 78     | 38     | 48.72      | 33                  | 42.31      |
| 5                         | 152    | 73     | 48.03      | 59                  | 38.82      |
| 6                         | 29     | 11     | 37.93      | 12                  | 41.38      |
| Total                     | 259    | 122    | 47.10      | 104                 | 40.15      |
| Incidence                 |        |        |            |                     |            |
| 4                         | 78     | 31     | 39.74      | 25                  | 32.05      |
| 5                         | 152    | 54     | 35.53      | 45                  | 29.61      |
| 6                         | 29     | 6      | 20.69      | 4                   | 13.79      |
| Total                     | 259    | 91     | 35.14      | 74                  | 28.57      |
| Female preschool children |        |        |            |                     |            |
| Prevalence                |        |        |            |                     |            |
| 4                         | 93     | 40     | 43.01      | 35                  | 37.63      |
| 5                         | 139    | 43     | 30.94      | 45                  | 32.37      |
| 6                         | 17     | 8      | 47.06      | 5                   | 29.41      |
| Total                     | 249    | 91     | 36.55      | 85                  | 34.14      |
| Incidence                 |        |        |            |                     |            |
| 4                         | 93     | 32     | 34.41      | 25                  | 26.88      |
| 5                         | 139    | 28     | 20.14      | 29                  | 20.86      |
| 6                         | 17     | 6      | 35.29      | 5                   | 29.41      |
| Total                     | 249    | 66     | 26.51      | 59                  | 23.69      |

of the high correlation between prevalence and incidence of both conditions, we focused our assessment of the relationship with environmental risk factors by using the prevalence data in the subsequent analyses.

Spatially, the distribution of the positive and negative cases for the prevalence of asthma and rhinoconjunctivitis by DCCA is displayed in Figure 1A and B. A majority of the children were living in 2 of the DCCAs named Tin Shui Wai and Yuen Long Town Centre.

### Indoor Exposure

Using  $\chi^2$  test, it was found that moisture or mold on wall in the first year of life was positively associated with the prevalence of asthma ( $\chi^2 = 15.69$ ;  $P < .001$ ) and rhinoconjunctivitis ( $\chi^2 = 11.85$ ;  $P < .001$ ; Table 3). The finding was supported by bivariate analysis, both for asthma (crude odds ratio [OR] = 3.08, 95% confidence interval [CI] = 1.74-5.49) and rhinoconjunctivitis (crude OR = 2.58, 95% CI = 1.49-4.48). After adjusting for the potential confounders, including gender, age, place of birth, maternal asthma, and maternal rhinoconjunctivitis, the presence of moisture or mold on wall in the first year of life gave a 2.5-fold and 2-fold higher risk for asthma (adjusted odds ratio [aOR] = 2.56, 95% CI = 1.40-4.68) and rhinoconjunctivitis (aOR = 2.09, 95% CI = 1.15-3.80) prevalence, respectively. There was no association between the 2 allergic conditions and currently having moisture or mold on wall at home (Table 4).

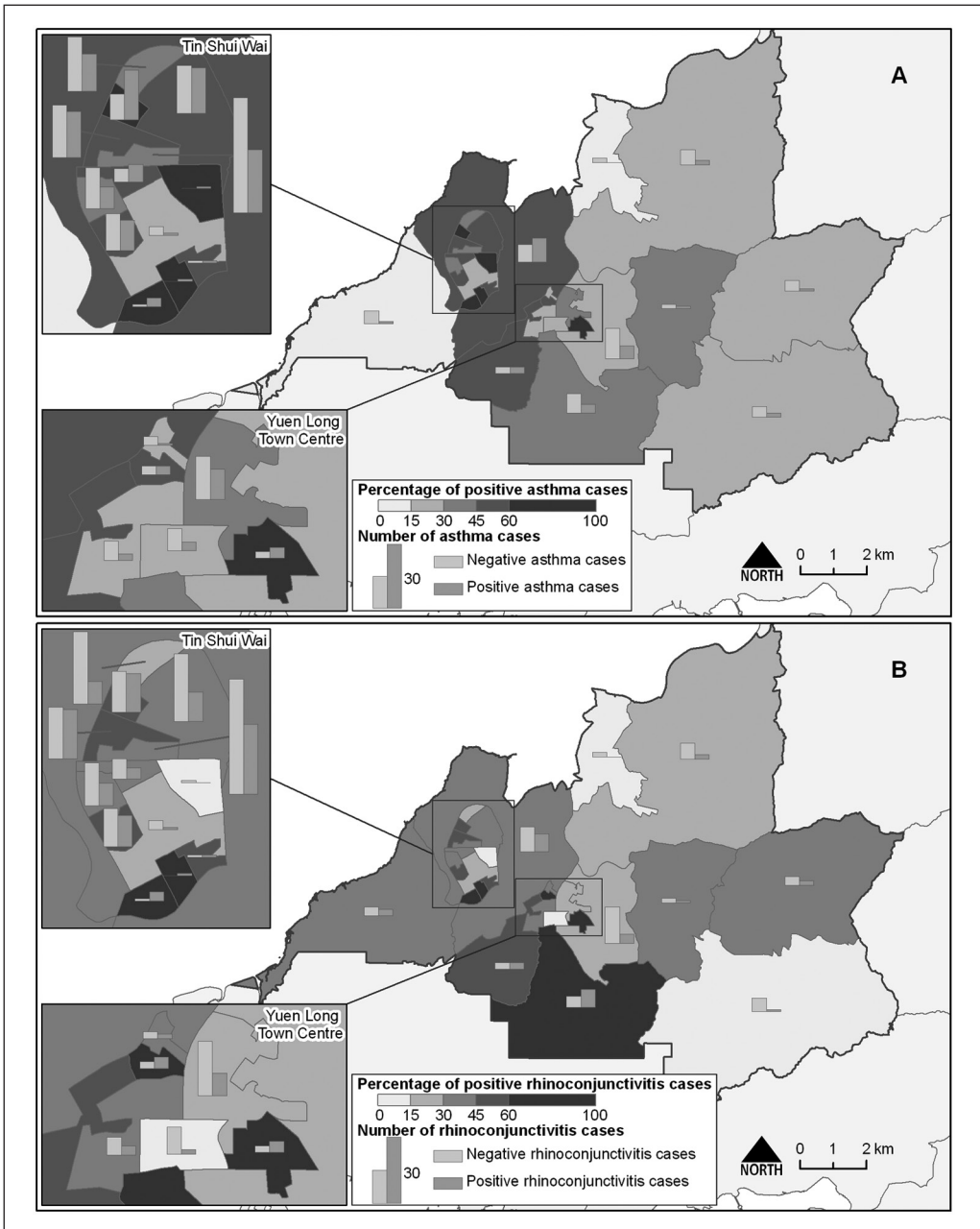


**Figure 1.** Spatial distribution of prevalent cases of allergy conditions in Yuen Long district in Hong Kong A, Asthma and nonasthma cases among preschool children. B, Rhinoconjunctivitis and nonrhinoconjunctivitis cases among pre-school children.

As regards other home conditions including pet keeping, air-conditioning and secondhand tobacco smoke, only current maternal smoking was associated with the prevalence of asthma, with  $\chi^2$  of 4.84 ( $P = .028$ ). The results of  $\chi^2$  test of other home conditions are shown in Table 3. Bivariate analysis showed that current maternal smoking was significantly associated with the

**Table 3.** Association of Asthma and Rhinoconjunctivitis With Indoor Environmental Factors by Chi-square Tests

| Indoor Environmental Factors    | Prevalence of Asthma |       | Prevalence of Rhinoconjunctivitis |      |
|---------------------------------|----------------------|-------|-----------------------------------|------|
|                                 | $\chi^2$             | P     | $\chi^2$                          | P    |
| Moisture or mold on wall        |                      |       |                                   |      |
| Current                         | 0.67                 | .420  | 1.53                              | .217 |
| Before 1 year of age            | 15.69                | .0001 | 11.85                             | .001 |
| Smoking family members: current | 3.57                 | .059  | 0.097                             | .756 |
| Maternal smoking                |                      |       |                                   |      |
| Current                         | 4.84                 | .028  | 0.046                             | .830 |
| Before 1 year of age            | 3.11                 | .078  | 0.35                              | .554 |
| During pregnancy                | 2.06                 | .151  | 0.27                              | .868 |
| Pet keeping                     |                      |       |                                   |      |
| Current                         | 0.28                 | .605  | 1.35                              | .245 |
| Before 1 year of age            | 2.82                 | .093  | 0.85                              | .355 |
| Air-conditioning: current       | 0.13                 | .716  | 0.48                              | .486 |

**Table 4.** Association of Asthma and Rhinoconjunctivitis With Indoor Environments by Bivariate Analysis

| Indoor Environments             | Prevalence of Asthma |                        |                 |                        | Prevalence of Rhinoconjunctivitis |                        |                 |                        |
|---------------------------------|----------------------|------------------------|-----------------|------------------------|-----------------------------------|------------------------|-----------------|------------------------|
|                                 | OR                   | 95% CI                 | OR <sup>a</sup> | 95% CI <sup>a</sup>    | OR                                | 95% CI                 | OR <sup>a</sup> | 95% CI <sup>a</sup>    |
| Moisture or mold on wall        |                      |                        |                 |                        |                                   |                        |                 |                        |
| Current                         | 1.30                 | 0.71-2.39              | —               | —                      | 1.47                              | 0.80-2.71              | —               | —                      |
| Before 1 year of age            | 3.08                 | 1.74-5.49 <sup>b</sup> | 2.56            | 1.40-4.68 <sup>b</sup> | 2.58                              | 1.49-4.48 <sup>b</sup> | 2.09            | 1.15-3.80 <sup>b</sup> |
| Smoking family members: current | 1.41                 | 0.99-2.02              | —               | —                      | 1.06                              | 0.74-1.53              | —               | —                      |
| Maternal smoking                |                      |                        |                 |                        |                                   |                        |                 |                        |
| Current                         | 1.96                 | 1.07-3.61 <sup>b</sup> | 2.00            | 1.04-3.84 <sup>b</sup> | 1.07                              | 0.58-1.99              | —               | —                      |
| Before 1 year of age            | 1.88                 | 0.92-3.80              | —               | —                      | 1.24                              | 0.61-2.54              | —               | —                      |
| During pregnancy                | 2.03                 | 0.76-5.41              | —               | —                      | 0.60                              | 0.17-2.10              | —               | —                      |

Abbreviations: OR, odds ratio; CI, confidence interval.

<sup>a</sup>Adjusted for gender, age, place of birth, maternal asthma, and maternal rhinoconjunctivitis.

<sup>b</sup>P < .05.

prevalence of asthma (crude OR = 1.96, 95% CI = 1.07-3.61; aOR = 2.00, 95% CI = 1.04-3.84), but not for the case of rhinoconjunctivitis (Table 4).

### Outdoor Exposure

The mean ( $\pm$  SD) distance from a child's residence to the nearest major traffic road was 369 m ( $\pm$ 343). Only 6.3% of children (n = 32) resided within 75 m of a major traffic road, whereas 67.4% (n = 342) of the residences were 150 m away from a major traffic road (Figure 2). The prevalence of asthma and rhinoconjunctivitis was not associated with the residential distance to a major traffic road (Table 5). The distance between residential location and high traffic flow road was then evaluated, considering that exposure to traffic-related pollutants may relate not only to the distance of residence from the traffic road but also to the traffic flow. There was

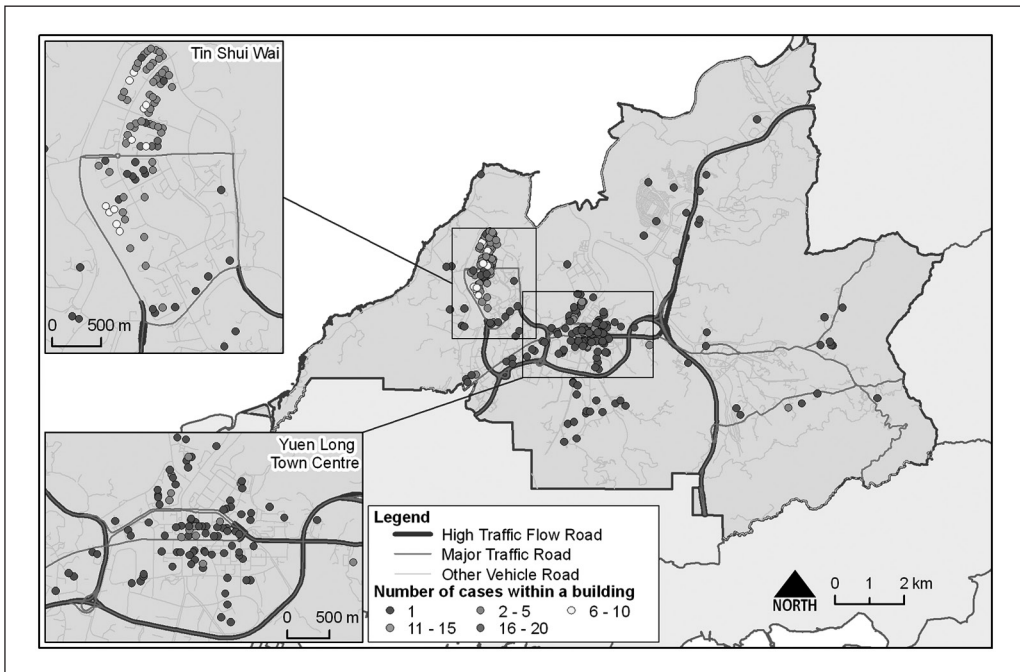


**Figure 2.** Distribution of all enrolled preschool children's residence and their spatial relationships with road traffic

again no association between the prevalence of asthma and rhinoconjunctivitis and the residential distance to the nearest high traffic flow road (Table 5). Comparing between the presence and absence of vehicle roads within a 75-m buffer zone of a residence, no association with prevalence of asthma and rhinoconjunctivitis could be observed (Table 5).

Possible exposure to traffic-related pollutants was assessed by determining the distance between residence and school. The prevalence of asthma and rhinoconjunctivitis was not significantly associated with the travel distance. Yet bivariate analysis did suggest a higher risk for a shorter distance, the significance of which declined when the distance between home and school was increased (Table 6).

## Discussion

In this study, the possible impacts of outdoor and indoor environments on the prevalence of asthma and rhinoconjunctivitis were explored, using data from a territory-wide allergy research program but focusing on a selected district. The approach enables us to assess the relative importance of different aspects of the built environment, as the background climatic condition in a small district should have been relatively uniform. Foremost, exposure to moisture and mold in the first year of life was found to be significantly associated with prevalence of asthma and rhinoconjunctivitis. This finding was consistent with previous studies conducted elsewhere. In a case-control study of 3360 children aged 5 to 8 years in Spain, 6.4% of them had current rhinoconjunctivitis, and the risk of allergic rhinoconjunctivitis was associated with moisture and mold on walls in the first year of life, with an aOR of 2.47 (95% CI = 1.63-3.73) and 2.46 (95% CI = 1.52-4.00), respectively.<sup>18</sup> In a population-based birth cohort study of 4089 children in Stockholm,<sup>19</sup> the cumulative incidence of asthma up to age 2 years was 8.5%, and an increased

**Table 5.** Association of Asthma and Rhinoconjunctivitis With Outdoor Environments Using Traffic Road Distance as Surrogate

| Traffic Road Distance (m)                                        | Number | Prevalence of Asthma |           | Prevalence of Rhinoconjunctivitis |            |
|------------------------------------------------------------------|--------|----------------------|-----------|-----------------------------------|------------|
|                                                                  |        | OR                   | 95% CI    | OR                                | 95% CI     |
| Distance between residence to the nearest major traffic road     |        |                      |           |                                   |            |
| <75                                                              | 32     | 0.79                 | 0.37-1.69 | 1.11                              | 0.51-2.40  |
| 75-150                                                           | 134    | 0.71                 | 0.46-1.11 | 1.07                              | 0.68-1.68  |
| 150-300                                                          | 137    | 0.75                 | 0.49-1.17 | 1.28                              | 0.81-1.99  |
| >300                                                             | 205    | 1                    | —         | 1                                 | —          |
| Distance between residence to the nearest high traffic-flow road |        |                      |           |                                   |            |
| <75                                                              | 4      | 1.34                 | 0.19-9.56 | 1.65                              | 0.23-11.82 |
| 75-150                                                           | 17     | 1.19                 | 0.45-3.12 | 0.51                              | 0.16-1.58  |
| 150-300                                                          | 34     | 0.48                 | 0.21-1.05 | 0.90                              | 0.43-1.86  |
| >300                                                             | 453    | 1                    | —         | 1                                 | —          |
| Total road length within 75-m buffer zone                        |        |                      |           |                                   |            |
| 0                                                                | 66     | 1                    | —         | 1                                 | —          |
| 0-105                                                            | 67     | 1.17                 | 0.59-2.34 | 1.24                              | 0.63-2.46  |
| 105-185                                                          | 118    | 1.30                 | 0.70-2.40 | 0.75                              | 0.41-1.39  |
| 185-268                                                          | 130    | 1.03                 | 0.56-1.88 | 0.79                              | 0.43-1.45  |
| ≥268                                                             | 127    | 1.07                 | 0.58-1.96 | 0.60                              | 0.32-1.11  |

Abbreviations: OR, odds ratio; CI, confidence interval.

**Table 6.** Association of Asthma and Rhinoconjunctivitis With Outdoor Environments Using Distance Between Residence and School as Surrogate

| Distance Between Residence and School (m) | Number | Prevalence of Asthma |           | Prevalence of Rhinoconjunctivitis |           |
|-------------------------------------------|--------|----------------------|-----------|-----------------------------------|-----------|
|                                           |        | OR                   | 95% CI    | OR                                | 95% CI    |
| <166.94                                   | 124    | 1                    | —         | 1                                 | —         |
| 166.94-486.44                             | 130    | 1.51                 | 0.91-2.50 | 1.38                              | 0.83-2.30 |
| 486.44-1378.21                            | 127    | 1.39                 | 0.84-2.31 | 1.11                              | 0.66-1.86 |
| ≥1378.21                                  | 127    | 1.39                 | 0.84-2.31 | 1.00                              | 0.59-1.68 |

Abbreviations: OR, odds ratio; CI, confidence interval.

risk of asthma among children in damp house environments during the first 2 year of life was reported, with an aOR of 1.75 (95% CI = 1.26-2.43). In a birth cohort study of 849 infants in America, 10.8% and 17.1% of the participants had wheeze and persistent cough, respectively, for more than 30 days during their first year of life, and the risk of wheeze and persistent cough was reported to be related to the presence of mold or mildew at homes.<sup>20</sup> The mechanisms by which dampness causes allergic diseases have not been well characterized. It has been suggested that dampness may facilitate the growth of molds and dust-mites, favoring higher allergen concentrations, which may trigger immunoglobulin E-mediated hypersensitivity reactions and nonspecific inflammatory reactions.<sup>10,21</sup> Furthermore, dampness may damage building materials and furnishings, leading to release of chemicals, which may trigger allergic attacks.<sup>22</sup> To reduce

exposure to allergens, allowing sunlight into the house may help control humidity and hence reduce the harmful impact of allergens.<sup>23</sup>

Unlike exposure to moisture and mold in the first year of life, current exposure was not associated with increased prevalence of the allergic conditions in our study. The aOR was 1.3, which was not statistically significant. It is plausible that allergen exposure early in life when the lungs are still under development may adversely affect lung function and lead to subsequent development of allergy.<sup>24</sup> On the other hand, it could be argued that parents with an allergic child might have cleaned up the indoor environment or have managed to maintain a low level of humidity at home after spotting moisture or mold during the child's first year of life. In fact, almost two thirds (34 out of 59) of our participants who had exposure to moisture and visible mold in the first year of life were no longer exposed to the same environment at the time of the study. Out of these 34 children, about 70% (24) had prevalent asthma and rhinoconjunctivitis.

Unlike moisture, ETS is, by itself, an important indoor pollutant. With the gradual introduction of legislative ban on public smoking in Hong Kong in the past decade, home exposure is likely to be emerging as the dominant source of ETS. In our study, children with smoking family members were at marginally increased risk of asthma (crude OR = 1.41, 95% CI = 0.99-2.02;  $P = .059$ ), whereas maternal smoking conferred even a statistically significant risk (aOR = 2.00, 95% CI = 1.04-3.84;  $P = .03$ ). It is probable that mothers tend to have more direct contacts with their children at home compared with other family members. Our findings are in line with other studies showing that children suffered more often from respiratory symptoms as a result of exposure to ETS at home and more specifically maternal smoking.<sup>9,25,26</sup> Other studies revealed that exposure to ETS in utero and during infancy were also associated with adverse respiratory outcomes.<sup>9,27,28</sup> However, similar observations were not made in our study. The discrepancy could have been methodological, especially as missing data for maternal smoking during the first year of age accounted for some 20% of all cases in the data set, and that only 3.3% of the pregnant mothers did smoke.

We also studied the impact of outdoor environments on the prevalence of asthma and rhinoconjunctivitis. With the use of the GIS, the residential addresses of the children and roadways could be located accurately, and hence, the distances between residence and traffic road of each participant, which were used as a proxy for exposure to traffic-related air pollutants, could be effectively estimated. Despite our *a priori* hypothesis of a linkage between allergic diseases and exposure to traffic-related air pollutants, no association was found. Elsewhere, a marked increase in the exposure to traffic-related air pollutants was observed within 75 m of larger roadways, whereas the concentrations declined precipitously within 150 to 300 m.<sup>6</sup> In our study, only 6.3% and 0.79% of children were actually living within 75 m from a major traffic road and a high traffic flow road, respectively. Hence, the power to detect the effect of traffic-related pollutants may be limited. Moreover, sophistications of the built environment may have affected the exposure risk to outdoor environments. For example, air-conditioning may have modified the effects of traffic-related pollutants to respiratory health among preschool children.<sup>29</sup> In Hong Kong, most of the dwellings have air-conditioning. In fact, more than 97% of the children in our data set lived in air-conditioned flats and about 87% slept in an air-conditioned bedroom. It was also plausible that parents with allergic children may tend to close the windows and switch on the air conditioner when the air quality was judged to be poor. Furthermore, residential exposure to traffic-related air pollutants may be influenced by other factors such as type of traffic and level of residences besides the proximity between residences and traffic roads and traffic flow. As children travelling to and from school were readily exposed to traffic-related pollutants, our *a priori* hypothesis was that the longer the distance between home and school, the higher the risk of prevalence of the allergic diseases. Yet our results, though not statistically significant, showed

that the risks seemed to be higher in a shorter distance and declined when the distance between home and school was increased. Means of travelling (eg, walking or by bus) may have modified the exposure to traffic-related pollutants. In an exposure-response study in India, there were significantly more respiratory problems among children who went to school on foot.<sup>30</sup> Therefore, further study incorporating means of travelling may be worthwhile to establish the relationship.

Our study did carry some limitations. The assessment of impacts of indoor environments on allergic diseases using the ISAAC questionnaires posed some intrinsic difficulties because the responses were based on memory, which could have been affected by the sensitivity of the parents or caregivers. Recall bias could not be excluded as parents of allergic children might tend to report exposure indicators differently compared with the parents of children without the allergic diseases. Selection bias might also be introduced since parents of the allergic children were more likely to change the susceptible housing conditions. On the other hand, the duration of living in the same residence might be expected to influence the risk of asthma and rhinoconjunctivitis associated with traffic-related exposure. Impact of exposure may be misestimated if children have stayed at the reported residence addresses for only a short period of time. Although children usually spent 3 to 6 hours at school during school days, the impacts of school environments cannot be ignored. Furthermore, their mobility pattern may also have contributed to the levels of exposure to outdoor pollutants, the importance of which cannot be substantiated in this study. Last, the ISAAC questionnaires have limited ability to quantify exposure to indoor allergens in the absence of indoor air quality assessment. Thus, a number of possible determinants in the development of allergic conditions in children, such as particulate matter, ozone, nitric oxides, and pollen and volatile organic compounds in indoor and outdoor environments, remain unexplored in this questionnaire-based study.

## Conclusion

Our study demonstrated that exposure at home to increased moisture or mold during infancy and ETS, especially that from maternal smoking, played an important role in the predisposition to asthma and rhinoconjunctivitis in preschool children. Environmental dampness, presence of mold, and indoor smoking are potentially modifiable factors, the rectification of which may reduce the occurrence of allergic diseases. Specifically, smoking cessation at home may provide significant health benefits to our children. In an urbanized society such as Hong Kong, the influence of outdoor environment is likely to be less important. It is nevertheless desirable to conduct specifically designed spatial studies to further evaluate the impacts of traffic-related pollutants.

## Acknowledgments

The authors wish to thank the children, parents, and staff of the schools for their participation in the survey. Candy Wong, Phoebe Pang, and Ping Yang are thanked for performing data transformation for the research and conducting initial explorations.

## Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interests with respect to the research, authorship, and/or publication of this article.

## Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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