ORIGINAL ARTICLE

Urbanisation but not biomass fuel smoke exposure is associated with asthma prevalence in four resource-limited settings

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ABSTRACT

Background Urbanisation is an important contributor to the prevalence of asthma worldwide, and the burden of this effect in low-income and middle-income countries undergoing rapid industrialisation appears to be growing. We sought to characterise adult asthma prevalence across four geographically diverse settings in Peru and identify both individual and environmental risk factors associated with adult asthma.

Methods We collected sociodemographics, clinical history and spirometry in adults aged ≥35 years. We defined asthma as meeting one of the three criteria: physician diagnosis, self-report of wheezing attack or use of asthma medications. We used multivariable logistic regression to assess individual and environmental factors associated with adult asthma.

Results We analysed data from 2953 participants (mean age 55 years; 49% male). Overall asthma prevalence was 7.1%, which varied with urbanisation: highest in Lima (14.5%), followed by urban Puno (4.0%), semiurban Tumbes (3.8%) and rural Puno (1.8%). In multivariable analysis, being male (OR=0.60, 95% CI 0.39 to 0.93) and living at high altitude (OR=0.26, 95% CI 0.16 to 0.42) were associated with lower odds of having asthma, whereas living in an urban setting (OR=4.72, 95% CI 3.15 to 7.23) and family history of asthma (OR=1.83, 95% CI 1.19 to 2.73) were associated with higher odds. Current daily exposure to biomass fuel smoke (OR=1.18, 95% CI 0.70 to 1.91) and smoking (OR=0.99, 95% CI 0.73 to 1.22) were not associated with asthma.

Conclusions These findings confirm that urbanisation is an environmental risk factor of asthma, questions biomass fuel smoke exposure as an important risk factor and proposes high altitude as possibly protective against the development of asthma.

Key messages

What is the key question?

- We wanted to characterise the prevalence of adult asthma in four resource-limited settings of Peru and identify the individual and environmental factors associated with adult asthma.

What is the bottom line?

- Our study confirmed that urbanisation is an environmental risk factor of asthma and disputed biomass fuel smoke exposure as an important risk factor.

Why read on?

- The diversity of settings with varying levels of urbanisation, elevation and biomass fuel use allowed for a comprehensive analysis of risk factors associated with the prevalence of asthma in low-income and middle-income countries.

INTRODUCTION

Asthma affects 300 million people worldwide, and it is responsible for 15 million disability-adjusted life years lost per year.[1] Asthma is commonly considered to be a childhood disease.[2] Specifically, 95% of all patients with asthma have their first asthma episode before 6 years, and outgrowing asthma is common among children with mild disease.[2 3] However, severe asthma in very early childhood has been shown to persist into adulthood.[3]

Asthma results from the complex interplay between environmental and genetic factors.[4] There is evidence that supports the link between urbanisation and asthma.[5–7] It is not fully understood what factors in urbanisation lead to increased prevalence of asthma, but contributing comorbidities include obesity,[8] increased allergen exposure,[6] traffic-related pollution[9] and poorer nutritional health.[10] The first report of differences in asthma in urban and rural environments occurred from Germany in 1965.[11] Since then, there have been many reports of higher rates of asthma symptoms in urban than rural environments, including Africa and Latin America.[5–7 11] Our study contributes to this body of evidence by characterising asthma in a novel population: Peruvian adults. We also investigated asthma prevalence across diverse settings with varying levels of altitude and biomass fuel use. The diversity of the settings has allowed us to conduct a comprehensive analysis of risk factors associated with asthma in low-income and middle-income countries (LMICs).

In LMICs, rapid industrialisation had led to the accelerated growth of cities. 66% of the world's

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population is estimated to live in an urban setting by 2050, and the majority of urban population growth will occur in LMICs, where the pace of urbanisation is most rapid.[12] It is expected that with this increased urbanisation, the global burden from asthma will worsen considerably, with prevalence estimated to increase by 50% every decade.[1 13]

We sought to characterise adult asthma prevalence across four geographically diverse but resource-poor settings, including coastal and highland regions. Our secondary objective was to identify risk factors associated with adult asthma. We hypothesised that urbanisation had a multifactorial effect on adult asthma prevalence, with the highest association seen in Lima, the most urbanised study site.

METHODS

Study setting

We conducted a population-based study aimed to determine the prevalence of chronic pulmonary and cardiovascular disease across four disparate regions in Peru. The study has been described in detail elsewhere.[14] The four sites vary by degrees of urbanisation, altitude and prevalence of daily biomass use (table 1). In Lima, the study site was Pampas de San Juan de Miraflores, a periurban community located 25 km south of Lima's city centre, with approximately 60 000 people in about 4 km^2, consisting mostly of Andean immigrants. This area is physically diverse and has experienced significant, but unplanned, sprawl. Tumbes is a semiurban sea-level community in the Northern coast of Peru and comprised a group of communities with about 20 000 people spread over 80 km^2, where the traditional agricultural landscape has become intermixed with rapidly growing urban sections. Puno is a South-Western city in the Andes, located on the shores of Lake Titicaca at 3825 m above sea level. Within Puno, we enrolled from two sites: an urban setting located at the city centre and a rural setting comprising inhabitants from surrounding communities.

Study design

We enrolled adults aged ≥35 years and full-time residents of the study sites. We used a computer-generated programme to select a simple random sample of sex-stratified and age-stratified participants, and approximately 1000 subjects were enrolled per site. In Puno, recruitment was stratified to include 500 participants each from urban and rural settings.[14] Exclusion criteria were pregnancy, physical disability that prevented the measurement of blood pressure or anthropometry, or active pulmonary TB. All participants provided verbal informed consent. Informed consents were verbal because of high illiteracy rates. The study was approved by the Institutional Review Boards of Universidad Peruana Cayetano Heredia and A.B. PRISMA, in Lima, Peru, and the Johns Hopkins Bloomberg School of Public Health in Baltimore, USA.

Data collection

Data collection took place over 12 months. Study questionnaires and procedures were conducted at our study centre or alternatively in participants' homes or nearest community centres. Participants responded to a questionnaire on sociodemographics, smoking history, respiratory symptoms, medical history and family history of disease.[14] Medical history was self-reported. A detailed questionnaire also evaluated the frequency and duration of cooking with biomass fuels. All questionnaires were conducted in a face-to-face interview by trained field workers. Field workers then measured weight and height using standardised techniques. Spirometry was conducted using the Easy-On-PC spirometer (ndd, Zurich, Switzerland) before and after 200 mcg of inhaled salbutamol via a spacer. Trained technicians measured prebronchodilator spirometry and postbronchodilator spirometry in participants following joint American Thoracic Society and European Respiratory Society guidelines.[15] We adapted a standardised grading system for quality control, review and interpretation.[16] Participants with low-quality spirometry were asked to repeat the test on another day for a total of three attempts. Overall, 96% of tests achieved an acceptable result and 95% met ATS/ERS criteria. We did not perform spirometry on any subject who had surgery of the heart, chest, lungs or eyes in the last 3 months or heart attack in the last 3 months, or blood pressure >180 mm Hg (systolic) or >100 mm Hg (diastolic). We did not use bronchodilators in participants with a heart rate >120 bpm. We rescheduled spirometry at a later date for participants who reported having a respiratory infection in the last 2 weeks, who had used short-term bronchodilators in the last 4 h or long-term bronchodilators in the last 12 h or who had smoked in the last hour.

Definitions

Adults were defined as having asthma if they met any of the following three criteria: (1) physician-diagnosis of asthma, (2) self-reported wheezing attack in the last 12 months, or (3) use of asthma medications in the last 12 months (table 2). We selected this definition because: (1) there were important differences in lung function between participants with and without asthma (table 2), (2) it minimised the asthma–COPD overlap syndrome (table 2) and (3) the reported prevalence using this definition was consistent with previous literature in our setting.[17] We defined COPD as having a postbronchodilator FEV_1/FVC<0.7.[14] We defined reversibility as an improvement of greater than 12% and 200 mL in forced expiratory volumes.

We defined high altitude as either living in urban or rural Puno. While there was a gradient of urbanisation across our

Table 1 Description of site characteristics

	Urbanisation	Setting	Vehicular traffic	Development	Altitude	Daily use of biomass fuels
Lima	Urban	Dense shanty town outside centre of Lima	Dense throughout the day (50)	Paved and dirt roads	Sea level	Rare
Urban Puno	Urban	Dense city centre	Dense between 7:00 to 19:00, otherwise minimal	Primarily paved roads	3825 m elevation	Rare
Tumbes	Semiurban	Semiurban setting with enrolment predominantly from farming communities far from city centre	Little to none; bicycles and walking are the primary forms of transportation	Primarily dirt roads	Sea level	Moderately prevalent
Rural Puno	Rural	Farming communities far from city centre	Little to none; bicycles and walking are the primary forms of transportation	All dirt roads	3825 m elevation	Highly prevalent

Table 2 Lung function depending on number of criteria met for diagnosis of asthma

	Meets at least 1 of 3 criteria	Meets no asthma criteria	p Value	Meets at least 2 of 3 criteria	Meets <2 criteria	p Value	Meets all 3 criteria	Meets <3 criteria	p Value
Overall prevalence, n (%)	210 (7.11)	2743 (92.89)		63 (2.13)	2890 (97.87)		21 (0.71)	2932 (99.29)	
COPD prevalence, n (%)	23 (10.95)	154 (5.61)	0.003	13 (20.63)	164 (5.67)	<0.001	8 (38.10)	169 (5.76)	<0.001
Prebronchodilator lung function, mean±SD									
FVC (L)	3.18±1.01	3.45±1.00	<0.001	3.04±0.99	3.44±1.00	0.002	2.61±0.85	3.44±1.00	<0.001
FEV_1 (L)	2.40±0.79	2.67±0.77	<0.001	2.20±0.79	2.66±0.78	<0.001	1.71±0.67	2.66±0.78	<0.001
FEV_1/height^2 (L/m^2)	0.99±0.27	1.08±0.25	<0.001	0.91±0.28	1.07±0.25	<0.001	0.73±0.27	1.07±0.25	<0.001
FEV_1/FVC (%)	75.57±9.31	77.55±6.62	0.003	71.89±11.19	77.53±6.69	<0.001	64.94±12.81	77.50±6.73	<0.001
Postbronchodilator lung function, mean±SD									
FVC (L)	3.27±1.00	3.49±0.98	0.002	3.21±0.99	3.48±0.99	0.032	2.85±0.91	3.48±0.99	0.005
FEV_1 (L)	2.56±0.80	2.80±0.79	<0.001	2.42±0.80	2.79±0.79	<0.001	1.99±0.73	2.79±0.79	<0.001
FEV_1/height^2 (L/m^2)	1.06±0.27	1.13±0.25	<0.001	1.00±0.28	1.12±0.25	<0.001	0.85±0.29	1.12±0.25	<0.001
FEV_1/FVC (%)	78.49±8.69	80.24±6.18	0.005	75.22±10.29	80.22±6.25	<0.001	69.65±13.05	80.19±6.27	0.001
Respiratory symptoms, n (%)									
Dyspnoea on exertion	61 (29.04)	204 (7.43)	<0.001	28 (44.44)	237 (8.20)	<0.001	10 (47.62)	255 (8.70)	<0.001
Hospitalisation in last 12 months due to respiratory symptoms	6 (2.86)	12 (0.43)	<0.001	5 (7.94)	13 (0.45)	<0.001	4 (19.10)	14 (0.48)	<0.001
Missed working days in the last 12 months due to respiratory symptoms	28 (13.33)	45 (1.64)	<0.001	15 (23.81)	58 (2.00)	<0.001	8 (38.10)	65 (2.21)	<0.001

settings (Lima was the most urbanised, followed by urban Puno, semiurban Tumbes and rural Puno), we defined Lima and urban Puno as urban. We created a wealth index according to assets, household facilities, household income and occupation.[18] We defined daily smoking as having at least one cigarette a day and hypertension as having systolic blood pressure ≥140 mm Hg or diastolic blood pressure ≥90 mm Hg, self-report of a physician diagnosis or current use of antihypertensive medications.

Biostatistical analysis

We used t tests or Mann–Whitney tests to compare continuous variables and χ^2 or Fisher exact tests to compare categorical variables between groups, as appropriate. We constructed a multivariable logistic regression model of asthma as a function of urbanisation and adjusted for age, sex, height, living at high altitude, smoking, body mass index (BMI), having hypertension, daily use of biomass fuels, family history of asthma and socioeconomic status. Statistical analyses were conducted in R (http://www.r-project.org).

RESULTS

Participant characteristics

We enrolled 4325 participants of whom 3601 (83%) had complete questionnaires. Of these, 2953 (79%) had complete spirometry and were considered to have complete data. Non-participation occurred when a participant declined answering specific questions or did not complete components of the study. There were no differences in age (p=0.21), sex (p=0.97), daily smoking (p=0.51), daily biomass use (p=0.66), wealth index (p=0.44), site (p=0.49), or prevalence of asthma (p=0.62) among participants with or without complete data.

Among the 2953 participants, average age was 55.4 years and 49.3% were male (table 3). There was marked variation by site in reported family history of asthma with a gradient that corresponded to the degree of urbanisation (p<0.001). The prevalence of obesity was higher at the sea-level sites versus high altitude sites (p<0.001). Daily smoking was low across all sites, with the lowest prevalence in rural Puno and the highest in Tumbes (p<0.001).[19] Median pack-years among smokers was low, at 0.2 pack-years. Daily biomass fuel use was highest in Rural Puno, moderate in Tumbes and minimal in Lima and urban Puno (p<0.001).

Asthma prevalence and characteristics

A total of 210 participants (7.1%) had asthma. At each of the four sites, asthma diagnosis was most commonly based on meeting one of the two following criteria: Physician diagnosis or wheezing in the last 12 months. Details of criteria met by site can be found in table 3. Participants who met criteria for asthma were more likely to meet spirometry definition for COPD (11.0%) compared with those without asthma (5.6%). We found a noticeable variation in asthma prevalence by site with a gradient that corresponded to the degree of urbanisation (table 3). We compared the characteristics of participants with asthma to those without asthma (table 4). Participants with asthma were more likely to be female and had a higher BMI. Those with asthma had worse lung function and were more likely to report dyspnoea on exertion, hospitalisation and missed working days due to respiratory symptoms (table 2). Participants with asthma were also more likely to report family history of asthma (table 4). Notably, those with asthma had a lower prevalence of daily smoking and a lower prevalence of daily biomass fuel usage.

Table 3 Characteristics of study population by site

	Lima	Urban Puno	Tumbes	Rural Puno	Total	p Value
Participants	998	503	946	506	2953	
General characteristics						
Age (years), mean±SD	55.0±11.8	55.3±12.1	55.8±13.2	55.5±12.5	55.4±12.4	0.573
Male, n (%)	492 (49.3)	249 (49.5)	475 (50.2)	240 (47.4)	1456 (49.3)	0.794
Weight (kg), mean±SD	68.2±11.8	68.7±12.0	71.1±13.1	61.0±10.6	68.0±12.6	<0.001
BMI (kg/m^2), mean±SD	28.4±4.4	27.9±4.4	28.3±4.7	25.2±3.7	27.8±4.6	<0.001
Obese (BMI ≥30 kg/m^2), n (%)	329 (39.6)	135 (16.3)	309 (37.2)	57 (6.9)	830 (27.4)	<0.001
Criteria for asthma diagnosis, n (%)						
Physician diagnosis	82 (8.2)	13 (2.6)	16 (1.7)	3 (0.6)	114 (3.9)	<0.001
Used asthma medications within last 12 months	37 (3.7)	6 (1.2)	8 (0.8)	0 (0.0)	51 (1.7)	<0.001
Wheezing attack within the last 12 months	90 (9.0)	9 (1.8)	24 (2.5)	6 (1.2)	129 (4.4)	<0.001
Asthma prevalence, n (%)	145 (14.5)	20 (4.0)	36 (3.8)	9 (1.8)	210 (7.1)	<0.001
Wealth index, n (%)						
Low	119 (11.9)	120 (23.9)	307 (32.5)	356 (70.4)	902 (30.5)	<0.001
Middle	366 (36.7)	129 (25.6)	387 (40.9)	136 (26.9)	1018 (34.5)	
High	513 (51.4)	254 (50.5)	252 (26.6)	14 (2.8)	1033 (35.0)	
Self-reported physician diagnoses, n (%)						
History of stroke	10 (1.0)	1 (0.2)	2 (0.2)	0 (0.0)	13 (0.4)	0.018
History of TB	69 (6.9)	3 (0.6)	7 (0.7)	7 (1.4)	86 (2.9)	<0.001
History of chronic bronchitis	69 (6.9)	30 (6.0)	13 (1.4)	3 (0.6)	115 (3.9)	<0.001
History of COPD	2 (0.2)	1 (0.2)	0 (0.0)	1 (0.2)	4 (0.1)	0.467
History of emphysema	1 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.0)	1.000
Family history of asthma, n (%)	146 (14.6)	18 (3.6)	51 (5.4)	8 (1.6)	223 (7.6)	<0.001
Exposures						
Daily smoking, n (%)	32 (3.2)	11 (2.2)	53 (5.6)	1 (0.2)	97 (3.2)	<0.001
Prevalence of ≥10 pack-years smoking, n (%)	28 (2.8)	15 (3.0)	50 (5.3)	6 (1.2)	99 (3.4)	<0.001
Smoking per 10 pack-years, mean±SD	0.13±0.64	0.09±0.44	0.22±0.86	0.03±0.22	0.13±0.65	<0.001
Daily biomass fuel use, n (%)	61 (6.1)	25 (5.0)	221 (23.4)	483 (95.5)	790 (26.8)	<0.001

BMI, body mass index.

Factors associated with asthma

We performed a single variable analysis and identified several potential demographic, environmental, behavioural and clinical factors (table 5). We considered the major components that made each site unique (tables 1 and 3) and included those components as risk factors for asthma in our analyses. The single variable analysis suggested that sex, height, altitude, BMI, urbanisation, family history of asthma and biomass fuel usage may be associated with asthma prevalence (table 5). We noticed a gradient in asthma prevalence between urban and rural environments both at high altitude (4.0% vs 1.8%; p=0.04) and sea-level (14.5% vs 3.8%; p<0.001). In multivariable analysis, we found being male and living at a high altitude were both associated with lower odds of having asthma. Conversely, living in an urban setting and having a family history of asthma were associated with a higher odds of having asthma. Notably, BMI and biomass fuel usage were not associated with asthma in multivariable analyses. We repeated this analysis excluding participants with COPD (postbronchodilator $FEV_1/FVC<0.7$) and found that the results were unchanged: male sex (OR=0.61; p=0.04) and high altitude (OR=0.24; p<0.001) were associated with a decreased odds of having asthma and urban living (OR=4.33; p<0.001) and family history of asthma (OR=1.88; p=0.004) were associated with increased odds of having asthma. Biomass fuel exposure remained non-significant (OR=1.08; p=0.79).

DISCUSSION

In this multicentre, population-based study in Peru, we found significant variation in asthma prevalence across four resource-poor sites with varying degrees of urbanisation, altitude and biomass fuel usage. We observed a clear gradient that corresponded to the degree of urbanisation for both asthma prevalence and family history of asthma prevalence, suggesting that urbanisation increases asthma prevalence. Asthma was associated with being female, living at low altitude, having a family history of asthma and living in an urban setting. We did not find any association between daily biomass fuel and asthma.

We found that the asthma prevalence was 7.1% among adults across four sites in Peru. A study in Cameroon characterised adulthood asthma and determined that the overall prevalence was 2.7%, based on self-reported diagnosis of asthma by a health professional.[20] This value was similar to our findings of self-reported physician diagnosis of asthma (3.9%).[20] According to a study by To *et al*,[17] who analysed World Health Survey data collected between 2002 and 2003, the estimated prevalence of asthma in Latin America among adults was 4.3% for doctor-diagnosed asthma, 4.4% for clinical asthma and 7.6% for wheezing symptoms. Our estimates of asthma prevalence are in line with the estimates of To *et al*.[17] Ultimately, by using a more comprehensive definition of asthma, as we chose to do for our study, we increased sensitivity for detecting asthma prevalence, which is important in LMICs where not everyone has access to a physician for accurate diagnosis.[17]

In the literature, urbanisation is recognised as a risk factor for asthma, and the gradient we observed by site and the association found in our multivariable analysis results confirmed the negative impact between urbanisation and asthma prevalence.[5–7] It is still not well understood what factors in urbanisation contribute

Table 4 Characteristics of asthma and non-asthma subjects

	Asthma	No Asthma	p Value
Overall prevalence, n (%)	210 (7.1)	2743 (92.9)	
Demographic characteristics			
Gender, n (%)			
Male	81 (38.6)	1375 (50.1)	0.002
Female	129 (61.4)	1368 (49.9)	
Age (years), mean±SD	55.7±12.3	55.4±12.4	0.713
Clinical measurements, mean±SD			
Height (cm)	154.4±8.6	156.6±8.7	<0.001
Weight (kg)	68.5±11.5	67.9±12.6	0.51
BMI (kg/m^2)	28.8±4.6	27.7±4.6	<0.001
BMI categories, n (%)			
Low	1 (0.4)	6 (0.2)	0.404
Normal	41 (19.5)	774 (28.2)	0.008
Overweight	92 (43.8)	1209 (44.1)	0.998
Obese	76 (36.2)	754 (27.5)	0.009
Systolic blood pressure (mm Hg)	116.9±19.8	117.3±18.7	0.788
Hypertension, n (%)	52 (24.8)	535 (19.5)	0.080
Respiratory indicators, mean±SD			
Pre-FVC (L)	3.18±1.01	3.45±1.00	<0.001
Pre-FEV$_1$ (L)	2.40±0.79	2.67±0.77	<0.001
Preratio (%)	75.57±9.31	77.55±6.62	0.003
Post-FVC (L)	3.27±1.00	3.49±0.98	0.002
Post-FEV$_1$. (L)	2.56±0.80	2.80±0.79	<0.001
Postratio (%)	78.49±8.69	80.24±6.18	0.005
Height adjusted (pre-FEV$_1$/height^2) (L/m^2)	0.99±0.27	1.08±0.25	<0.001
Height adjusted (post-FEV$_1$/height^2) (L/m^2)	1.06±0.27	1.13±0.25	<0.001
Reversibility, n (%)	35 (16.7)	297 (10.8)	0.014
Self-reported physician diagnoses, n (%)			
History of hypertension	70 (33.3)	462 (15.7)	<0.001
History of heart disease	17 (8.1)	99 (3.4)	0.002
History of stroke	1 (0.5)	12 (0.4)	0.618
History of TB	15 (7.1)	71 (2.6)	<0.001
History of chronic bronchitis	42 (20.0)	73 (2.7)	<0.001
History of COPD	1 (0.5)	3 (0.1)	0.256
History of emphysema	0 (0.00)	1 (0.04)	1.000
Family history of asthma, n (%)	35 (16.7)	188 (6.9)	<0.001
Wealth index, n (%)			
Low	54 (25.7)	848 (30.9)	0.187
Middle	72 (34.3)	946 (34.5)	
High	84 (40.0)	949 (34.6)	
Exposures			
Daily smoking, n (%)	2 (1.0)	95 (3.5)	0.044
Prevalence of ≥10 pack-years' smoking, n (%)	3 (1.4)	96 (3.5)	0.158
Smoking per 10 pack-years, mean±SD	0.11±0.82	0.14±0.64	0.690
Daily biomass fuel usage, n (%)	30 (14.3)	760 (27.7)	<0.001

BMI, body mass index.

to the increased prevalence of asthma but contributing comorbidities include obesity,[8] increased antigen exposure with decreased sensitivity,[6] traffic related pollution[9] and overall poorer nutritional health.[10] We also found that family history of asthma was associated with asthma prevalence. This finding aligns well with the literature, where it is well established that hereditary factors contribute to the pathogenesis of asthma.[21] Obesity and cardiovascular diseases have been linked to urbanisation[22] and obesity has been associated with asthma.[8] We found statistically significant differences in BMI, obesity and history of self-reported physician diagnosis of hypertension and heart disease between participants with and without asthma. However, BMI and hypertension were not significantly associated with asthma in the multivariable analysis. This may be due to the strength of the influence of other risk factors and warrants further attention to the topic.

We observed a strong association between high altitude and decreased asthma prevalence. There is limited and conflicting literature on the role of living at high altitude on the risk of asthma. The ISAAC study found no association between altitude and asthma prevalence,[23] while another study in Mexico found that higher altitude was associated with a lower asthma prevalence.[24] There could be several explanations for why there is a lower asthma prevalence at high altitudes. One hypothesis is that high altitude environments have a lower presence of allergenic exposures[25] including pollen and mites,[26 27] or may have true differences in airway inflammation[28] or airway responsiveness.[29] It is also possible that natural selection may play a role.[30] Well-designed longitudinal studies are needed to further clarify the relationship between asthma and high altitude.

There is more controversy regarding the role of biomass as a risk factor for asthma.[31] A literature search by Diette *et al*[31] found that studies examining biomass and asthma in adults are not uniformly positive and the associations with specific fuel type are inconsistent. The ISAAC study found a strong association between the use of biomass fuels for cooking and asthma in children[32] and studies in other LMICs have suggested a relationship between biomass fuel exposure and asthma.[31 33] However, similar to other studies,[34 35] our multivariable analysis indicates there is no association between daily biomass fuel smoke exposure and asthma prevalence in adults aged 35 years and older.[31] Given the cross-sectional nature of this study, it is difficult to draw a conclusion; however, this relationship may suggest that biomass fuel exposure is not a risk factor for asthma or could merely reflect the idea that people with asthma avoid biomass fuel smoke because of their symptoms. Further longitudinal studies are needed to address this controversy.

Our study has several strengths. The sample size of the study was robust, with approximately 3000 participants total with 1000 participants per study site. Each site had diverse geographical and social characteristics. Our data collection was comprehensive, including demographic, behavioural, environmental and clinical data. An asthma characterisation study of this scale has not previously been conducted in Peru. Some limitations to this study include inherent biases of cross-sectional studies including under-reporting of self-reported symptoms. Given that our study relies on participant report of symptoms and physician diagnosis, our results are prone to reporting bias, and it is possible that more accessible settings (Lima and urban Puno) would report more clinical findings compared with rural settings (Tumbes and rural Puno). This could mean that the variation in asthma prevalence seen across sites may be exaggerated as two of the asthma diagnostic criteria required a physician evaluation (physician diagnosis and asthma medication usage). We are also missing data on atopy or allergic disease and inflammation, which would have enabled a more thorough analysis of the risk factors.

CONCLUSION

Previous studies have focused on characterising asthma in children. This study characterised adult asthma prevalence across diverse settings in a low-income and middle-income country, and associated urbanisation, female sex, low altitude and family

Table 5 Factors associated with greater asthma prevalence across four sites in Peru

	Single variable			Multivariable		
n=2953	OR	95% CI	p Value	OR	95% CI	p Value
Age (per 10 years)	1.02	(0.91 to 1.14)	0.71	1.03	(0.90 to 1.18)	0.68
Male vs female sex (female as reference)	0.62	(0.47 to 0.83)	0.001	0.60	(0.39 to 0.93)	0.02
Height (cm)	0.97	(0.96 to 0.99)	<0.001	1.01	(0.98 to 1.03)	0.582
High altitude vs sea-level (sea-level as reference)	0.29	(0.19 to 0.42)	<0.001	0.26	(0.16 to 0.42)	<0.001
Smoking per 10 pack-years	0.94	(0.68 to 1.16)	0.62	0.99	(0.73 to 1.22)	0.93
BMI (kg/m^2)	1.05	(1.02 to 1.08)	<0.001	1.02	(0.98 to 1.05)	0.35
Urban vs rural (rural as reference)	3.86	(2.78 to 5.47)	<0.001	4.72	(3.15 to 7.23)	<0.001
Family history of asthma	2.72	(1.81 to 3.98)	<0.001	1.83	(1.19 to 2.73)	0.004
Hypertension	1.36	(0.97 to 1.87)	0.07	1.24	(0.85 to 1.79)	0.27
Daily vs other biomass fuel usage	0.43	(0.29 to 0.63)	<0.001	1.18	(0.70 to 1.91)	0.51
High wealth index	1.26	(0.94 to 1.68)	0.11	0.80	(0.54 to 4.02)	0.16

BMI, body mass index.

history of asthma with asthma in Peruvian adults. We observed a clear gradient that corresponded to the degree of urbanisation for both asthma prevalence and family history of asthma prevalence. We found a limited association between biomass fuel use and asthma prevalence, even when adjusting for altitude. We found that using one of three asthma criteria for the diagnosis of asthma to be sufficient, especially in a low-income and middle-income setting where there is minimal accessibility to a physician for formal diagnosis and treatment. Overall, our results can guide future investigations on adult asthma and provide methods for diagnosing asthma in epidemiological studies in low-income and middle-income countries.

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Contributors WC, JJM, and AB-O conceived, designed and supervised the overall study. WC, JJM, and AB-O coordinated and supervised fieldwork activities in Lima, Tumbes and Puno. CG, CHM, and WC developed the idea for this manuscript, led the statistical analysis, and wrote the first draft. RAW, RHG, DJ, JJM, AB-O, and NNH participated in writing of the manuscript, provided important intellectual content and gave their final approval of the version submitted for publication. WC had ultimate oversight over study conduct, analysis plan and writing of manuscript.

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