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ENVIRONMENTAL CONTROL

Does urban extent from satellite images relate to symptoms of asthma, rhinoconjunctivitis and eczema in children? A cross-sectional study from ISAAC Phase Three

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Abstract

Objective: The relationship between urbanisation and the symptom prevalence of asthma, rhinoconjunctivitis and eczema is not clear, and varying definitions of urban extent have been used. Furthermore, a global analysis has not been undertaken. This study aimed to determine whether the symptom prevalence of asthma, rhinoconjunctivitis and eczema in centres involved in the International Study of Asthma and Allergies in Childhood (ISAAC) were higher in urban than rural centres, using a definition of urban extent as land cover from satellite data. **Methods:** A global map of urban extent from satellite images (MOD500 map) was used to define the urban extent criterion. Maps from the ISAAC centres were digitised and merged with the MOD500 map to describe the urban percentage of each centre. We investigated the association between the symptom prevalence of asthma, rhinoconjunctivitis and eczema and the percentage of urban extent by centre. **Results:** A weak negative relationship was found between the percentage of urban extent of each ISAAC centre and current wheeze in the 13–14-year age group. This association was not statistically significant after adjusting for region of the world and gross national income. No other relationship was found between urban extent and symptoms of asthma, rhinoconjunctivitis and eczema. **Conclusions:** In this study, the prevalence of symptoms of asthma, rhinoconjunctivitis and eczema in children were not associated with urbanisation, according to the land cover definition of urban extent from satellite data. Comparable standardised definitions of urbanisation need to be developed so that global comparisons can be made.

Keywords

Asthma, children, eczema, ISAAC, rhinoconjunctivitis, satellite map, urbanisation

History

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Introduction

Asthma is the most common chronic disease in childhood, with more than 10% of children affected in the world, although asthma prevalence differs widely between regions [1]. Most studies showed a higher prevalence in urban areas [2–9], while a few reported no difference [10–12] or even higher prevalence in rural environments [13]. This evidence is, however, geographically discontinuous as the regions are not randomised areas of the world. There has not been as yet any global analyses to relate asthma to urbanisation. Although there are fewer studies of the related diseases rhinitis and eczema; a meta-analysis of eczema showed no effect of urbanisation [14]. The causes of the increases in prevalence of these diseases are unknown [15], although progressive urbanisation may be one driver of these trends [9,16,17].

How is urbanisation defined?

A review of the literature up to 2011 by Lim and colleagues on the symptom prevalence of asthma, rhinoconjunctivitis and eczema in urban and rural areas was undertaken to determine if a standard definition of urbanisation was used. They found 73 relevant articles, however only 26% of them used a specific definition to distinguish between urban and rural extent [18], and these definitions varied from one study to another, making valid international comparisons difficult. Thus a standardised definition is required.

Some criteria could be used to establish a standardised definition of urbanisation of multi-centre comparisons, such as infrastructure factors, level of pollution, socioeconomic factors and/or lifestyle [19], but such criteria have not been developed or used. Political and administrative boundaries are not reliable means to establish town limits because they change frequently over time, and they may over- or underestimate the extent of urban land. Similarly, land use, which involves the management of natural environment into settlements, crops, pastures and managed woods, may not be a good indicator to define

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urban extent as recreational areas (e.g., parks or golf courses) would be included as urban space when they are in fact vegetation. Global maps from census data correspond to population density, which is not synonymous of urban extent, and the quality of data is not reliable in some locations. Finally, nighttime lights maps may correlate more with the income of that region than with the urban land, and gas flares and fires in rural areas would be included in the nighttime lights maps, so this definition too has limitations.

A new measure of using land cover, based on the physical attributes of the Earth's surface, is an approach that has been made feasible for global analyses, because of the recent availability of satellite data, enabling the application of consistent definitions and methodologies [20]. Nevertheless, the differing scales of satellite imagery has led to inconsistent or ambiguous definitions of urban extent, as some of them are based on data fusion or unsupervised classification of the data and others are not up-to-date [20,21]. Moreover, those derived from coarse spatial resolutions have high rates of omission of small cities and significant errors along city edges. Considering all these factors, the map of global urban extent from MODIS 500 m data (MOD500) stands out among the others as being potentially useful [20,21].

This is an up-to-date high resolution map that uses a supervised classification based on a decision-tree algorithm, which was used in their previous map MOD1k, to classify satellite data. This algorithm was a hierarchical automated method that split a data set repeatedly into smaller divisions until the partition contains only observations from a single class (e.g., 'urban') [21–23]. In MOD500, urban extent is defined as places that are dominated by the built environment, that incorporates all non-vegetative, human-constructed elements, including among other things roads, buildings, runways, and industrial facilities where these elements cover at least 50% of a given pixel. It was produced from Collection 5 (C5) MODIS data circa 2001–2002 with a spatial resolution of 500 m [21–23].

In our study, we aimed to determine whether the prevalence of asthma, rhinoconjunctivitis and eczema was higher in urban rather than rural centres that participated in Phase Three of the International Study of Asthma and Allergies in Childhood (ISAAC) according to the land cover definition of urban extent, using the MOD500 map.

Methods

Digitisation of ISAAC maps

All ISAAC Phase Three centres (237) completed a centre report which included a written description of their study area boundaries. Most of these centres (221 (93%)) also provided a hard copy map of the study area (political map) with the boundaries of the study area hand drawn in. The ISAAC maps were digitised using ArcGIS software (ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute), which is a geographic information system (GIS) for working with maps and geographic information.

First, a Bing Street Map was imported into ArcGIS ArcMap V10.0 program and used as the base map (WGS 1984 map projection) and a single shapefile was created to trace centre

boundaries. The 237 ISAAC centres were then added to the shapefile using one of the following methods:

- (i) 'Centres with an available hardcopy map that encompasses an Administrative Area' (70 (30%) centres): the database of Global Administrative Areas (GADM) (<http://www.gadm.org>) is a spatial database of the location of the world's administrative boundaries for use in ArcGIS and similar software. The GADM was searched for the centre name and if the shape matched the centre map, the GADM shape was imported into the shapefile instead of tracing the provided map.
- (ii) 'Centres with an available hardcopy map' that did not fit the criteria above (134 (56%) centres): when a hardcopy map of the centres was compiled, it was scanned at the highest resolution possible (600 dpi) into pdf files. If the scanned map was geographically correct and the boundaries easily identifiable, the centre boundaries were traced as a polygon using the scanned map as a guide. If the scanned map was not geographically correct or identifiable, it was imported into ArcMap as tiff files (converted from pdf versions using Photoshop CS5.1) and was rectified onto the base map. Then centre boundaries on the rectified map were traced as a polygon.
- (iii) 'Centres with a written description and no map' (16 (7%) centres) and 'centres that provided a country-level map of insufficient detail to ascertain the centre boundaries' (17 (7%) centres): centre boundaries were directly drawn on the shapefile according to the boundary definition in the ISAAC registration documents.
- (iv) The centre boundary polygons created using these three methods were organised in an attribute table that could be exported as an excel file.

Merging ISAAC centre maps and MOD500

Each ISAAC centre polygon was matched with the MOD500 map in order to calculate the percentage of urbanisation of each ISAAC centre. First, MOD500 data (2002v5_urban_only_geog_mos.bip.zip) was downloaded from the Centre for Sustainability and the Global Environment (SAGE) website after authorisation (<http://www.sage.wisc.edu/people/schneider/research/data.html>). The MOD500 data was then imported into ArcGis ArcMap program as a raster file, or bitmap image made of pixels, and was slightly reduced in the X axis (0.99994) to make it match perfectly with the ISAAC centres map. Then the adjusted MOD500 map was turned into a vector file using the conversion tool "From Raster to Polygon," to get a shape map. Finally the shape map was merged with the ISAAC centres map using the tool "Intersect." This resulted in a new map being produced with an attribute table where each centre was subdivided into multiple smaller areas and each labelled as urban or rural, using the MOD500 criteria.

Urban extent percentage of ISAAC centres

The attribute table of the merged map was exported as an excel file to be analysed with Microsoft Excel 2010. The sum of all urban areas within each centre was obtained and compared to

Table 1. Relationship of urbanicity with the outcomes and adjustment by region and GNI*.

	Ages 6–7 Percentage Change in Outcome for 10% difference in Urbanicity (95% CI)	Ages 13–14 Percentage Change in Outcome for 10% difference in Urbanicity (95% CI)
CURRENT WHEEZE		
Urban extent	–2.3% (–5.0%, 0.5%) <i>P</i> = 0.11	–2.3% (–4.5%, 0.1%) <i>P</i> = 0.06
Urban extent adjusted by region and GNI	–2.2% (–4.7%, 0.4%) <i>P</i> = 0.10	–1.3% (–3.6%, 1.0%) <i>P</i> = 0.27
SEVERE WHEEZE		
Urban extent	–0.1% (–1.6%, 1.3%) <i>P</i> = 0.86	0.0% (–1.0%, 1.0%) <i>P</i> = 0.99
Urban extent adjusted by region and GNI	–1.3% (–2.9%, 0.3%) <i>P</i> = 0.11	–0.5% (–1.5%, 0.5%) <i>P</i> = 0.30
CURRENT RHINOCONJUNCTIVITIS		
Urban extent	–2.0% (–4.6%, 0.7%) <i>P</i> = 0.15	–0.5% (–2.6%, 1.5%) <i>P</i> = 0.61
Urban extent adjusted by region and GNI	–0.8% (–3.0%, 1.5%) <i>P</i> = 0.50	0.9% (–1.2%, 3.1%) <i>P</i> = 0.39
SEVERE RHINOCONJUNCTIVITIS		
Urban extent	2.7% (–1.6%, 7.2%) <i>P</i> = 0.22	0.8% (–2.5%, 4.1%) <i>P</i> = 0.65
Urban extent adjusted by region and GNI	1.3% (–2.9%, 5.5%) <i>P</i> = 0.56	–1.7% (–4.9%, 1.6%) <i>P</i> = 0.30
CURRENT ECZEMA		
Urban extent	–4.4% (–7.4%, –1.4%) <i>P</i> = 0.01	–1.8% (–4.4%, 0.8%) <i>P</i> = 0.17
Urban extent adjusted by region and GNI	–0.9% (–3.8%, 2.0%) <i>P</i> = 0.53	0.1% (–2.7%, 3.0%) <i>P</i> = 0.95
SEVERE ECZEMA		
Urban extent	–3.9% (–7.6%, –0.1%) <i>P</i> = 0.04	–0.8% (–4.1%, 2.6%) <i>P</i> = 0.65
Urban extent adjusted by region and GNI	–2.8% (–6.4%, 0.9%) <i>P</i> = 0.13	0.5% (–3.0%, 4.2%) <i>P</i> = 0.77

*Based on generalised linear mixed model analysis of 233 centres (13–14 yrs) and 144 centres (6–7 yrs).

the total extent of the ISAAC centre to obtain a percentage of urbanisation. Face validity of the urban extent percentages were assessed by making a visual comparison of 18 centres in New Zealand, Spain, United Kingdom, Mexico and India with Google Earth satellite images and were found to be appropriate for each centre.

Analysis of symptoms of asthma, rhinoconjunctivitis and eczema

ISAAC Phase Three, an international, multicentre, cross sectional survey involved two groups of children aged 6–7 (parental completed questionnaires) and 13–14 years (self completed questionnaire) [1]. *Current wheeze* was defined as an affirmative response to ‘Have you (has your child) had wheezing or whistling in the chest during the last 12 months?’. Amongst current wheezers, responses to three other questions were used to determine severe wheeze. An answer of ≥ 4 asthma attacks to the question ‘How many attacks of wheezing have you (has your child) had during the last 12 months?’; and/or sleep disturbance ≥ 1 nights/week to ‘In the past 12 months, how often on average have you (has your child’s) sleep been disturbed due to wheezing?’, and/or a positive response to ‘In the past 12 months, has wheezing been severe enough to limit your (your child’s) speech to only one or two words at a time between breaths?’ [32].

Current rhinoconjunctivitis was assessed by the combination of positive answers to questions ‘In the past 12 months, have you (has your child) had a problem with sneezing or a runny or blocked nose, when you (he or she) did not have a cold or “the flu?” and ‘In the past 12 months, has this nose problem been accompanied by itchy-watery eyes?’. These questions and the answer ‘a lot’ to ‘In the past 12 months, how much did this nose problem interfere with your (your child’s) daily activities?’ were used to define *severe rhinoconjunctivitis* [32]. *Current eczema* was assessed by positive answers to the questions ‘Have you (Has your child) had this itchy rash at any time in the

past 12 months?’ and ‘Has this itchy rash at any time affected any or the following places: the folds of the elbows, behind the knees, in front of the ankles, under the buttocks, or around the neck, ears or eyes?’

Current eczema combined with sleep disturbance one or more nights per week was used as a definition of *severe eczema* [32]. The regressions of the two levels (current and severe) of the three disease outcomes on the centre urban percentage were assessed using a generalised linear mixed model with centre as random effect and using a log link and binomial distribution. Additionally, gross national income (GNI), which is the total domestic and foreign output claimed by residents of a country, and region of the world were included in the model to assess confounding. This model gives a risk ratio which was converted to a percentage change in outcome for differences of 10% urbanicity.

Table 1 gives the estimate and its 95% confidence interval, as well as *p* values. Further analyses were conducted to investigate whether the association between symptoms and urbanicity were confounded by other urban related asthma risk factors for which information was collected in the environmental questionnaire (cat and dog exposure, other animal exposure (6–7 years only), truck traffic, cooking fuels, fast food intake and exercise) but this was in a subset of the data because about half of the centres did not collect this information.

The authors declare that this study has conformed to the principles embodied in the Declaration of Helsinki.

Results

First, 237 worldwide centres were included in the ISAAC Phase Three Study, 144 collected data from the 6–7-year age group and 233 centres from the 13–14-year age group. Figure 1 shows the number of centres by 10% intervals of urban extent percentage. A total of 72 centres were equal or less than 10% urbanised, and 39 were higher than 90%. The distribution of the ISAAC centres according to the percentages of urban extent is

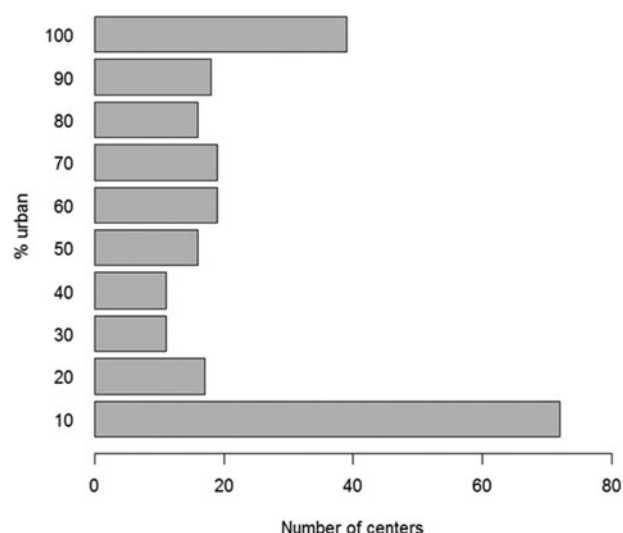


Figure 1. Frequency of ISAAC centres according to the percentage of urbanisation in 10% intervals (0–10%, 10.1–20%, 20.1–30%, 30.1–40%, 40.1–50%, 50.1–60%, 60.1–70%, 70.1–80%, 80.1–90%, 90.1–100%).

represented in Supplementary Figure 1, which shows the findings for each centre.

In the 13–14-year age group no relationship between urban extent percentage and symptoms of asthma, rhinoconjunctivitis or eczema was found (Figures 2–4 and Table 1). In the 6–7-year age group a statistically significant negative association was observed between urban area and current and severe eczema but when controlling for GNI and region this effect was reduced (Figures 2–4 and Table 1). No other relationship was found.

There appeared to be some confounding of the urban extent measure by region of the world and GNI in that in most of the analyses the regression coefficient for the urban extent variable reduced when region and GNI were added to the model. This occurred for both age groups (Table 1). Thus, the association between the percentage of urbanisation and current wheeze in the 13–14-year age group was not statistically significant after the adjustment. We discovered that the distribution of urban areas was affected by GNI: as GNI reduced, the more urbanised the ISAAC centre was. We found that centres in Western Europe and Oceania were less urban compared to South-East Asia/Indian Sub-Continent and Latin America (data not shown).

However, in a subset of centres that included environmental data (113 centres for 13–14 years and 72 for 6–7 years) the addition of these environmental variables as covariates to the model had very little influence on the regression coefficient for urban extent.

Discussion

Definition of urban extent

We updated the literature review carried out by Lim et al. [18] extending it from 2012 to May 2014: Articles in English and Spanish in which the main topic was a comparison of asthma prevalence between urban and rural areas were included. We found 28 new articles, of which 20 gave no explanation on how the study locality was classified (citations are available on request). In five articles, some characteristics of the

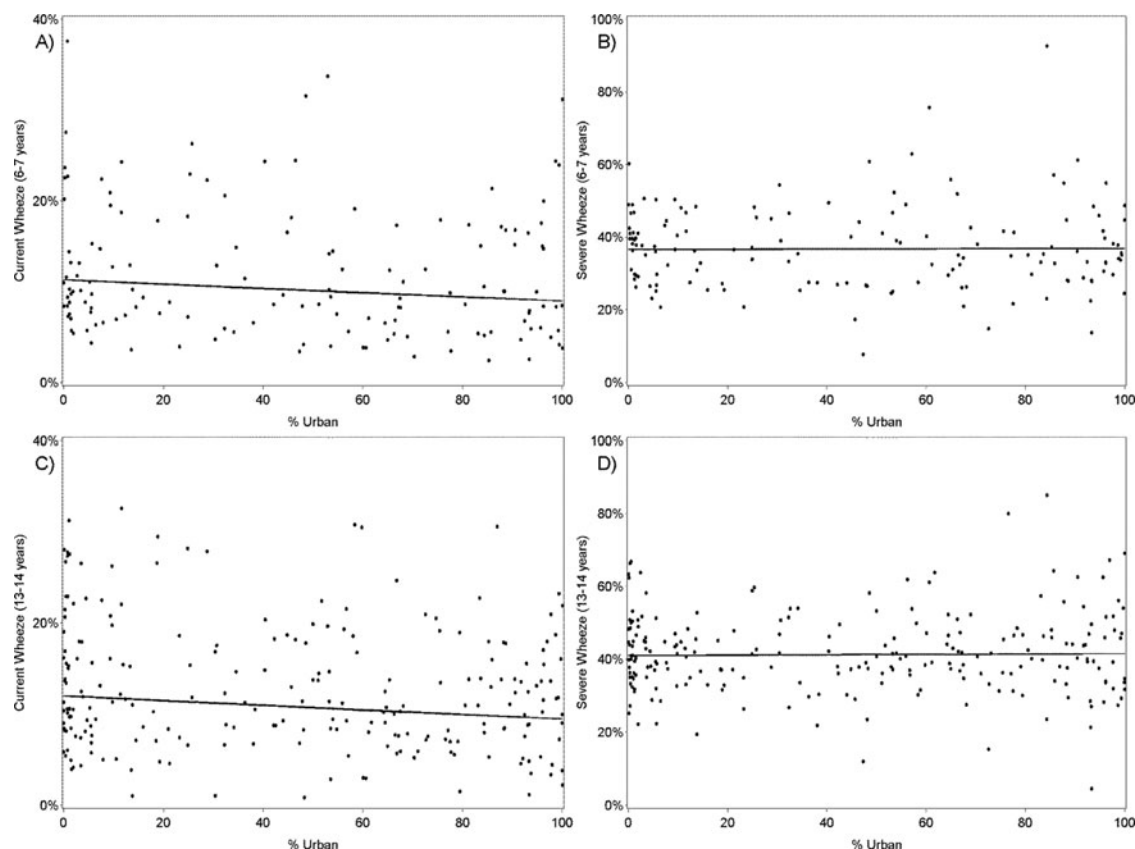


Figure 2. Relationship between the percentage of wheeze and the percentage of urbanisation in each centre. A) and B) Current wheeze and Severe wheeze, respectively, in the 6–7-year age group. C) and D) Current wheeze and Severe wheeze respectively in the 13–14-year age group.

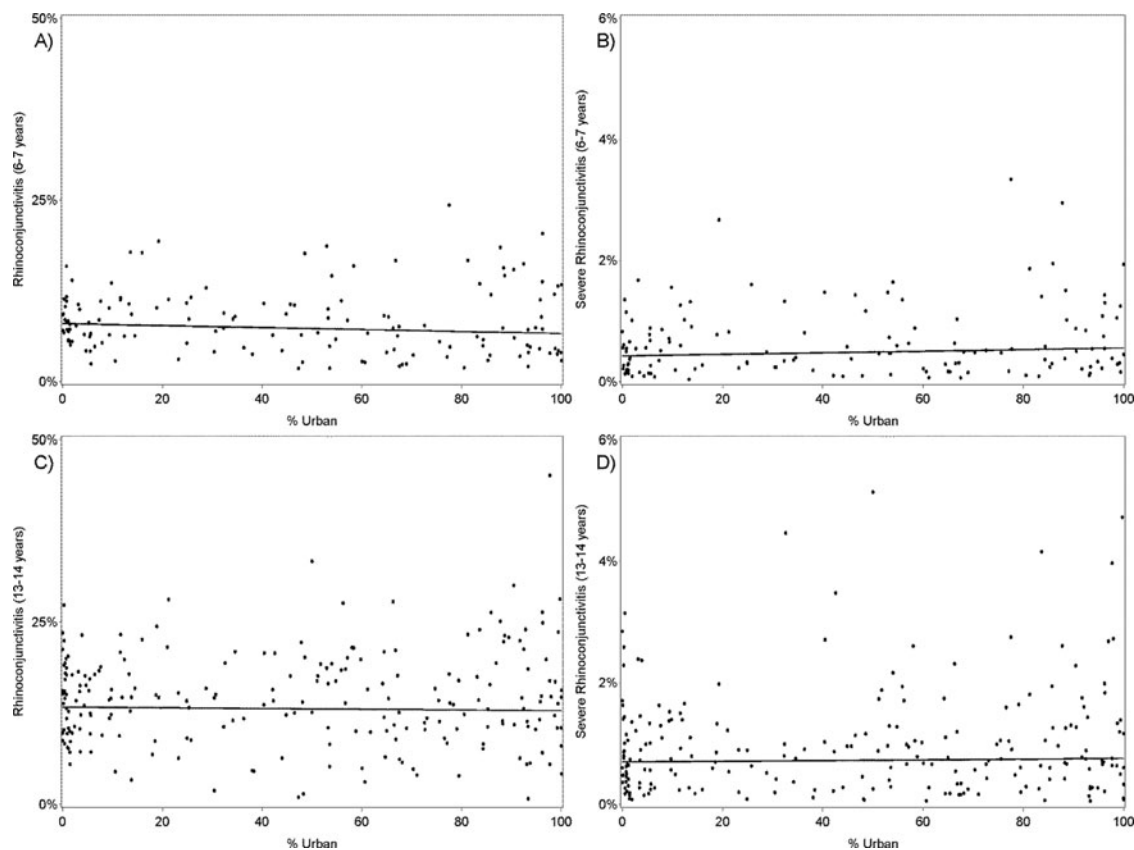


Figure 3. Relationship between the percentage of rhinoconjunctivitis and the percentage of urbanisation in each centre. A) and B) Current rhinoconjunctivitis and Severe rhinoconjunctivitis respectively in the 6–7-year age group. C) and D) Current rhinoconjunctivitis and Severe rhinoconjunctivitis respectively in the 13–14-year age group.

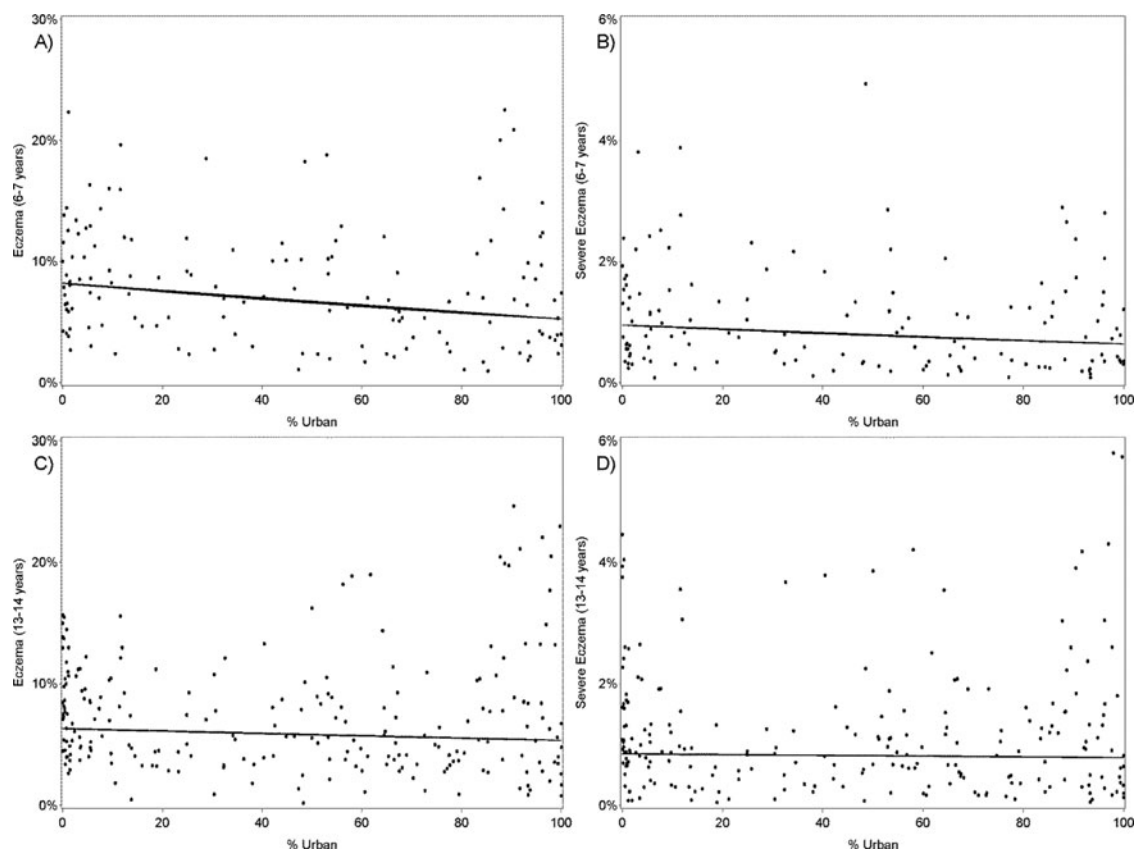


Figure 4. Relationship between the percentage of eczema and the percentage of urbanisation in each centre. A) and B) Current eczema and Severe eczema respectively in the 6–7-year age group. C) and D) Current eczema and Severe eczema respectively in the 13–14-year age group.

studied place were described, such as the location, total area, population size, weather conditions, air pollution, sanitation system, traffic and/or main income source [24–28], and in a further three the authors classified the region according to a priori fixed criteria [29–31].

The updated literature review confirmed that there is no current standardised measure of urban extent available for global analyses, apart from land cover definition of urban extent, using the MOD500 map.

Discussion of the results

In this first global study of urban extent using land cover from satellite data as our definition and data for the prevalence of symptoms of asthma, rhinoconjunctivitis and eczema, no consistent relationship was found. The majority of articles published about asthma symptom prevalence in urban/rural regions pointed to an increase in symptom prevalence as areas were more urbanised. However more recent evidence supports the opposite relationship [33–37].

This could be due to the differences in the methodology between the studies, such as the origin or age of the studied population, the method used to define asthma or to collect the data, or the different criteria used to define urban extent. The strength of our study is that it provides a global analysis of asthma symptoms defined the same way in all centres and collected from the same age groups, and they are related to the urban extent based on the same criteria.

Our results show a distribution of the ISAAC centres according to the percentage of urbanisation as a skewed curve at both extremes. Almost a third of the centres were less than 10% urban, which means that less than 10% of their areas were at least 50% built-up. This result was surprising considering that many of those centres were, on the face of it, considered as urban areas. The strict criteria used in MOD500 map to define urban extent within a region could be the explanation for this discrepancy [21,22]. However, some urban areas, when inspected closely on the map, included a large extent of countryside.

Like some of the recent literature [33–37], our results suggest a negative relationship between current wheeze prevalence and urbanisation in the 13–14-year olds. However, this association was weak and confounded by region of the world and GNI. We found a different distribution of the urban areas in ISAAC according to region and GNI and that could be due to the self-selection of the centres: rural populations were more ‘accessible’ in low and middle income developed countries.

Our results suggest that no association between the prevalence of asthma, rhinoconjunctivitis or eczema and urbanisation exists, according to our definition of urban extent as land cover using satellite data. Schram and colleagues described the same lack of relationship in their global systematic review for atopic eczema [14]. Moreover, the same result was found in the systematic reviews for asthma performed in the United Kingdom [38,39] and among African American populations [40].

There are some limitations of MODIS methods that could affect the results. The classification of an area as urban or not was an automatic process that could generate systematic errors, even though an assessment of its accuracy was performed. This map was based only on satellite images, so it took into account

the urban extent but not the height of buildings as a parameter of urban density. As a consequence, some cities appear equally urbanised, like Ciudad de Mexico, Barcelona and Marrakech that are considered nearly 100% urban, when in reality their urban density seems very different. Neither did MOD500 consider other factors related to urban density such as population density, traffic congestion or level of pollution.

Moreover, the strict definition of urban extent as at least 50% built-up made many centres appear rural, like the Madrid ISAAC Centre (0.78% urban); this ISAAC centre encompassed towns and countryside surrounding Madrid city, rather than the city centre. The use of a dichotomised measure instead of a continuous measure resulted in urban areas appearing to be equally urbanised, when in fact there were degrees of urbanisation. Regardless, to date, MOD500 is the most reliable, accurate up-to-date map of urban extent that exists [20].

The limitations of ISAAC methods are discussed elsewhere [1]. However the large amount of data from around the world gives it a high validity. The within centre data comes from children who may live in a range of urban or rural settings. For example, the Auckland ISAAC centre (7.62% urban) includes the built-up Auckland city heart, which is a small proportion of the area of the centre, homes with large gardens, and large areas of countryside surround the city heart. The analysis was performed using ‘urban extent’ at the centre level (ecological analyses) as the child’s home address, or the school addresses, were not available for analyses. Thus some children could have been considered as they lived in urban areas when not, and vice versa, resulting in a misclassification of part of the population. As a consequence, the effects of urbanisation on prevalence of asthma, rhinoconjunctivitis and eczema could have been diluted, driving to null results, which is what we had found.

Another possible limitation of ISAAC study is that symptoms of asthma was not defined using medication, because the relationship between them was likely to be affected by health care factors such as accessibility to care and the quality of the care received, which varies considerably within and between countries [41].

In this study, symptom prevalence of asthma, rhinoconjunctivitis and eczema were compared with land cover, based on the physical attributes of the Earth’s surface. It may be possible that an association between any of these symptoms and ‘urbanisation’ does exist but this relationship is not based on the physical urban structure but on other factors related to urbanisation. Anderson and colleagues investigated a possible relationship of asthma symptoms with air pollution, which could have some relationship to urbanisation, but no association was found, supporting our findings [42]. Air pollution, particularly that most related to combustion (NO₂) is likely to be highly related to land cover or other measures of urbanisation. It would be interesting if new studies compared asthma, rhinoconjunctivitis and eczema data with other standardised worldwide urban indicators such as infrastructure factors (e.g., sanitation system, proximity to health systems), socioeconomic factors (e.g., population density, level of education on health), and/or lifestyle (diet, heating method, life stress). To do so, reliable worldwide databases are required, but these are difficult to find.

Finally, it may not be urbanisation that affects the prevalence of these diseases, but other factors like altitude, climate, proximity to different vegetation or residency near the coast. Global

studies should be performed to investigate these possible associations.

To the best of our knowledge this is the first study that compares urban extent from satellite data with a global health problem. Analysis of global data of other health conditions will help us better understand the impact of worldwide urbanisation on health, which should be considered in new urban planning policies.

Conclusions

This is the first global study that relates the prevalence of symptoms of asthma, rhinoconjunctivitis and eczema with urbanisation based on a standardised classification of urban extent of worldwide areas. No consistent association was found according to the definition of urban extent as land cover using satellite imagery. New global studies should seek comparable standardised definitions of urbanisation to enable further investigation into the effects of urban and rural environments on asthma, rhinoconjunctivitis and eczema as well as other health issues.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article.

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