Applied Geography 47 (2014) 10–19

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

An investigation of the environmental determinants of asthma hospitalizations: An applied spatial approach

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Keywords:
Air pollution
Asthma
Satellite data
Spatial epidemiology
Urbanization

A B S T R A C T

Several previous studies have connected asthma exacerbations with environmental factors such as pollutants. However, the majority do not analyze the information spatially. The objective of this study was to evaluate the relationship between asthma hospital admissions and several environmental variables in mainland Portugal using spatial data from remote sensing and spatial modeling. A set of five environmental variables were considered: near-surface air temperature (T_a) from the temperature profile of the Moderate Resolution Imaging Spectroradiometer (MODIS); relative humidity (RH) from meteorological station data interpolated by kriging; vegetation density from MODIS Normalized Difference Vegetation Index (NDVI); and space-time estimates of nitrogen dioxide (NO_2) and particulate matter less than 10 μm (PM_{10}), both from Land-Use Regression (LUR) models based on data from air quality stations. Districts were aggregated into three groups based on their percent urban cover, and the municipality was chosen as the sampling unit to assess the relationship between asthma hospital admission rates and environmental variables by season for the years 2003–2008. In the most urban group, T_a, NDVI, and NO_2 had consistent relationships with asthma in all seasons (Pearson correlation coefficients ranging from 0.351 to 0.600, −0.376 to −0.498, and 0.405 to 0.513, respectively). The associations in the other groups were very weak or non-existent. The percentage of urban cover influences the relationship between the environment and asthma. The results suggest that asthmatic people living in highly urbanized and sparsely vegetated areas are at a greater risk of suffering severe asthma attacks that lead to hospital admissions.

Introduction

Asthma is a chronic inflammatory disorder of the airways that affects people of all ages throughout the world. The chronic inflammation is associated with a hyper-responsiveness of the airways that leads to recurrent episodes of wheezing, breathlessness, chest tightness, and coughing, particularly at night or in the early morning. The disease is prevalent in all age groups (GINA, 2011; Sa-Sousa et al., 2012) and affects approximately 300 million people worldwide, causing 250 thousand deaths per year (GINA, 2011). The disease can be exacerbated by environmental factors such as allergens, air pollution or weather changes (Portnov, Reiser, Karkabi, Cohen-Kastel, & Dubnov, 2012) and infectious factors such as viruses and bacteria (GINA, 2011). When uncontrolled, asthma can place severe limits on daily life and is sometimes fatal.

In recent years, several studies have analyzed how asthma is exacerbated by pollutants (Wilhelm et al., 2008) such as ozone (O_3), particulate matter (PM) with aerodynamic diameters less than 10 μm or 2.5 μm (PM_{10} or $PM_{2.5}$, respectively), nitrogen dioxide (NO_2), carbon monoxide (CO), and sulfur dioxide (SO_2). However, the results of these studies do not agree (Akinbami, Lynch, Parker, & Woodruff, 2010; Delamater, Finley, & Banerjee, 2012), and thus, the role of pollutants in asthma exacerbations remains controversial (GINA, 2011). The discrepancies among studies could be explained by variations in study design and the modeling methods adopted (Akinbami et al., 2010). In addition, the choice of outcome (e.g., prevalence, emergency department visits, hospitalizations, and

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0143-6228/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apgeog.2013.11.011

mortality), spatio-temporal scale (e.g., data aggregation level, temporal resolution), and exposure modeling (e.g., ambient monitor data, personal exposure data) have the potential to influence the observed relationship (Delamater et al., 2012).

The majority of asthma studies are not spatially explicit. Non-spatial studies have relied on data gathered at a single monitoring station or on an average value from multiple monitoring stations, which may lead to misclassifications of exposure (Chen, Mengersen, & Tong, 2007). The exacerbation of a chronic disease is controlled by epidemiological factors that operate over a range of spatial and temporal scales to produce spatially and temporally complex patterns of disease incidence (Graham, Atkinson, & Danson, 2004). Therefore, it is important to incorporate spatial information in the study of environment-related diseases (Delamater et al., 2012). In addition to spatial prediction techniques (e.g., inverse distance weighting and kriging), remote sensing has been widely used in health sciences, particularly in the study of infectious diseases (Maxwell, Meliker, & Goovaerts, 2010). Remotely sensed data have the major advantage of providing synoptic and frequent overviews of the Earth's surface, whereas the distribution of ground-based measurements is usually sparse and uneven. Additionally, using these data avoids expensive and time-consuming monitoring campaigns.

The objective of this study was to examine the association between severe asthma exacerbations requiring hospital admission and weather conditions, vegetation density, and air pollution in mainland Portugal by using both remotely sensed and modeled spatial data. Specifically, the near-surface air temperature (T_a), relative humidity (RH), Normalized Difference Vegetation Index (NDVI), and the air pollutants NO_2 and PM_{10} were analyzed from 2003 to 2008 in a retrospective ecological study.

Materials and methods

Study area

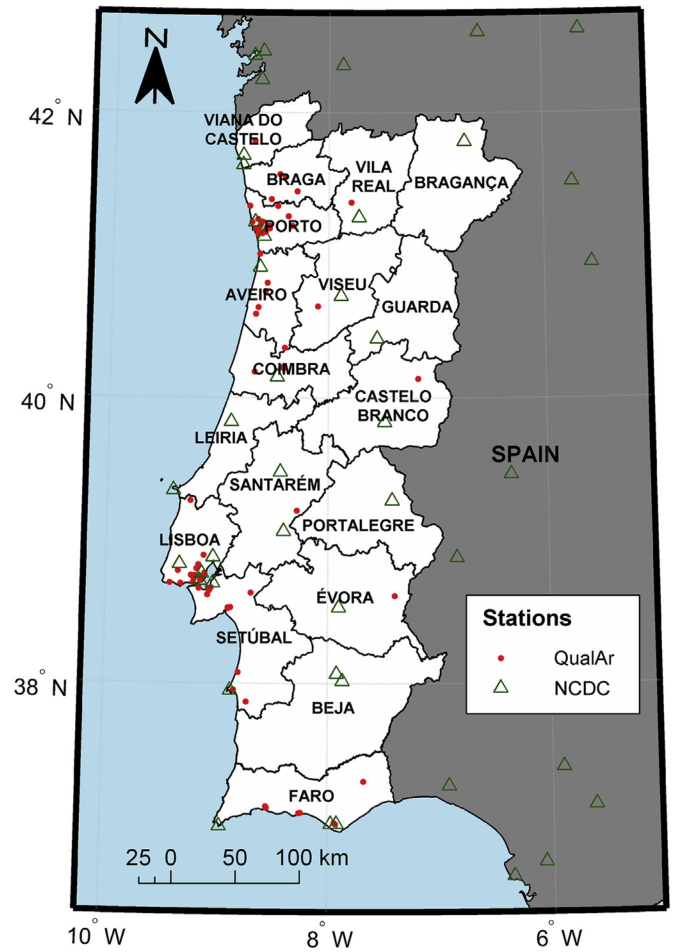

Fig. 1. Mainland Portugal divided by districts. NCDC's meteorological stations are marked with triangles and QualAr's air quality stations with dots.

Mainland Portugal (Fig. 1) has a total area of approximately 89,000 km^2 and is subdivided into three major administrative levels: 18 districts, 278 municipalities, and 4050 sub-municipalities (as of the study period). Between 2003 and 2008, the total population ranged from 9,991,654 to 10,135,309.

Data sources

The data sources used to obtain the variables T_a, RH, NDVI, NO_2, and PM_{10} are briefly described below.

Satellite imagery

Three parameters were retrieved from the Moderate Resolution Imaging Spectroradiometer (MODIS) (Table 1): temperature profiles from the daily level 2 atmospheric profile product, collected from both Aqua (MYD07) and Terra platforms (MOD07); Aerosol Optical Thickness at 550 nm (AOT550) from the daily level 2 aerosol product, collected from both Aqua (MYD07) and Terra platforms (MOD04); and NDVI from the monthly level 3 Vegetation Indices product, collected from Terra platform (MOD13A3). Hereafter, the terms MOD07 and MOD04 will be used to refer to both Terra- and Aqua-derived products. All products were freely acquired from the National Aeronautics and Space Administration (NASA) and from the U.S. Geological Survey (http://modis-atmos.gsfc.nasa.gov/; http://e4ftl01.cr.usgs.gov/MOLT/MOD13A3.005/) during the study period (2003–2008). More details can be found in Levy, Remer, Tanré, Mattoo, and Kaufman (2009), Seemann, Borbas, Li, Menzel, and Gumley (2006), and Solano, Didan, Jacobson, and Huete (2010). All MODIS parameters were pre-processed using MATLAB, which included data correction using quality flags (except for AOT550, which is already corrected), resamples to a regular grid (except for NDVI, which already has a projected coordinate system), and the calculation of real values by applying a scale factor and an offset. Additionally, AOT550 from both Aqua and Terra satellites were used to calculate the AOT550 simple monthly averages.

The Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission (SRTM) (Farr et al., 2007) is composed of 23 1 × 1-degree images with 90 m of spatial resolution for Portugal, and it was acquired from the U.S. Geological Survey (http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/Eurasia/). All images were merged and resampled (bilinearly) in a 100 m resolution image (DEM1) and in a 5 km resolution image (DEM5) using ArcGIS 10.0 (ESRI Inc., Redlands, CA, USA).

Vector data

The Portuguese Geographic Institute (*Instituto Geográfico Português* – IGP) provided the CORINE Land Cover 2006 map (CLC06_PT), which has a three-level hierarchical classification with 44 classes in the third, most detailed level (Caetano, Nunes, & Nunes, 2009). This map was posteriorly aggregated into seven new classes (Table 2 and Fig. 2) using ArcGIS 10.0. IGP also provided a Portuguese Official Administrative map (CAOP2011) showing the delimitation and demarcation of the Portuguese territorial units, updated through August 2011.

The Portuguese road network was downloaded from OpenStreetMap, an open access global map (http://download.geofabrik.