Effect of particulate matter, atmospheric gases, temperature, and humidity on respiratory and circulatory diseases' trends in Lisbon, Portugal

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Abstract This study addresses the significant effects of both well-known contaminants (particles, gases) and less-studied variables (temperature, humidity) on serious, if relatively common, respiratory and circulatory diseases. The area of study is Lisbon, Portugal, and time series of health outcome (daily admissions in 12 hospitals) and environmental data (daily averages of air temperature, relative humidity, PM₁₀, SO₂, NO, NO₂, CO, and O₃) have been gathered for 1999–2004 to ascertain (1) whether concentrations of air pollutants and levels of temperature and humidity do interfere on human health, as gauged by hospital admissions due to respiratory and circulatory ailments; and (2) whether there is an effect of population age in such admissions. In general terms, statistically significant ($p < 0.001$) correlations were

found between hospital admissions and temperature, humidity, PM₁₀, and all gaseous pollutants except CO and NO. Age appears to influence respiratory conditions in association with temperature, whereas, for circulatory conditions, such an influence likely involves temperature as well as the gaseous pollutants NO₂ and SO₂.

Keywords Airborne pollutants · Cardiorespiratory diseases · Epidemiological trends · Hospital admissions · Temperature–humidity · Urban environments

Introduction

Understanding—and eventually assessing—the impact of airborne pollutants on human health has become a major quest to scientists and regulators alike. Especially since the late 1980s, epidemiological evidence has pointed to convincing links between air quality and people's wellbeing, even if asserting risk thresholds or impact rates strongly depends on many disparate factors—from personal-income amount and healthcare quality to urban features, to name just a few. Extreme episodes and their acute effects have been noticed much earlier, though.

The majority of deaths during the London fog episode of 1952 have been related to bronchitis-afflicted individuals (Logan 1953). Physicians and

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public-health officers alike came to the conclusion that people suffering from cardiorespiratory conditions had been particularly susceptible to such an episode (UK Ministry of Health 1954). Respiratory and circulatory wellbeing may also be adversely affected by daily variations in ambient-air quality. Increases in daily air-pollution levels in London, rather than plain weather, were associated with an exacerbation of chronic bronchitis for the periods 1959–1960, 1964–1965, and 1967–1968 (Lawther et al. 1970).

An association between a personal pollution index and acute illness in patients with chronic bronchopulmonary conditions was found through two large studies in Chicago, IL, USA 1968 (Carnow et al. 1969). In the 1950s, researchers had already shown that air pollution was not only the cause of sudden exacerbation in patients suffering from chronic obstructive pulmonary disease (COPD), but also that higher pollution induced it in postmen from other areas (Fairbairn and Reid 1958). A later study on the general population reached the same conclusions (Lambert and Reid 1970), and another survey on postmen during the 1960s had already pointed to reduced levels of lung function in areas with an increased air pollution (Holland and Reid 1965). A higher prevalence of respiratory conditions compatible with COPD in areas with poor air quality was also observed in the USA and Poland (Burrows et al. 1968; Ferris et al. 1971; Sawicki 1972; Love et al. 1981).

More recently, rates of asthma symptoms in countries whose predominant language is English were found to be high. Conversely, while enhanced rates of asthma symptoms were also found in some non-English-speaking countries, such rates were not uniformly high among countries sharing the same language (International Study of Asthma and Allergies in Childhood Steering Committee 1998). For example, Peru and Costa Rica had a much higher prevalence than Spain, and Brazil and Hong Kong a higher prevalence than Portugal and China, respectively. Major differences between populations put forward by the ISAAC, Phase One, are likely due to environmental factors (ISAAC Steering Committee 1998).

Epidemiology has clearly shown a link between increases in particulate air pollution and death

tolls or hospital admissions caused by heart failure, myocardial infarction, and cardioarrhythmia (Routledge et al. 2003). The present paper describes an epidemiological research conducted in the period 1999–2004, on the role of air pollution in hospital admissions due to respiratory and cardiovascular diseases in Lisbon, Portugal, which features higher levels of particles and lower levels of gases in the atmosphere than the European Union regulations, even if the air-pollution profile has gone through significant changes due to mobile sources and industrial emissions. Being an Atlantic, Southern European country, with relatively cold winters and hot summers, the high humidity and the widespread absence of in-house heating during the winter season may induce—or aggravate—health conditions related to air temperature and relative humidity. As so, these two meteorological parameters were also included in the study dealt with herein.

Methodology

Air-pollution data were obtained from the Portuguese Environmental Agency air-quality monitoring network, an array of automated stations throughout Portugal providing hourly values of the main atmospheric pollutants, such as concentrations of PM₁₀ (airborne particles with an aerodynamic diameter below 10 µm), SO₂, NO, NO₂, CO, and O₃. Three of such stations in Lisbon were considered: Avenida da Liberdade and Entrecampos may be regarded as typical urban (inner city) locations; Olivais is located in the outskirts of Lisbon, in a suburban (mostly residential) area. Air-quality indicators for the present analysis were PM₁₀ (24-h averages), and the gaseous pollutants SO₂ (24-h averages), NO (maximum; 1-h averages), NO₂ (maximum; 1-h averages), CO (maximum; 1-h averages), and O₃ (maximum; 1-h averages).

The experimental design required at least 75% of the 1-h values on a particular day for the calculation of 24-h averages for PM₁₀ and SO₂, as well as for the maxima of 1-h averages for NO, NO₂, and CO. Since the maximum O₃ levels always occur during daylight hours, it was also required at least 75% of 1-h values from 6 A.M. until 7 P.M. for

computing the maximum of 1-h averages for O₃. Local data from every station were then averaged to yield single, representative (citywide) estimates of the daily concentrations for each pollutant. Missing data from either monitoring station were replaced by a weighted average of values from the other stations. For days with missing data from all stations, the resulting series also had a missing value, which was replaced by an average of the corresponding values for the previous and next days. Consecutive days with missing values were not filled in.

Mean temperature and humidity for each day were calculated from continuous weather data made available by the Portuguese Meteorological Institute (IM).

Health data were obtained from the Institute for Computer and Financial Management of Health Services (IGIF), of the Portuguese Ministry of Health. Daily counts of hospital admissions in 12 institutions were assessed for all circulatory-related causes and all respiratory-related causes, according to the International Statistical Classification of Diseases, Injuries and Causes of Death, Ninth Revision—ICD-9—by the World Health Organization (WHO 1977). The next ICD-9 codes (in brackets) refer to cause categories in terms of the former classification that has been designed for international comparability in the collection, processing, classification, and presentation of mortality statistics.

Condition breakdown was as follows: (1) All circulatory conditions (ICD-9; 390–459), and distributed by cardiac diseases (ICD-9; 390–429), ischemic heart disease (ICD-9; 410–414), and stroke (ICD-9; 430–438); (2) All respiratory conditions

(ICD-9; 470–519), and distributed by asthma (ICD-9; 493) and chronic obstructive pulmonary disease (ICD-9; 490–492, 495, 496). All data were split into the following age intervals: 0–14, 15–64, >64 years old.

For the statistical procedures, PM₁₀, SO₂, NO, NO₂, CO, O₃, air temperature, and relative humidity were taken as independent variables, with the above diseases—for each age group—as dependent variables. Data structure and relationships were searched for by *t* tests, *F* tests, and parametric (Pearson) correlations. In every case, a lag time of zero was considered. Standard packages for exploratory, correlation, and trend analyses were STATISTICA® 6.0 (StatSoft Inc.) and SPSS 11.0 for Windows® (SPSS Inc.).

Results and discussion

Environmental data for the three monitoring stations of Lisbon in the period 1999–2004 are listed in Table 1. Since consecutive days with missing values were not filled in, and some zeros exist in the data of SO₂ and O₃, Table 1 shows SO₂ and O₃ values in the situation of zero exclusion and zero inclusion. PM₁₀ concentrations slightly exceed the European and Portuguese (as of 2005) standard of 40 µg m⁻³ (based on an average of 3 years), with a mean of 43.2 µg m⁻³; the maximum was 206.8 µg m⁻³ (República Portuguesa 2002, 2003; European Union 2008). Daily values should not exceed 50 µg m⁻³ more than 35 times per year according to the same guidelines, yet the actual rate of exceedance is almost three times higher (98 times per year). The other pollutants under

Table 1 Environmental data

Property [unit]	Days	Mean	SD	Min	10 th	Median	90 th	Max
PM ₁₀ [µg m ⁻³]	2008	43.2	20.9	10.6	22.2	38.6	70.7	206.8
SO ₂ [µg m ⁻³]	2008				0.0		11.1	
	(1988)	5.3	7.3	0.0	(0.7)	3.2	(11.2)	124.5
NO [µg m ⁻³]	2008	132.5	127.7	2.3	29.0	86.2	297.3	972.4
NO ₂ [µg m ⁻³]	2008	75.4	33.0	16.3	39.0	70.7	114.7	289.0
CO [µg m ⁻³]	2008	1,563.4	1,383.7	228.3	555.3	1,100.0	3,180	11,567
O ₃ [µg m ⁻³]	2008			0.0	9.0		91.0	
	(1820)	54.7	30.7	(4.0)	(30.0)	55.0	(130)	189.5
Temperature [°C]	2008	16.4	4.7	4.5	10.5	16.0	22.3	32.0
Humidity [%]	2008	72.7	12.8	15.1	56.0	73.5	88.0	98.0

Figures within brackets refer to situations for which zero values were not considered

legislation—SO₂, NO₂, CO, O₃—have maxima over their regulated values, but the averages are lower.

Pearson coefficients (*r*) for correlations between pollutants, temperature, and humidity are given in Table 2. While high degrees of association are not apparent, moderate correlations were found between PM₁₀ and NO (*r* = 0.62), CO and NO (*r* = 0.73), and NO and (NO₂ *r* = 0.65); other correlations between pollutants feature *r* around 0.5. Negative correlations were found for: (1) O₃ in all cases (weak though), but with NO₂ (positive, if virtually null) and temperature (*r* = 0.40); (2) temperature in all cases, but with O₃ and PM₁₀ (again, virtually null); and (3) humidity in all cases, but with NO and CO. These findings are consistent with an a priori knowledge on such parameters and the geographic situation of Lisbon. It may be concluded that none of them is actually a relevant confounder for the others.

Means and standard deviations of the daily hospital admissions for all the studied health conditions were as follows: all respiratory diseases—17 ± 5; asthma—0.24 ± 0.53; COPD—1.7 ± 1.4; all circulatory diseases—31 ± 8; cardiac diseases—24 ± 7; ischemic heart disease—1.6 ± 1.7; stroke—20 ± 1.5. Asthma, COPD, and ischemic heart disease have practically no registrations, most likely because hospital records do not specify the type of respiratory or circulatory conditions but when cardiac arrest and stroke are involved.

Tables 3, 4, 5, and 6 summarize the results of a linear-trend analysis between independent (environmental) and dependent (health) variates. Two-tailed *t* tests were performed to check whether slopes were significantly different from zero (*p* < 0.001), thus indicating statistically relevant impacts of atmospheric variables on physical conditions. The present discussion will consider slopes

above 1% and below −1%, which go highlighted (in bold type) with the corresponding *p* levels in italics.

Significant at *p* < 0.001 was the increase of all respiratory diseases with the decrease in temperature for <15 years (2.94%), >64 years (9.52%), and all ages (8.15%). For the population group of 15–64 years though, the slope was positive, indicating that an increase in temperature makes the respiratory diseases increase by 4.30%. Also significant (*p* < 0.001) was the 1.54% rise of all respiratory diseases for all ages with the increase in PM₁₀ concentrations.

As for gaseous pollutants, an increase in SO₂ levels translates into significant (*p* < 0.001) rate gains of 3.76%, 5.20%, 4.62%, and 13.57% for all respiratory diseases in the <15 years, 15–64 years, >64 years, and all-set age groups, respectively. In the case of NO₂, and for all respiratory diseases as well, gains of 1.57%, 1.35%, and 3.56% have been observed for age groups 15–64 years, >64 years, and the entire set, respectively. A statistically significant (*p* < 0.001), negative slope resulted from the association of O₃ with all respiratory diseases for all ages, meaning that an abatement in ozone levels leads to an increase of 1.3% in such diseases. Slopes were close to zero for asthma and COPD in all cases, a situation that might be anticipated from the scarcity of corresponding records at hospitals, as mentioned before.

The increase in air temperature is significantly (*p* < 0.001) associated with an increase in all circulatory conditions and cardiac diseases for <15 years (12.89% and 12.41%), 15–64 years (11.44% and 4.90%), >64 years (2.68% and 2.07%), and all ages (27.01% and 19.37%). An increase in all circulatory conditions (2.19%) and cardiac diseases (1.83%) with increasing concentrations of PM₁₀ was observed for all ages as a

Table 2 Pearson correlation matrix between the environmental (independent) variables

	PM ₁₀	SO ₂	NO	NO ₂	CO	O ₃	Temperature
SO ₂	0.40						
NO	0.62	0.48					
NO ₂	0.50	0.53	0.65				
CO	0.52	0.55	0.73	0.57			
O ₃	−0.03	−0.17	−0.32	0.03	−0.35		
Temperature	0.03	−0.20	−0.36	−0.19	−0.34	0.40	
Humidity	−0.17	−0.14	0.10	−0.20	0.12	−0.42	−0.46

Table 3 Pollution, temperature, and humidity *versus* daily hospital admissions due to all respiratory diseases and COPD, for <15, 15–64, >64 years, and all ages

Health condition	Age	Trend	PM ₁₀	SO ₂	NO	NO ₂	CO	O ₃	Temp.	Hum.
All respiratory diseases	< 15	Slope (%)	0.35	3.76	0.09	0.64	0.02	−0.59	−2.94	−0.20
		Unc. (%)	0.15	0.44	0.03	0.10	0.00	0.10	0.69	0.25
		P level	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	15–64	Slope (%)	0.97	5.20	0.15	1.57	0.02	−0.11	4.30	−1.61
		Unc. (%)	0.41	1.18	0.07	0.26	0.01	0.28	1.83	0.67
		P level	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	> 64	Slope (%)	0.22	4.62	0.17	1.35	0.03	−0.60	−9.52	0.90
		Unc. (%)	0.27	0.76	0.04	0.17	0.00	0.18	1.17	0.43
		P level	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	All	Slope (%)	1.54	13.57	0.41	3.56	0.06	−1.31	−8.15	−0.91
		Unc. (%)	0.56	1.58	0.09	0.34	0.01	0.38	2.48	0.91
		P level	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
COPD	< 15	Slope (%)	0.05	0.01	0.01	0.01	0.00	−0.03	0.18	−0.06
		Unc. (%)	0.04	0.11	0.01	0.02	0.00	0.03	0.17	0.06
		P level	0.000	0.600	0.000	0.000	0.000	0.000	0.000	0.000
	15–64	Slope (%)	0.08	−0.20	0.01	0.04	0.00	0.18	−0.12	−0.03
		Unc. (%)	0.13	0.38	0.02	0.08	0.00	0.09	0.59	0.22
		P level	1.033	0.030	0.000	0.000	0.000	0.000	0.000	0.000
	> 64	Slope (%)	−0.08	0.01	−0.01	−0.03	0.00	−0.02	−0.56	0.28
		Unc. (%)	0.06	0.17	0.01	0.04	0.00	0.04	0.26	0.09
		P level	0.001	0.700	0.000	0.000	0.000	0.000	0.000	0.000
	All	Slope (%)	0.06	−0.18	0.01	0.02	0.00	0.13	−0.50	0.19
		Unc. (%)	0.15	0.44	0.02	0.10	0.00	0.10	0.68	0.25
		P level	0.100	0.090	0.000	0.000	0.000	0.000	0.000	0.000

unique set. Conversely, a decrease in all circulatory conditions and cardiac diseases (−5.09% and −4.81%) could be observed for younger ages (<15 years) with increasing SO₂ levels. For 15–64 and >64 years though, there are positive rate gains (2.40% and 2.29%; 3.47% and 2.46%) for all circulatory conditions and cardiac diseases with an increase in SO₂ levels.

Age also reverses trend in the seemingly NO₂-impacted, circulatory conditions: −1.36% (all conditions) and −1.40% (cardiac diseases only) for <15 years, comparing to 1.19% for >64 years (all conditions). No association of the independent variables with ischemic heart disease was found, again most likely due to the few registered cases of this disease. As for stroke, temperature appears to raise its incidence in the majority of the population—3.84% for 15–64 years; 3.45% for the entire set.

A negative association of −12.9% between ozone and hospital admissions due to asthma and COPD has already been reported (Anderson et al. 2001). In our work, no associations were found

with asthma and COPD, but with all respiratory diseases, probably due to the administrative procedure of keeping unspecific records. However, a −1.31% decline in hospital admissions relating to all respiratory diseases could indeed be observed. Positive associations in the order of 11% and 8% have also been found between asthma and COPD, and SO₂ and PM₁₀, respectively (Anderson et al. 2001), while the corresponding figures from the present study for all respiratory diseases are 13.6% and 1.5%. The partial (negative) trend between respiratory-related, hospital admissions of elderly people and temperature found in the present study also concurs with previous reports (Künzli 2002).

On the other hand, former evidence shows an airborne-pollution impact of: 1.31% (0.1–2.5%) in hospital admissions (all ages) ascribed to respiratory diseases; 1.25% (0.7–1.9%) to cardiovascular diseases; 9.8% (0.9–19.4%) to chronic bronchitis in people aged ≥25 years; 30.6% (13.5–50.2%) to acute bronchitis in children aged <15 years; 4.4% (2.7–6.2%) to asthma attacks in children;

Table 4 Pollution, temperature, and humidity *versus* daily hospital admissions due to all circulatory diseases and asthma, for <15, 15–64, >64 years, and all ages

Health condition	Age	Trend	PM ₁₀	SO ₂	NO	NO ₂	CO	O ₃	Temp.	Hum.
All circulatory diseases	< 15	Slope (%)	0.59	−5.09	−0.15	−1.36	−0.04	0.06	12.89	−3.67
		Unc. (%)	0.56	1.60	0.09	0.35	0.01	0.38	2.46	0.90
		P level	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	15–64	Slope (%)	0.89	2.40	−0.05	0.76	0.01	−0.19	11.44	−2.72
		Unc. (%)	0.41	1.20	0.07	0.26	0.01	0.28	1.83	0.68
		P level	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	> 64	Slope (%)	0.70	3.47	0.08	1.19	0.01	−0.28	2.68	−1.61
		Unc. (%)	0.29	0.82	0.05	0.18	0.00	0.19	1.27	0.47
		P level	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	All	Slope (%)	2.19	0.78	−0.13	0.59	−0.02	−0.41	27.01	−8.00
		Unc. (%)	0.83	2.40	0.14	0.53	0.01	0.57	3.66	1.35
		P level	0.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000
Asthma	< 15	Slope (%)	0.00	−0.01	0.00	0.00	0.00	0.00	−0.01	0.00
		Unc. (%)	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.01
		P level	0.003	0.004	0.000	0.000	0.000	0.000	0.000	0.000
	15–64	Slope (%)	0.01	−0.14	0.00	0.00	0.00	0.03	0.15	−0.02
		Unc. (%)	0.04	0.12	0.01	0.03	0.00	0.03	0.19	0.07
		P level	0.400	0.006	0.000	0.002	0.000	0.000	0.000	0.000
	> 64	Slope (%)	0.01	−0.08	0.01	0.03	0.00	0.04	0.02	0.03
		Unc. (%)	0.04	0.11	0.01	0.02	0.00	0.02	0.16	0.06
		P level	0.500	0.308	0.000	0.000	0.000	0.000	0.000	0.000
	All	Slope (%)	0.01	−0.23	0.01	0.02	0.00	0.07	0.16	0.02
		Unc. (%)	0.06	0.16	0.01	0.04	0.00	0.04	0.25	0.09
		P level	0.400	0.001	0.000	0.000	0.000	0.000	0.000	0.000

and 3.9% (1.9–5.9%) to asthma attacks in adults (Anderson et al. 2001). Rates of incidence found through the present study fall within the previous orders of magnitude.

In Michigan, USA (1986–1989), it was found that PM₁₀ induces an increase in hospital admissions due to ischemic heart disease and heart failure at a rate of 1.018% and 1.024%, respectively, while heart-failure admissions could as well reflect increasing CO levels at a rate of 1.022% (Schwartz and Morris 1995). Such an association—at a rate of 1.10–1.37% when CO increased by 10 mg kg^{−1}—could also be found through a study in seven US cities, 1986–1989 (Morris et al. 1995). In Birmingham, UK (1992–1994), positive risks for respiratory (rate: 2.4%) or cerebrovascular (rate: 2.1%) hospital admissions were linked to an increase of 10 µg m^{−3} in PM₁₀ (Wordley et al. 1997). Both PM₁₀ and CO were deemed responsible for enhancing cardiovascular-related, hospital admissions in Tucson, AZ, USA (1997) at rates of 2.75% and 2.79%, respectively. Little association

was found between circulatory diseases and either SO₂ or O₃, though (Schwartz 1997).

On the contrary, associations of heart-failure admissions with CO (rate: 1.065%) in ten Canadian cities, 1981–1991 (Burnett et al. 1997), as well as of cardiovascular-related admissions with PM₁₀ (rate: 2.48%) and CO (rate: 2.79%) in eight US counties, 1988–1990 (Schwartz 1999), all but sustain the former trend. The present study found an all-circulatory impact rate around 2% for PM₁₀, even if no association with CO and O₃ could be disclosed. Still in Canada (Toronto; 1992–1994), increasing levels of NO₂, SO₂, and O₃ lead to an increase of 13% in cardiovascular-related admissions (Burnett et al. 1999), whereas, through our work, such pollutants seem to influence more elderly people at a rate of around 4.5%.

The proportion of the world's population living in large conurbations has grown from around 5% to 50% over the past two centuries. Due to an earlier start and a far smaller demographic pressure, cities have expanded less rapidly in the

Table 5 Pollution, temperature, and humidity *versus* daily hospital admissions due to all cardiac and ischemic heart diseases, for <15, 15–64, >64 years, and all ages

Health condition	Age	Trend	PM ₁₀	SO ₂	NO	NO ₂	CO	O ₃	Temp.	Hum.
Cardiac diseases	< 15	Slope (%)	0.55	−4.81	−0.15	−1.40	−0.03	0.00	12.41	−3.43
		Unc. (%)	0.54	1.55	0.09	0.34	0.01	0.37	2.39	0.88
		P level	0.021	0.000	0.000	0.000	0.000	0.700	0.000	0.000
	15–64	Slope (%)	0.79	2.29	0.02	0.75	0.01	−0.23	4.90	−1.52
		Unc. (%)	0.30	0.88	0.05	0.19	0.00	0.21	1.35	0.50
		P level	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	> 64	Slope (%)	0.48	2.46	0.06	0.99	0.01	−0.36	2.07	−1.26
		Unc. (%)	0.25	0.73	0.04	0.16	0.00	0.17	1.13	0.41
		P level	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	All	Slope (%)	1.83	−0.06	−0.07	0.33	−0.02	−0.59	19.37	−6.22
		Unc. (%)	0.73	2.11	0.12	0.46	0.01	0.50	3.23	1.19
		P level	0.000	0.900	0.000	0.000	0.000	0.000	0.000	0.000
Ischemic heart	< 15	Slope (%)	−0.01	0.08	0.00	0.03	0.00	−0.03	−0.12	0.00
		Unc. (%)	0.02	0.06	0.00	0.01	0.00	0.01	0.10	0.04
		P level	0.200	0.002	0.000	0.000	0.000	0.000	0.000	0.167
	15–64	Slope (%)	0.21	0.55	0.03	−0.02	0.01	−0.42	0.01	−0.01
		Unc. (%)	0.14	0.39	0.02	0.09	0.00	0.09	0.61	0.22
		P level	0.000	0.001	0.000	0.000	0.000	0.000	0.400	0.300
	> 64	Slope (%)	−0.03	0.29	−0.01	0.01	0.00	−0.22	−0.12	−0.03
		Unc. (%)	0.09	0.27	0.02	0.06	0.00	0.06	0.42	0.15
		P level	0.200	0.014	0.000	0.000	0.000	0.000	0.000	0.000
	All	Slope (%)	0.18	0.91	0.02	0.03	0.01	−0.68	−0.24	−0.04
		Unc. (%)	0.18	0.53	0.03	0.12	0.00	0.13	0.82	0.30
		P level	0.041	0.000	0.000	0.000	0.000	0.000	0.000	0.000

European territory than in most developing countries. Nevertheless, the impact of urbanization has been quite important (McMichael 1999). There are three main pathways through which the urban environment affects human health: the social transformation that comes with urbanism, and the consequent changes in behavior-induced, health

risks; the microbiological and toxicological risks associated with the urban environment proper; and the impact of urbanization on the biosphere at large (McMichael 2000). Depending on how cities are structured, on the quality of housing, transportation, and social services, and on the general quality of community life, the ultimate balance of

Table 6 Pollution, temperature, and humidity *versus* daily hospital admissions due to stroke, for <15, 15–64, >64 years, and all ages

Health condition	Age	Trend	PM ₁₀	SO ₂	NO	NO ₂	CO	O ₃	Temp.	Hum.
Stroke	< 15	Slope (%)	0.07	0.25	0.02	0.02	0.00	−0.13	−0.39	0.07
		Unc. (%)	0.05	0.14	0.01	0.03	0.00	0.03	0.22	0.08
		P level	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	15–64	Slope (%)	0.17	−0.37	−0.02	0.02	0.00	−0.05	3.84	−0.63
		Unc. (%)	0.14	0.42	0.02	0.09	0.00	0.10	0.64	0.24
		P level	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	> 64	Slope (%)	0.08	0.35	0.01	0.09	0.00	−0.02	0.01	−0.03
		Unc. (%)	0.05	0.14	0.01	0.03	0.00	0.03	0.22	0.08
		P level	0.000	0.000	0.000	0.000	0.000	0.000	9.909	0.000
	All	Slope (%)	0.33	0.23	0.01	0.12	0.00	−0.19	3.45	−0.59
		Unc. (%)	0.16	0.46	0.03	0.10	0.00	0.11	0.71	0.26
		P level	0.000	0.040	0.000	0.000	0.000	0.000	0.000	0.000

risks and benefits of urban life can, thus, be quite variable.

The Third Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) estimates a mean global warming of land and sea surface layers of $0.6 \pm 0.2^\circ\text{C}$ since the mid-nineteenth century, with major variation past 1976 (IPCC 2001). Precipitation patterns have also changed, with arid and semiarid regions becoming even drier, while other areas, especially in mid-to-high latitudes, becoming wetter. Projections over the next 100 years suggest that temperature and precipitation changes are likely to exceed those experienced during the nineteenth and twentieth centuries. The effects of climate variability on human health may be direct or indirect. For instance, alterations in weather patterns could increase or decrease local concentrations of air pollutants, particularly ozone. Exposure to elevated ozone concentrations can lead to distressing respiratory symptoms as a consequence of deprived lung function, enhanced airways' reactivity, and chances of lung inflammation (Bernard and Ebi 2001).

Judging from the results of the present study, the Lisbon population is highly sensitive to temperature and humidity variations. Rate values as large as 27% (positive rate) and 8% (negative rate) were found for the impact of air temperature on hospital admissions (all ages) caused by circulatory and respiratory ailments, respectively, while the impact of humidity on hospital admissions (all ages) due to all-circulatory and cardiac diseases could be assessed at 8% and 6% (negative rates), respectively. Temperature and humidity are also responsible for changes in the levels of PM_{10} and gaseous pollutants that may as well be already inflating the former figures.

Conclusions

Through this study for Lisbon, Portugal, in the period 1999–2004, statistically significant ($p < 0.001$) associations between atmospheric levels of PM_{10} , SO_2 , NO_2 , and O_3 and hospital admissions due to respiratory conditions (except asthma and COPD) and circulatory conditions (except ischemic heart disease) could be found. Degrees of association were faint-to-none for the former

exceptions, since public-health records hold very few registered entries of such diseases. It was also concluded that air temperature is responsible for higher admission rates due to respiratory and circulatory conditions, stepping them up by 8% and 27%, respectively. Relative humidity appears to boost admissions due to circulatory conditions as well.

The age of the population does influence respiratory conditions in association with the temperature; for circulatory conditions, such an influence is visible not only in association with temperature, but also with the gaseous pollutants NO_2 and SO_2 . For younger (<15 years) and elder (>64 years) people, higher temperatures are associated with fewer calls into the hospitals, while for the population aged 15–64 years, they seem to induce admissions at an enhanced rate. The latter group is also more susceptible to strokes when temperature rises, even if no such effect has been observed in the younger and elder individuals.

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