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# Air Pollution and Emergency Hospital Admissions—Evidences from Lisbon Metropolitan Area, Portugal

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**Abstract:** The relevance of air pollution in the public health agenda has recently been reinforced—it is known that exposure to it has negative effects in the health of individuals, especially in big cities and metropolitan areas. In this article we observed the evolution of air pollutants (CO, NO, $NO_2$, $O_3$, $PM_{10}$) emissions and we confront them with health vulnerabilities related to respiratory and circulatory diseases (all circulatory diseases, cardiac diseases, cerebrovascular disease, ischemic heart disease, all respiratory diseases, chronic lower respiratory diseases, acute upper respiratory infections). The study is supported in two databases, one of air pollutants and the other of emergency hospital admissions, in the 2005–2015 period, applied to the Lisbon Metropolitan Area. The analysis was conducted through Ordinary Least Squares (OLS) regression, while also using semi-elasticity to quantify associations. Results showed positive associations between air pollutants and admissions, tendentially higher in respiratory diseases, with CO and $O_3$ having the highest number of associations, and the senior age group being the most impacted. We concluded that $O_3$ is a good predictor for the under-15 age group and PM10 for the over-64 age group; also, there seems to exist a distinction between the urban city core and its suburban areas in air pollution and its relation to emergency hospital admissions.

**Keywords:** air pollution; public health; hospital emergency admissions; respiratory diseases; circulatory diseases

## 1. Introduction

In the last four decades, air pollution (AP) has been considered one of the most relevant environmental problems in the world. The increase of mobility, the continuous expansion of industrial production in new locations, and the increase of chemicals in agriculture contribute to the growth of air pollution and to enlarging the impacts of it in several domains, namely the recent emergence in the public health agenda [1]. This type of pollution expands to its maximum levels in urban areas, especially in big cities and metropolitan areas, due not only to the intense traffic and general concentration of pollutants, but also to the contribution of climate change in enhancing the environmental variables for the propagation of air pollution [2–4]. Europe is not an exception, as 77% of its urban population has been exposed to unsafe levels of air pollution [5,6].

Although being a relatively recent public health concern, the relation between air pollution and health has long been discussed in academia, where many epidemiological studies have supported that air pollution has an effect on the individual's health, while those impacts can be more or less harmful [7–19]. In fact, the share of population who are more prone to the dangerous consequences are the most vulnerable groups, the young and the elderly, but also those with preexistent morbidity conditions, in which are included habits such as smoking, that compromise populations' health and enhance risks [20–23]. Furthermore, while the young population seems to have a generally faster and fuller recovery from the contact and impact of air pollution, the elderly group is more severely affected in the decline of their expected years of life [24,25], a trend that is particularly evident in Europe and North America, where the populations have been ageing, and that shows no signs of reversing [26].

The increasing importance due to its noxious levels, climate change contribution (including inherent effects on other determinants), and its concrete influence on populations health status highlights air pollution's role in public health [17], an aspect that becomes particularly evident in cities that take up the leading role in terms of air pollution—in a great extent due to traffic [27–29], but also in terms of share of affected population and due to the higher population density [30,31]. So, air pollution is a determinant of health—exogenous—since it plays a role in the health of populations, being affected and affecting other determinants (like the aforementioned climate change, traffic, or population density).

Every pollutant has its own characteristics and, therefore, different impacts on the human being. This means that the health effects of air pollution are dependent (among other factors, like exposure) on the type of pollutant. However, the main diseases associated with air pollution are respiratory and circulatory diseases, such as chronic lower respiratory diseases, upper respiratory infections, cardiac diseases, or cerebrovascular disease. Although the pollutants' emissions have plenty of sources, for instance households, industry, or traffic; in an urban context, the traffic concentration is the main source of air pollution [32].

In the last few years, among the most studied air pollutants are inhalable particles $PM_{10}$ and $PM_{2.5}$, pollutants that have been related to the decline of pulmonary function and increased risk of developing cardiovascular and circulatory diseases [9–11,21,33–37]. Other important pollutants are nitrogen oxides (big contributors to the climate change and appearance of smog), particularly the nitrogen dioxide ($NO_2$) and nitric oxide (NO), these also demonstrate—primarily the former, which has the most impacts on health (Table 1)—to prompt the individual increase of risk in developing diseases of the respiratory tract [38–44]. One of the less studied air pollutants, is carbon monoxide (CO), commonly known with the nickname of "Silent Killer". The association between CO and health is incontrovertible, the gas increasing the risk of acquiring both a respiratory or a circulatory type disease [45–48]. Besides these primary pollutants, there is a secondary one much researched (mainly in the last years), the ozone ($O_3$), that reveals a connection with the population's health, especially when related to respiratory diseases [49–55]. Table 1 shows a pertinent bibliography concerning air pollution and population health.

This study focuses on $PM_{10}$, $NO_2$, NO, CO, and $O_3$. As previously demonstrated in many studies, these pollutants are closely associated with health impacts, so we followed the main findings and analyzed the air pollution relationship with all respiratory diseases and all circulatory diseases, then singled out all cardiac diseases—in specific ischemic heart disease, cerebrovascular disease, acute upper respiratory infections, and chronic lower respiratory diseases. That being said, we are not discussing whether the disease is caused by air pollution or is an *a priori* condition, or if it is based on an acute or chronic episode; we are exploring the occurrence of an episode and its relationship with air pollutants. The health data refers to daily hospital emergency admissions (HA) in the SNS (Portuguese National Health Service). The data comprises 11 years, from 2005 to 2015, and concerns the Lisbon Metropolitan Area (LMA).

**Table 1.** Studies that analyze the relationship between air pollutants and diseases. All circulatory diseases (ACD), cardiac diseases (CARD), ischemic heart disease (IHD), cerebrovascular diseases (CD), all respiratory diseases (ARD), chronic lower respiratory diseases (CLRD), and acute upper respiratory infections (AURI).

| | ACD | CARD | IHD | CD | ARD | CLRD | AURI |
|---|---|---|---|---|---|---|---|
| CO | Franck et al., 2013 [56] | Vahedian et al., 2017 [57]; Phosri et al., 2019 | Cheng et al., 2019 [58]; Lee et al., 2020 [59] | Liu et al., 2018 [45]; Chan et al., 2006 [60] | Zhao et al., 2019 [48]; Zanobetti et al., 2006 [61] | Tian et al., 2014 [62]; Chang et al., 2020 [63] | Estrella et al., 2019 [64] |
| NO | - | Yu et al., 2013 [65]; Alexeeff et al., 2018 [66] | - | Dastoorpoor et al., 2019 [67]; Allen et al., 2006 [68] | - | - | - |
| $NO_2$ | Zanobetti et al., 2006 [61]; Yu et al., 2013 [65] | Dastoorpoor et al., 2020 [47]; Ren et al., 2020 [69] | Stieb et al., 2020 [70]; Huynh et al., 2020 [71] | Zhang et al., 2011 [72]; Massimo et al., 2014 [73] | Liu et al., 2016 [74]; Pope et al., 1991 [9] | Ghozikali et al., 2016 [75]; Rovira et al., 2020 [76] | Dawson et al., 1979 [77]; Suryadhi et al., 2020 [78] |
| $O_3$ | Raza et al., 2018 [53]; Almeida et al., 2014 [79] | Chen et al., 2007 [80]; Chiu et al., 2017 [55] | Lim et al., 2019 [81]; Suissa et al., 2013 [82] | Orellano et al., 2020 [83]; Liu et al., 2020 [84] | Tian et al., 2020 [50]; Strosnider et al., 2019 [49] | Medina-Ramón et al., 2006 [85]; Sicard et al., 2019 [86] | Wang et al., 2020 [87]; Ware et al., 2016 |
| $PM_{10}$ | Lee et al., 2014 [21]; Du et al., 2016 [88] | Newby et al., 2015 [89]; Feng et al., 2019 [33] | Stockfelt et al., 2017 [90]; Soleimani et al., 2019 [91]; | Hahad et al., 2020 [92]; Gu et al., 2017 [93] | Fasola et al., 2020 [35]; Pope et al., 1992 [94] | Pothirat et al., 2019 [95]; Janssen et al., 2002 [96] | Carugno et al., 2018; Nascimento et al., 2020 [97] |

As the air pollution impacts, in terms of quantification, are not completely transferable from region to region, in this study we aim to assess the effects of air pollution (namely, $PM_{10}$, $NO_2$, NO, CO, and $O_3$) in the health of an urban population in Southern Europe, specifically in LMA (Portugal), as it is a region with relative scarcity of studies addressing this theme. So, we assessed the association between air pollution and emergency admissions caused by all respiratory, circulatory, cardiac, ischemic heart, cerebrovascular, acute upper respiratory infections, and chronic lower respiratory diseases. This paper sheds new lights on CO, giving (fresh) importance to its impacts on emergency hospital admissions, also understanding that $O_3$ and $PM_{10}$ are good predictors for air pollution effects for different age groups, while showing that $NO_2$, although with a relative low number of associations, always has great impacts on health.

## 2. Materials and Methods

The materials and methods used to produce the regression models are described in the following subsections, which include the description of the study area and the pollution inventory, the hospital emergency admissions, and the modeling strategy. The data, methods, and the modeling strategy are summarized in Figure 1.

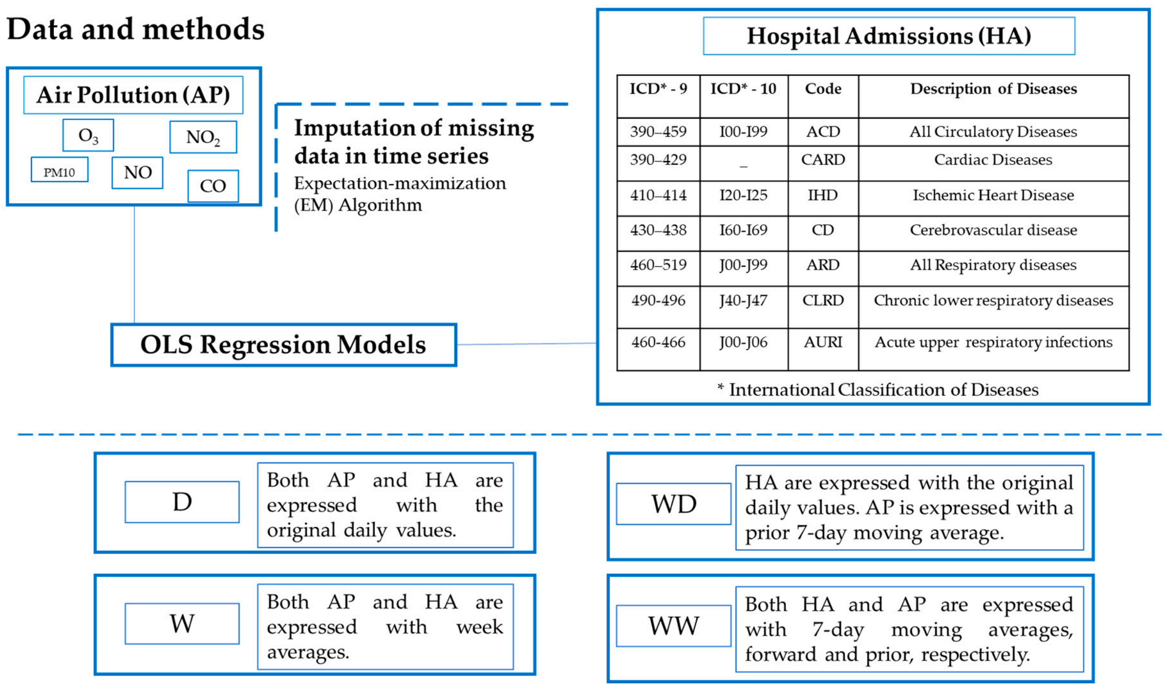


**Figure 1.** Data, methods, and modeling strategy.

### 2.1. Study Area

Although health data is complete for time and geographical frames, the air pollution data showed some liabilities. Besides the missing information regarding some air pollutants, there were too few air pollution measuring stations to be able to study the totality of Lisbon Metropolitan Area (LMA) territory with the same grade of certainty, as several municipalities had not a single measuring station within their borders, or in others the air pollution measures could only explain part of the territory (and its reality) as the bulk of population resided outside the territory of influence of the referred stations. This forced us to contain the study to three case studies, which in fact were the most urban municipalities of LMA. Also, due to the lack of data on air pollutants across all territories, we opted to maintain such a scale and develop a statistical analysis, instead of going to a parish/neighborhood scale and working on a spatial analysis base, as the main purpose was to access the municipal scale in LMA.

So, the study area includes the municipalities of Amadora, Odivelas, and Lisbon in the Lisbon Metropolitan Area. LMA is a territorial unit with a strong urban component, being one of the two existing metropolitan areas in Portugal. It is simultaneously a NUTS II and NUTS III (Nomenclature of Territorial Units for Statistical Purposes) and occupies an area of 3002 km$^2$, encompassing 18 municipalities. The three studied municipalities are located on the north flank of the Tagus river (Figure 2), being among the municipalities with the highest population density in the whole country [98].

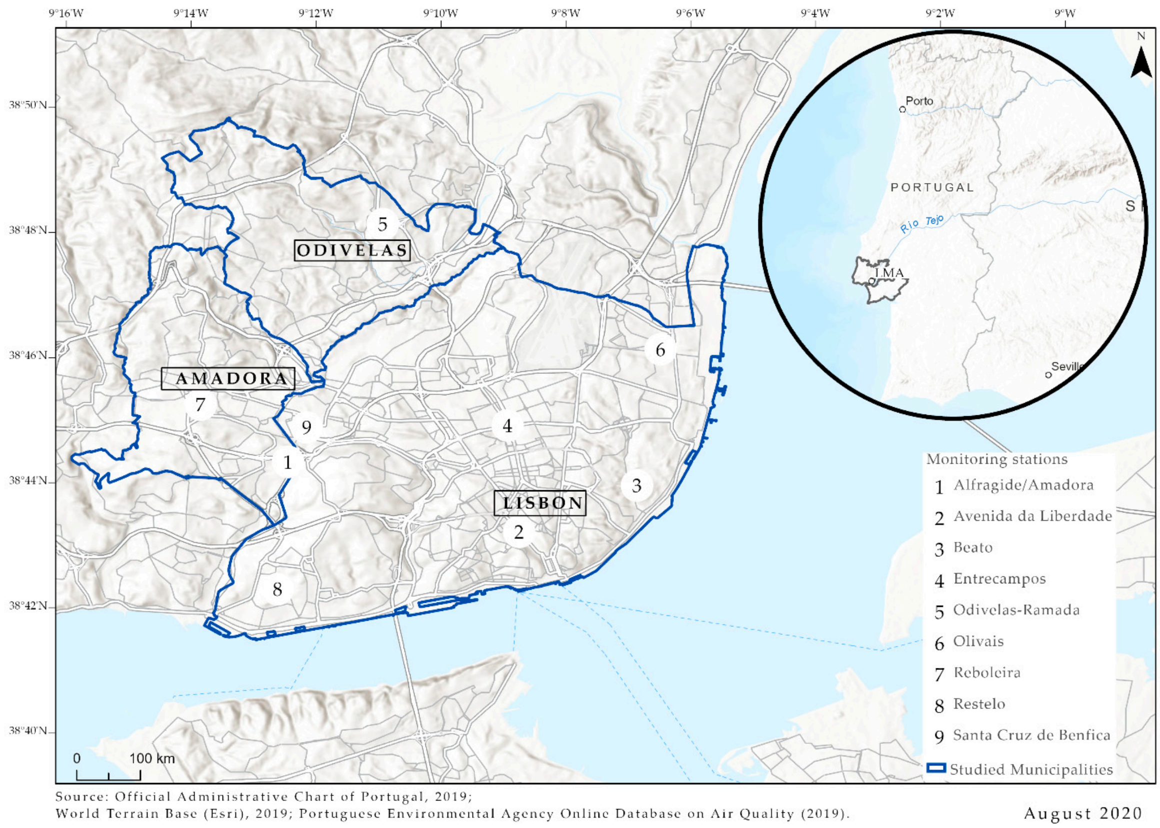


**Figure 2.** Spatial distribution of monitoring stations and Location of three municipalities: Amadora, Lisbon, and Odivelas.

The LMA constitutes the most problematic region in Portugal regarding the emission of pollutants, as it comprises municipalities with significant levels of air pollution and population (which in turn has more pollution inherent to daily life traffic and living, while putting a greater number of individuals at risk) [99]. Furthermore, studies related to this area show frequent exceedances of EU directive targets for air quality [100]. All this with a small territory and share of the economy adjudicated to industry—in fact, in the municipalities of Amadora, Odivelas, and Lisbon only an average of 3.5% of the workforce is employed in the more pollutant industries (like paper, food, chemicals, etc.) [101]. In the studied territories—and across all North LMA and almost the complete LMA—the major contributor to air pollution is traffic (over 60%), being followed at great distance by industry, energy production, and finally households' combustion [102].

However, LMA is not all the same; in fact, it is a heterogeneous region whose municipalities possess very distinct characteristics. The case studies are a good example of this trait. Lisbon municipality is the economic soul of LMA, with a thriving service economy complemented with the tourism sector, comprising the bulk of jobs in the region. Thus, it is the region's driver for growth and development. The cases of Amadora and Odivelas municipalities are much different, as these have activities related to logistics and, mainly, residential typology. These municipalities (among others in LMA) feed the workforce needs of Lisbon's dynamic economy [103].

But the differences are not only blurred in the economic part; the demographic and social questions are also dissimilar, as Table 2 shows with its demographic and socioeconomic indicators (important aspects in terms of population vulnerability). Lisbon has a larger concentration of senior population, as is expressed by the ageing index (representing the relation between the senior and young populations) and the elderly dependency index (representing the relation between the senior and active age—adult—populations), making it an older municipality and, thus, with higher vulnerability levels. In the socioeconomic aspect, Lisbon also appears as the highest scorer in each of the indicators, as one would expect for a regional economic driver. Nevertheless, Lisbon shows a consistent dichotomy in the social aspect, encompassing a great number of high-income neighborhoods with the highest median sales value per square meter, best transition/completion rate in secondary education, highest average earnings and purchasing power, socially most valued professionals, and individuals employed in consulting scientific, technical, and similar activities, while having by far the biggest concentration of social habitation (over 26,500 houses, against a total of about 3000 and 900 in Amadora and Odivelas), and the highest number of beneficiaries of social insertion income per 1000 inhabitants. So, although having some of the most qualified and richest populations in the region (and country), Lisbon also has the contrary opposite, some of the less qualified and poorest populations in the region. Hence, due to its demography and broad social aspects, Lisbon municipality shows a greater vulnerability to air pollution impacts on health. Therefore, we have three different realities and, consequently, three levels of vulnerability, as synthetized in Table 3. Also, one can never forget that this vulnerability to air pollution has a repercussion on climate change impacts.

**Table 2.** Population characteristics [101].

| | Municipality | | |
|---|---|---|---|
| | **Amadora** | **Lisbon** | **Odivelas** |
| **Ageing index** | 148.8 | 187 | 123.2 |
| **Elderly dependency index** | 35.6 | 50 | 30.2 |
| **Percentage of senior population** | 22.3 | 28.3 | 19.5 |
| **Transition/completion rate in secondary education** | 76.1 | 81.5 | 75.1 |
| **Average monthly earnings (€)** | 1283.60 | 1548.90 | 894.00 |
| **Median sales value per m$^2$ of dwellings (€)** | 895 | 2065 | 1110 |
| **Purchasing power (Portugal = 100))** | 103.87 | 214.54 | 90.27 |
| **Proportion of socially most valued professionals** | 20.81 | 42.46 | 21.44 |
| **Proportion of employment in consulting, scientific, technical, and similar activities** | 5.26 | 10.41 | 5.19 |
| **Beneficiaries of social insertion income, per 1000 inhabitants of active age** | 30.4 | 45.22 | 22.23 |

**Table 3.** Vulnerability to air pollution synthesis [101,103].

| Vulnerability Rank | Senior Population | Population Density | Socioeconomic Characteristics | Traffic | Overall |
|---|---|---|---|---|---|
| 1 | Lisbon | Amadora | Lisbon | Lisbon | Lisbon |
| 2 | Amadora | Odivelas | Odivelas | Odivelas | Odivelas |
| 3 | Odivelas | Lisbon | Amadora | Amadora | Amadora |

## *2.2. Air Pollution Data*

The pollutants concentrations for $O_3$, $NO_2$, $PM_{10}$, NO, and CO were obtained through the Portuguese Environmental Agency Online Database on Air Quality (QualAr), an online tool that provides information on air quality indexes and pollutant concentrations statistics at each monitoring station, throughout continuous measurements based on 1 h averages with data registration every

15 min (information for the period from 1 January 2005 to 31 December 2015). This data refers to nine air pollution measuring stations within an urban environment located in the three selected municipalities (Table 4).

**Table 4.** Air pollution (AP) measurement stations selected and type of influence.

| Municipality | Stations | Type of Influence |
|---|---|---|
| Amadora | Alfragide/Amadora | Background |
| | Reboleira | Background |
| | Santa Cruz de Benfica | Traffic |
| Lisbon | Beato | Background |
| | Olivais | Background |
| | Entrecampos | Traffic |
| | Avenida da Liberdade | Traffic |
| | Restelo | Background |
| Odivelas | Odivelas-Ramada | Traffic |

In the cases of Amadora (3 stations) and Lisbon (5 stations), the municipality data was obtained through the construction of a daily municipal average for each of the pollutants. This implied that at least one station had information for the pollutant in a given day. In Amadora, one station had no $O_3$ information, whilst in Lisbon there were two stations out of five with considerable missing data for $O_3$, $PM_{10}$, and CO (Table 5 presents information about data completion in all measuring stations). This was surpassed with the daily means construction, giving a daily data availability of information of over 90% (generally over 94%) in all AP for Amadora and over 99.7% in Lisbon. However, the case of Odivelas was substantially different, because in this municipality only one station was present, here the daily data availability was of almost 84.5% (except for $O_3$—63.5%—and CO—76.4%).

**Table 5.** Monitoring stations and air pollutants data considering a 75% threshold, classified as over and under the 75% mark.

| Stations | Pollutants | | | | |
|---|---|---|---|---|---|
| | **CO** | **NO** | **$NO_2$** | **$O_3$** | **$PM_{10}$** |
| Alfragide-Amadora | Over | Under | Under | Over | Under |
| Avenida da Liberdade | Under | Over | Over | Under | Over |
| Beato | Over | Under | Over | Over | Under |
| Entrecampos | Over | Over | Over | Over | Over |
| Odivelas-Ramada | Over | Over | Over | Under | Over |
| Olivais | Over | Over | Over | Over | Over |
| Reboleira | Over | Under | Over | Over | Over |
| Restelo | Over | Under | Over | Over | Under |
| Santa Cruz de Benfica | Over | Over | Over | Under | Under |

Due to the existence of some missing data, mainly in Odivelas municipality, and our overall modeling strategy, we opted to use the Expectation–Maximization algorithm—in SPSS (Statistical Package for the Social Sciences)—to impute the missing values. This method has one of the best yields when the matter is AP data [104,105].

### 2.3. Hospital Emergency Admissions

Health data information regarding the period from 1 January 2005 to 21 December 2015, was obtained from the Central Administration of the Health System (ACSS) of the Portuguese Ministry of Health. Individual daily admittance records for residents in the three municipalities were assessed for all circulatory and respiratory diseases and the age-groups: <15, 15–64, and >64 years of age. Only residents were counted because individuals not resident in these municipalities, and therefore characterized by different realities, can use a hospital located in the study area. Figure 1 shows the description of the diseases considered in this study, according to the International Statistical Classification of Diseases, 9th Revision (ICD-9), and International Statistical Classification of Diseases, 10th Revision (ICD-10). In total we selected 21 disease categories (including the three age groups in each): all circulatory diseases (ACD); ischemic heart disease (IHD); cardiac diseases (CD); cerebrovascular disease (CD); all respiratory diseases (ARD); chronic lower respiratory diseases (CLRD); acute upper respiratory infections (AURI).

### *2.4. Temporal Modeling Strategy*

In total there are 4017 original entries of data for each air pollutant and emergency hospital admissions defined. However, considering how air pollution and admissions do not correspond exactly in the time frames, as the repercussions of the first may not be noted in that exact moment, in hospital admissions four types of models were considered: D, W, WD, and WW (as shown in Figure 1). So, the temporal modeling strategy is summarized in Figure 1 and encompasses four models:

- D: the used values were the daily ones, both for air pollution and hospital emergency admissions.
- W: consists of an average value for each week, with every week counted as one temporal occurrence in air pollution and in hospital emergency admissions.
- WD: this model comprises moving averages in the air pollution part, being the seven days before the hospital admissions (beginning on this day), and the day in which admissions are registered.
- WW: finally, this model consists of two moving averages, in the air pollutants and in hospital emergency admissions, pollution is averaged for the seven days before and admissions are averaged for the seven days after. It is based on a week before (pollution)/week after (admissions) approach to hospital visits.

In terms of hospital emergency admissions, models D and WD are made with raw data, and models W and WW comprise a weekly average of admissions. As for air pollutants, only model D does not consist of an average value. This way, each model counts with 4017 (D), 573 (W), 4010 (WD), and 4003 (WW) observations, 4017 being the total number of days in the studied period. The models attempt to address the many possible temporal associations between air pollution and emergency hospital admissions; nevertheless, two of these models have the weekend problem—D and WD, as on these days admissions tend to be lower than in workdays, thus having unintended fluctuations. This was solved with the introduction of a dummy variable, which was marked as 1 for the workdays and 0 for the weekends; no dummy variable was needed in the remaining models as the moving average of seven days had already solved the aforementioned problem. As is universal knowledge, seasonality is also an issue in air pollution and emergency hospital admissions studies, hence dummy variables were inducted to control for seasonal confounding in all four models. These variables assumed the mean of daily observations for the month which they represent and 0 for the others. No control was done for national or municipal holidays.

The association between levels of air pollution and emergency hospital admissions were analyzed through ordinary least squares (OLS) linear regression using the R (4.0.1) Statistical Computing Environment, following similar studies in LMA [41,79,106]. In OLS, the dependent variables were the emergency hospital admissions, and the independent variables were the air pollutants. Multicollinearity of air pollution was always tested by assessing the variance inflation factor (VIF), enabling a better selection of independent variables; also, the zero-waste covariance was observed through the Durbin–Watson test. This analysis produced 252 regression models (4 data models; 21 disease typologies; 3 municipalities), while the number of total possible associations ascends to 1260. The models were then selected by their statistical significance when the air pollution slope was inferior to 5% ($p < 0.05$). After that, the semi-elasticity was calculated for the previously selected models. The semi-elasticity makes the comparison between the OLS regression models, the time-series studies with the Poisson regression, and the possible log-linear models (Risk Ratio effect measure).

## 3. Results

### *3.1. Air Pollution Concentration in Lisbon*

All air pollutants present a seasonal pattern with high winter levels and low summer levels—only summer and winter are shown because these seasons have the extreme climatic conditions considering temperature and humidity—except in the cases of $O_3$ and $PM_{10}$ (Table 6). In $O_3$, the summer higher values are explained by adequate weather conditions for its formation (sunlight, warm temperatures, and high emission of precursor pollutants (nitrogen oxides and volatile organic compounds) lead to high levels of this atmospheric oxidant during the summer season [107]. As for $PM_{10}$ the average and standard deviation values are higher in wintertime; however, the minimum and maximum values are higher in summertime. This variation can be justified by the seasonality of $PM_{10}$, which sees an increase in dust production in the spring and summer months compared to winter months (especially in dry years), this is due to the intrusion of Saharan particles. Also, another source of particulate matter is the natural increase in atmospheric moisture (water vapor) during the summer [108]. In general, differences between minimum and maximum are quite large, as was expected, consequently standard deviations are high, nonetheless the average and median are similar indicating a data normality.

**Table 6.** Summary statistics of air pollutants' daily average concentrations (μg $m^{-3}$, CO is in mg $m^{-3}$) for the 2005–2015 period.

| Pollutant | Municipality | Period: 2005–2015 | $\overline{X}$ | σ | Minimum | Maximum |
|---|---|---|---|---|---|---|
| $PM_{10}$ | Amadora | Summer/winter | 23.2/30.5 | 13.9/15.4 | 1.1/1.8 | 206.1/100.0 |
| | | total | 26.5 | 14.4 | 0.0 | 206.1 |
| | Lisbon | Summer/winter | 30.7/35.1 | 16.3/18.1 | 8.0/4.7 | 222.4/117.9 |
| | | total | 32.0 | 15.5 | 4.7 | 222.4 |
| | Odivelas | Summer/winter | 24.6/29.6 | 13.8/15.2 | 4.0/2.6 | 223.6/109.0 |
| | | total | 26.5 | 13.4 | 2.6 | 223.6 |
| $O_3$ | Amadora | Summer/winter | 61.0/42.6 | 17.1/19.3 | 15.8/2.8 | 123.2/92.7 |
| | | total | 52.3 | 21.0 | 1.6 | 123.2 |
| | Lisbon | Summer/winter | 60.9/41.7 | 17.0/18.2 | 18.3/4.0 | 119.5/87.0 |
| | | total | 52.5 | 20.4 | 3.6 | 119.5 |
| | Odivelas | Summer/winter | 63.0/48.5 | 16.0/17.0 | 22.5/3.1 | 129.7/99.7 |
| | | total | 57.1 | 17.8 | 3.1 | 129.8 |
| $NO_2$ | Amadora | Summer/winter | 24.5/41.8 | 15.7/19.6 | 4.3/4.0 | 106.1/102.1 |
| | | total | 34.2 | 19.1 | 4.0 | 112.7 |
| | Lisbon | Summer/winter | 29.8/44.7 | 14.3/17.2 | 8.5/9.3 | 100.5/111.0 |
| | | total | 38.1 | 16.9 | 8.5 | 122.8 |
| | Odivelas | Summer/winter | 21.8/35.2 | 10.6/15.3 | 1.8/4.8 | 78.4/98.3 |
| | | total | 29.4 | 14.5 | 1.8 | 125.2 |
| NO | Amadora | Summer/winter | 12.5/32.0 | 10.0/33.0 | 0.0/1.2 | 76.5/278.1 |
| | | total | 23.1 | 26.2 | 0.0 | 278.1 |
| | Lisbon | Summer/winter | 11.8/30.4 | 6.4/26.6 | 0.6/0.7 | 53.2/156.0 |
| | | total | 21.0 | 20.4 | 0.6 | 156.0 |
| | Odivelas | Summer/Winter | 10.0/22.8 | 5.4/20.0 | 0.3/1.6 | 39.6/164.6 |
| | | Total | 16.3 | 15.3 | 0.3 | 164.7 |
| CO | Amadora | Summer/winter | 0.3/0.5 | 0.1/0.3 | 0.0/0.2 | 1.3/1.5 |
| | | total | 0.4 | 0.2 | 0.0 | 1.5 |
| | Lisbon | Summer/winter | 0.2/0.4 | 0.1/0.1 | 0.1/0.1 | 1.2/1.2 |
| | | total | 0.3 | 0.1 | 0.1 | 1.2 |
| | Odivelas | Summer/winter | 0.2/0.3 | 0.1/0.2 | 0.1/0.1 | 0.9/1.1 |
| | | total | 0.3 | 0.1 | 0.07 | 1.1 |

When analyzing the values in Table 7 according to the European air quality guidelines suggested in Directive 2008/50/EC, it is possible to verify that, over the period in the study: (1) daily averages of $PM_{10}$ concentrations exceeded the limit of 50 μg $m^{-3}$; (2) $O_3$ concentrations in Amadora and Lisbon municipalities exceeded the octo-hourly maximum of 120 μg m$^{-3}$ (not to be exceeded more than 25 days per year); (3) daily averages of $NO_2$ concentrations exceeded the limit of 200 μg m$^{-3}$ (not to be exceeded more than 18 h per year) in the Amadora and Lisbon municipalities. Also, $NO_2$ and $PM_{10}$ annual concentrations exceeded the annual limit of 40 μg m$^{-3}$ in Amadora (4 times and 1 time, respectively) and Lisbon (18 and 9 times, respectively).

**Table 7.** Summary statistics of legal limit exceedances (μg m$^{-3}$) for the period 2005–2015.

| Year | Municipality | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Amadora | | | Lisbon | | | Odivelas | | |
| | $PM_{10}$ | $O_3$ | $NO_2$ | $PM_{10}$ | $O_3$ | $NO_2$ | $PM_{10}$ | $O_3$ | $NO_2$ |
| 2005 | 88 | 21 | 0 | 322 | 47 | 14 | 56 | 14 | 14 |
| 2006 | 53 | 18 | 6 | 280 | 17 | 21 | 48 | 8 | 7 |
| 2007 | 19 | 15 | 7 | 133 | 19 | 158 | 23 | 13 | 0 |
| 2008 | 18 | 4 | 30 | 126 | 31 | 57 | 11 | 14 | 1 |
| 2009 | 24 | 6 | 0 | 145 | 75 | 15 | 8 | - | 0 |
| 2010 | 8 | 5 | 2 | 140 | 15 | 20 | 15 | - | 0 |
| 2011 | 23 | 36 | 0 | 190 | 58 | 30 | 23 | 20 | 0 |
| 2012 | 12 | 13 | 15 | 101 | 19 | 11 | 3 | 7 | 0 |
| 2013 | 3 | 9 | 51 | 57 | 40 | 53 | 0 | 18 | 0 |
| 2014 | 1 | 13 | 48 | 47 | 21 | 21 | 3 | 0 | 0 |
| 2015 | 10 | 4 | 2 | 97 | 16 | 22 | 16 | - | 0 |

NO was not added to the table because it does not have a legal limit for exceedances. CO was not added to the table because there were no exceedances.

### *3.2. Hospital Emergency Admissions*

As depicted in Figure 3, there is a seasonality in emergency hospital admissions regarding all circulatory and all respiratory diseases. The winter months present higher values than the other months (January has the highest); in fact, the lowest values are recorded in the summer (August). These follow the air pollution trend, as all the air pollutants, except ozone, depict the highest concentrations in the winter. Also, it is known that the number of hospital emergency admissions have been rising year after year, as shown in Figures 4–6, following the overall aging of the populations in these municipalities.

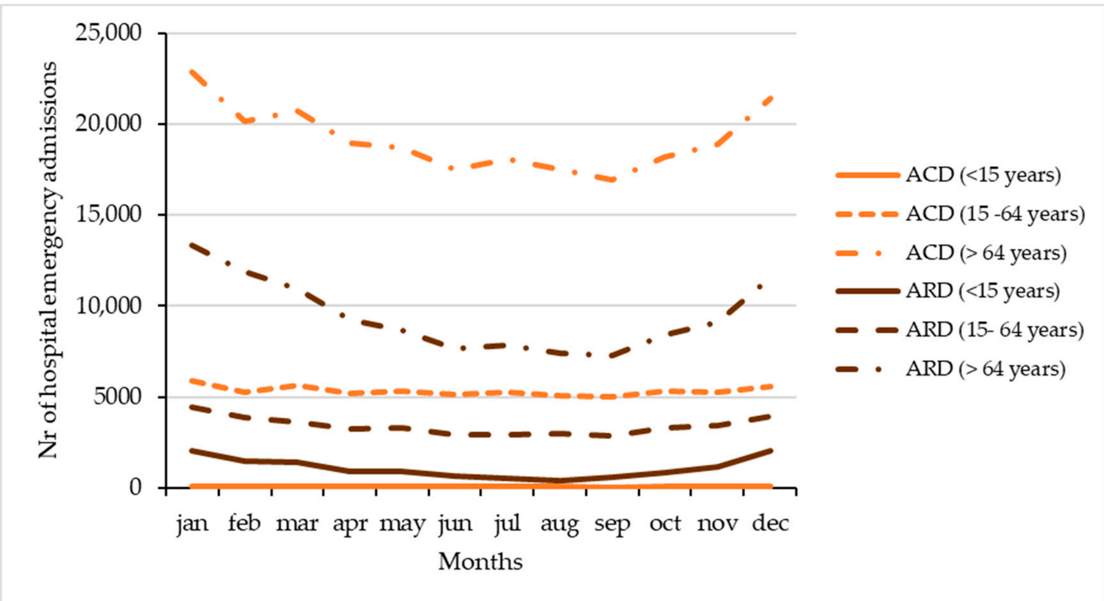


**Figure 3.** Hospital emergency admissions in all circulatory diseases (ACD) and all respiratory diseases (ARD) across all age groups (<15, 15–64, and >64 years old) by month in the 2005–2015 period.

The descriptive statistics regarding all circulatory diseases, cardiac diseases, ischemic heart diseases, cerebrovascular diseases, all respiratory diseases, chronic lower respiratory diseases, and acute upper respiratory infections in the 2005–2015 period for the three municipalities are shown in the box plot for each municipality (Figures 7–9). Results show higher emergency hospital admissions in Lisbon—this happens due to its larger population. Nevertheless, its per capita value is higher, which is closely linked with the senior population, much higher in this municipality.

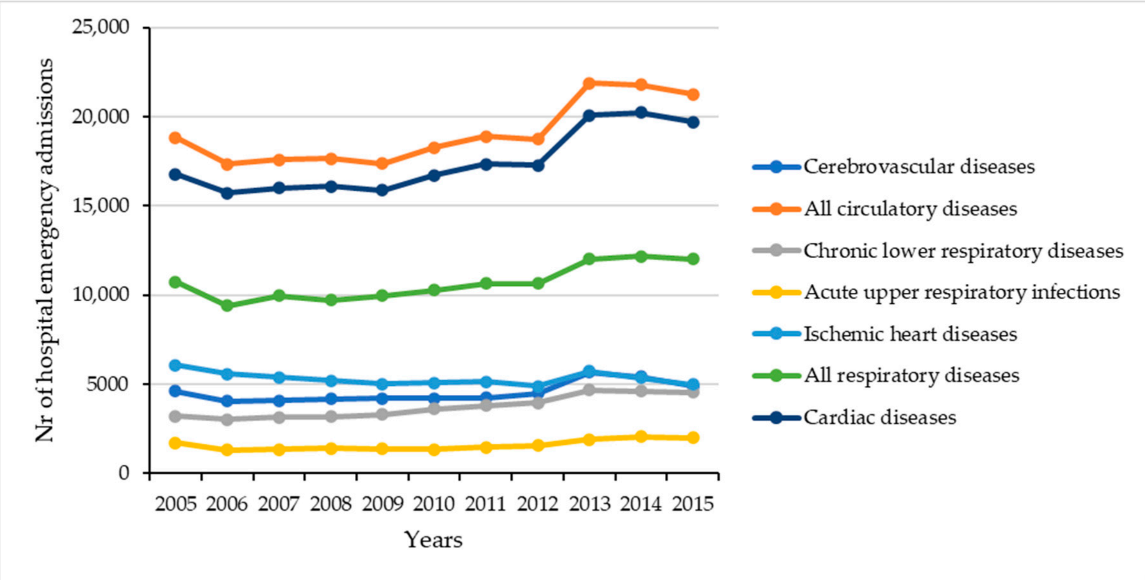


**Figure 4.** Hospital emergency admissions in all studied diseases from 2005 to 2015 in the Amadora municipality.

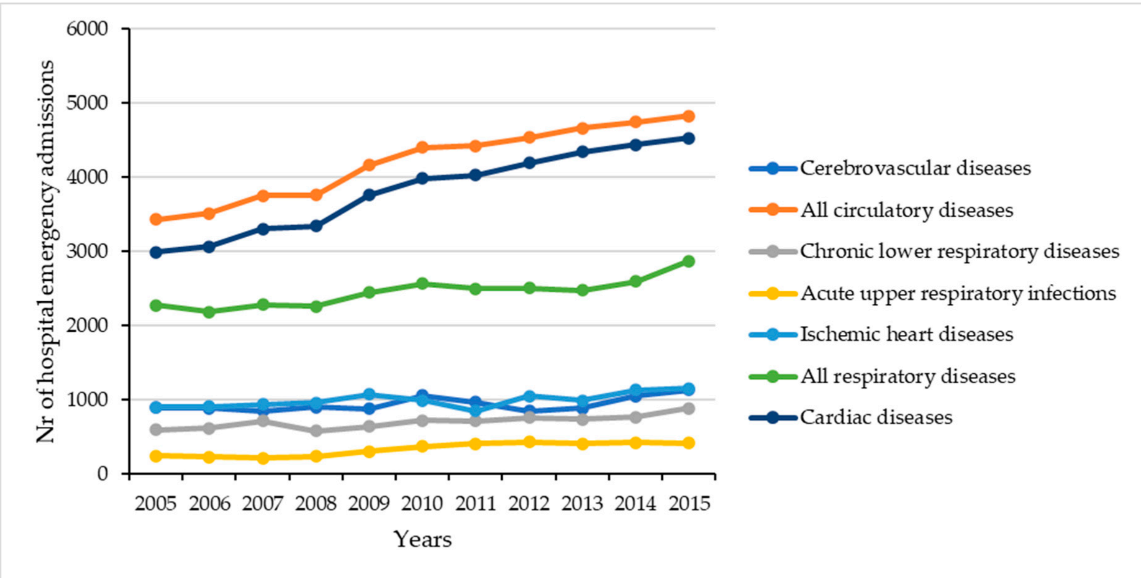


**Figure 5.** Hospital emergency admissions in all studied diseases from 2005 to 2015 in the Odivelas municipality.

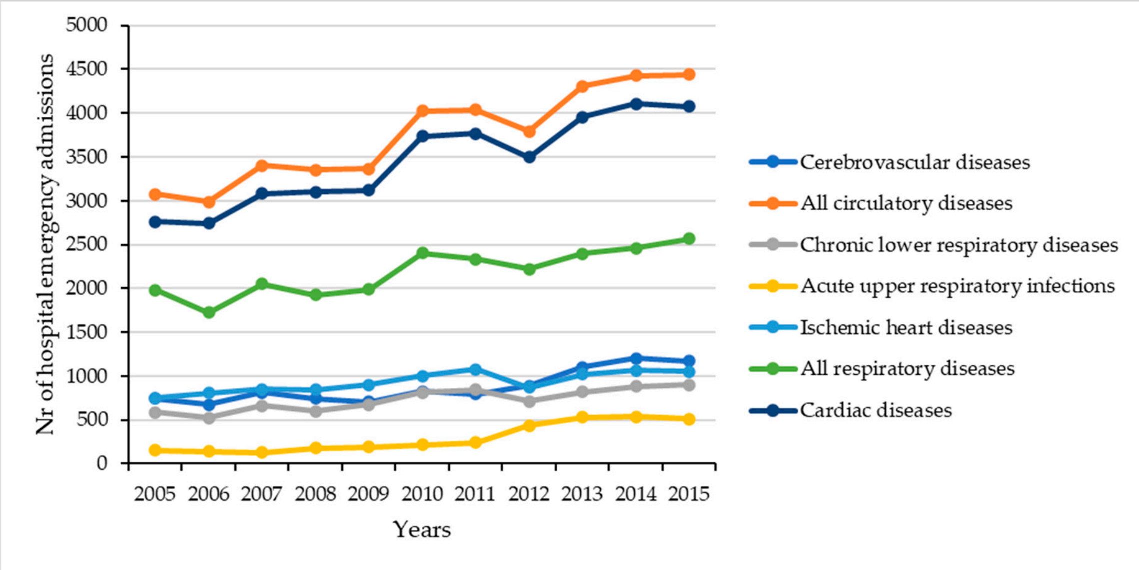


**Figure 6.** Hospital emergency admissions in all studied diseases from 2005 to 2015 in the Lisbon municipality.

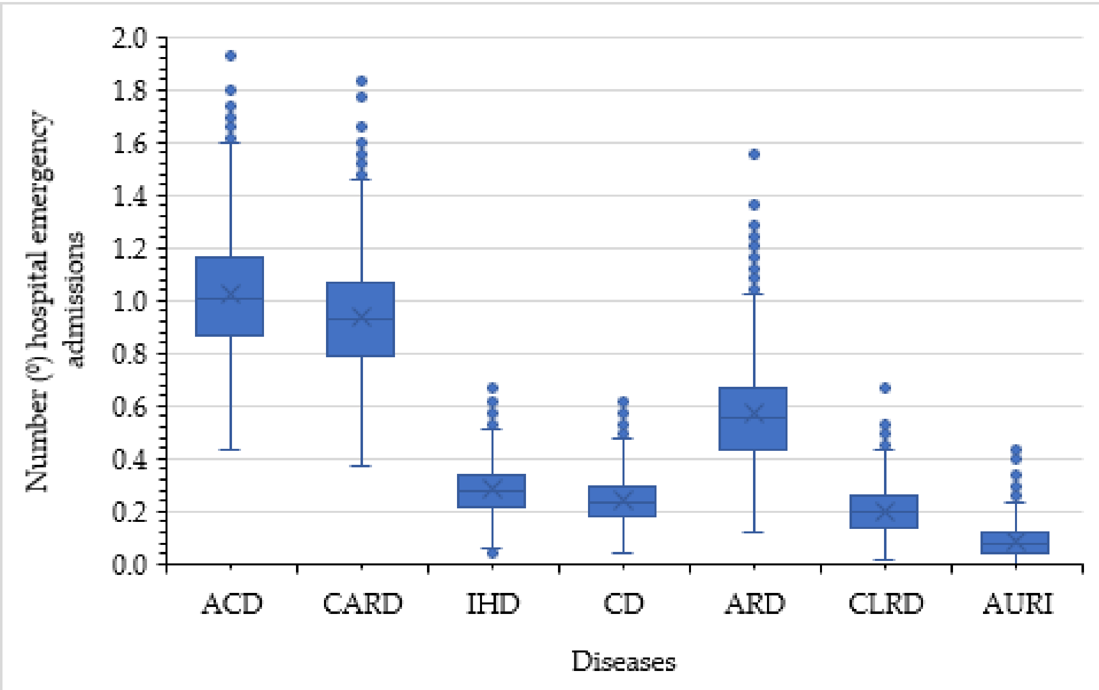


**Figure 7.** Daily hospital admissions per 10,000 inhabitants in the Lisbon municipality in the 2005–2015 period, for all circulatory diseases (**ACD**), cardiac diseases (**CARD**), ischemic heart disease (**IHD**), cerebrovascular diseases (**CD**), all respiratory diseases (**ARD**), chronic lower respiratory diseases (**CLRD**), and acute upper respiratory infections (**AURI**).

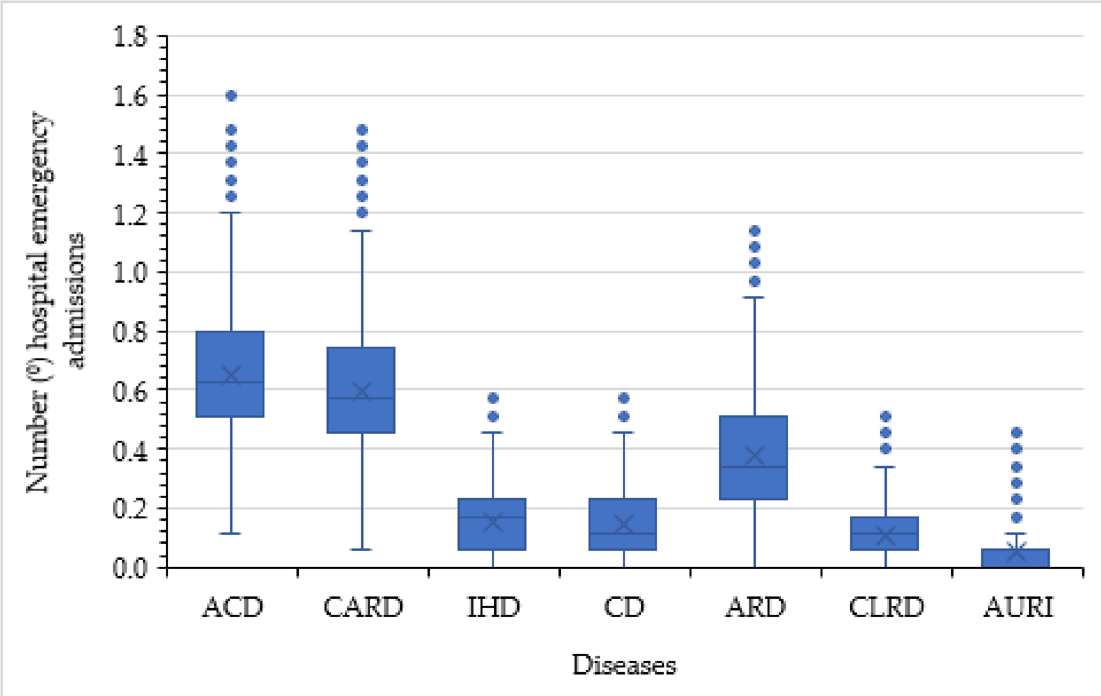


**Figure 8.** Daily hospital admissions per 10,000 inhabitants in the Amadora municipality in the 2005–2015 period, for all circulatory diseases (**ACD**), cardiac diseases (**CARD**), ischemic heart disease (**IHD**), cerebrovascular diseases (**CD**), all respiratory diseases (ARD), chronic lower respiratory diseases (**CLRD**), and acute upper respiratory infections (**AURI**).

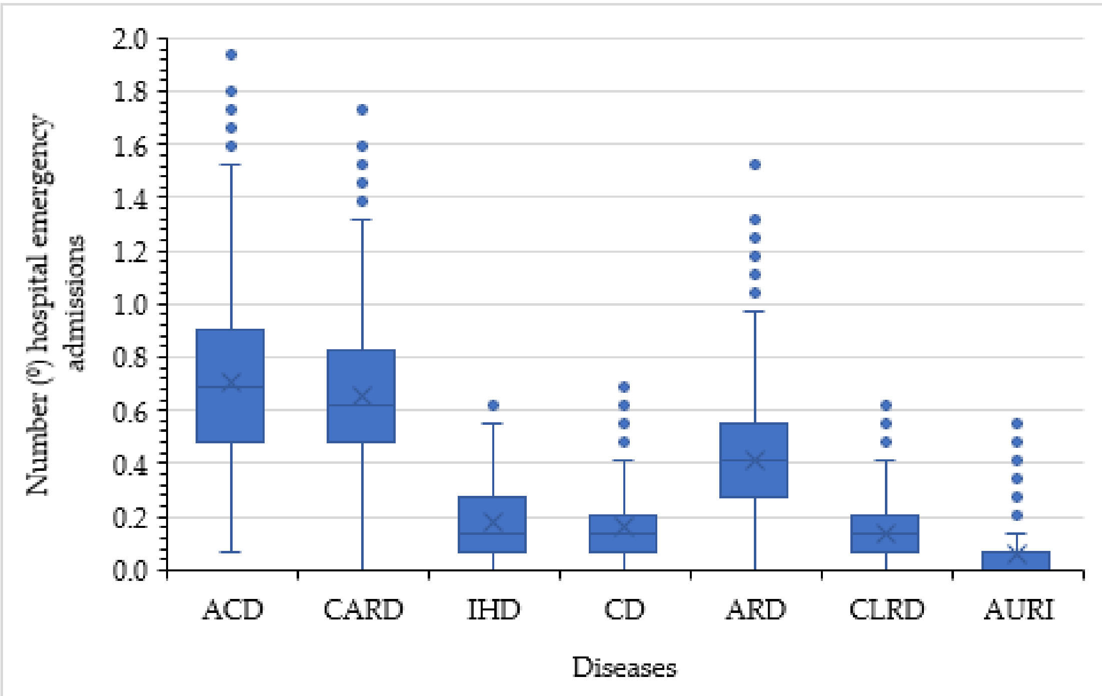


**Figure 9.** Daily hospital admissions per 10,000 inhabitants in Odivelas municipality in the 2005–2015 period, for all circulatory diseases (**ACD**), cardiac diseases (**CARD**), ischemic heart disease (**IHD**), cerebrovascular diseases (**CD**), all respiratory diseases (**ARD**), chronic lower respiratory diseases (**CLRD**), and acute upper respiratory infections (**AURI**).

### 3.3. Air Pollution Effects on Hospital Emergency Admissions

Considering all regression models obtained, about 62.3% showed a statistically significant ($p < 0.05$) association with air pollution (see Figure 10 for an example of the 4 temporal models for the cardiac diseases and the senior group). The diseases with stronger associations between air pollution and emergency hospital admissions were all respiratory diseases, followed by cardiac diseases, chronic lower respiratory diseases, and acute upper respiratory infections, so these are tendentially higher in respiratory diseases, as only cardiac diseases are of the circulatory sort. The highest average effects of air pollution in admissions are mainly felt in acute upper respiratory infections (2.93% per 10 μg $m^{-3}$ increase in air pollution), followed by ischemic heart disease (2.76% per 10 μg $m^{-3}$ increase in air pollution). In terms of all circulatory diseases and all respiratory diseases, the latter has the biggest increase due to a 10 μg $m^{-3}$ rise in air pollution: 2.2% against 1.45%.

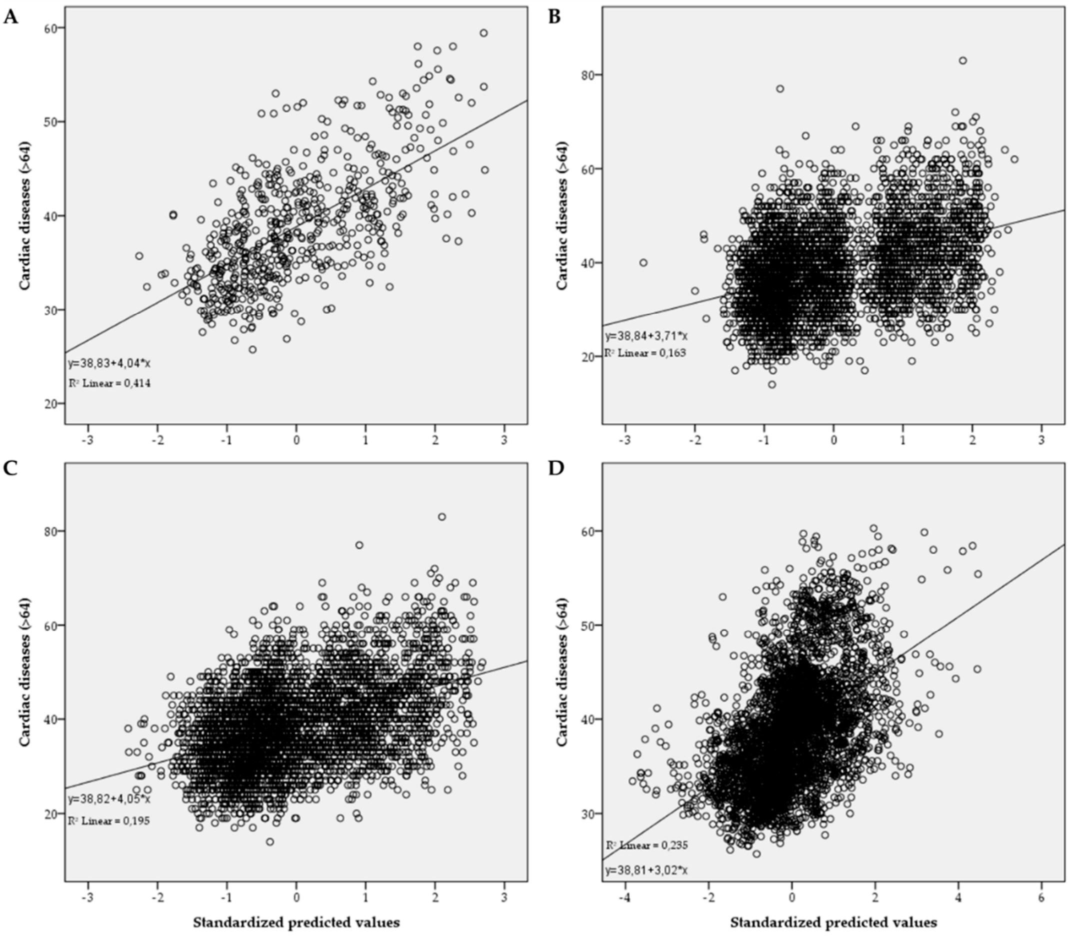


**Figure 10.** Relationship between the slopes of cardiac diseases (senior age group) (y axis) and the standardized predicted values (x axis), including the slopes and $R^2$ values. (**A**)—temporal model W; (**B**)—temporal model D; (**C**)—temporal model WD; (**D**)—temporal model WW.

Many models with no statistically significant association between air pollution and emergency hospital admissions were found in the temporal modeling strategy D; also, the municipalities of Amadora and Odivelas were the ones which counted more of these situations and Lisbon counted the opposite. The age group of <15 years old was more prone to present in these models, which is consistent with the observations, as it usually counts with the least hospital admissions of all age groups (in the diseases selected), as shown in Figure 3. On the other side, for total number of associations and highest effects in emergency hospital admissions, the models W and WW have the biggest impact across all municipalities and age groups.

Results show positive correlations between air pollution and emergency hospital admissions in all municipalities and across all temporal modeling strategies (Table A1). Nonetheless, the municipality of Amadora had the least diversity of air pollutants associations, as over 72% was with CO, Lisbon being the one with highest diversity.

In general, CO is the pollutant that counts the most associations with emergency hospital admissions across all models (constituting 46.8% of associations), as is shown in Table 8 (Table A1). However, it normally yields the lowest increase per 10 μg $m^{-3}$—especially in the <15 age group, very rarely having a rise higher than 1%, happening only with acute upper respiratory infections in Lisbon and cerebrovascular disease in Odivelas.

**Table 8.** Significant statistical relationship between air pollutants (with substantial associations, CO and $O_3$) and emergency hospital admissions per municipality and age group (observed in at least two of the temporal modeling strategies, D, W, WD, WW).

| | | **Amadora** | | | **Lisbon** | | | **Odivelas** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Pollutant** | **Disease** | **<15** | **15–64** | **>64** | **<15** | **1–64** | **>64** | **<15** | **15–64** | **>64** |
| | ACD | | X | X | | X | X | | X | X |
| | ARD | | X | X | X | X | X | | X | X |
| | AURI | | X | X | X | X | X | | | |
| CO | CARD | | X | X | X | X | X | | X | X |
| | CD | | | X | | | X | | X | X |
| | CLRD | X | X | X | | X | X | | X | |
| | IHD | | X | X | | | X | | | X |
| | ACD | | | | | X | X | | X | |
| | ARD | | | | | X | X | | | X |
| | AURI | | X | | | X | X | | | X |
| $O_3$ | CARD | | | | | X | X | | X | |
| | CD | | | X | | X | X | | | |
| | CLRD | | | | | X | X | | X | |
| | IHD | | | | | | X | | X | |

(X) Presents a significant statistical relation with that disease in at least two temporal modeling strategies.

The other substantial pollutant is $O_3$, appearing consistently in 24.2% of models and showing important effects in emergency hospital admissions. Nevertheless, its impact is most significant in Lisbon, as the bulk of its associations and greater effects are felt in this municipality. Also, this air pollutant shows no correlations with the under-15 age group. Its biggest impacts are felt in respiratory diseases, namely acute upper respiratory infections, and chronic lower respiratory diseases, increasing admissions an average of 4.1% and 4.8% per 10 μg $m^{-3}$ (the smallest values in temporal modeling strategy D and highest in W).

The biggest average effect in emergency hospital admissions across all models, municipalities and age groups comes from $NO_2$, about 4.4% increase per 10 μg $m^{-3}$. This pollutant shows greater impact in the Odivelas municipality, with little to no associations in Lisbon and Amadora. As for the diseases, its highest values appear in chronic lower respiratory diseases (>64) and acute upper respiratory infections (15–64). $NO_2$ usually shows the highest effects in adults and lowest in seniors.

NO and $PM_{10}$ demonstrate to have fewer associations in every municipality and temporal modeling strategy than other pollutants (fewer than 9% each), thus being the least meaningful across all study. Nonetheless, these air pollutants show important impacts, averaging in total over 2.93% (NO) and 3.74% ($PM_{10}$) increases in emergency hospital admissions per 10 μg $m^{-3}$ growth in air pollution. The bulk of associations of these pollutants are in Lisbon, denoting a smaller role in Amadora and being nonexistent in Odivelas. $PM_{10}$ has its major impact in all respiratory diseases (4.52% per 10 μg $m^{-3}$ increase), but, nevertheless, has a considerable effect in cardiac diseases (3.87% per 10 μg $m^{-3}$ increase). NO has its biggest effect in ischemic heart disease (4.88% per 10 μg $m^{-3}$ increase) and chronic lower respiratory diseases (4.18% per 10 μg $m^{-3}$ increase). Both $PM_{10}$ and NO seem to denote considerable stronger effects in the under 15 and 15 to 64-year-old age groups than in the senior population.

Overall, the age group of less than 15 years old shows the fewest associations with air pollution in every study area, most of these being in the circulatory diseases as expected (Table A1). Nevertheless, the biggest effects in this age group are shown by $PM_{10}$. For the adults age group, the biggest increases in emergency hospital admissions are due to $NO_2$ and then $PM_{10}$. As for the senior age group, which shows the most total relations, the biggest effects are also produced by $NO_2$, closely followed by $O_3$.

## 4. Discussion

The temporal models used in this paper (D, W, WD, WW) accounted for various temporal relations between air pollution and emergency hospital admissions, from the smallest same-day exposure and hospital care relationship, to the week before exposure and week after hospital care. All models construct information and relate it at different times, so each one has its own validity; nonetheless, the biggest coefficients of determination are present in the W and WW data models (as the example in Figure 10 shows), especially in the respiratory diseases, reaching values as high as 0.69 (acute upper respiratory infections in the <15 age group in Lisbon). This shows the goodness-of-fit of the said models, concluding that these explain (depending on the disease and age group) a considerable amount of variation in this type of hospital admissions. So, air pollution can be reiterated as an important health determinant, especially in urban areas such as LMA.

In this study, as opposed to many others (not only in the LMA region), the statistical significance was not a problem due to the analyzed period of 11 years—this translates to the existence of considerable amounts of data that ultimately sustained the findings (models and associations). Therefore, even temporal model W manages to have not only widespread statistically significant values but also many statistically significant associations between air pollution and emergency hospital admissions.

The discrepancy between municipalities is a fact. The population of Amadora seems to be less prone to air pollution effects on health (with exception to $PM_{10}$), as it generally denotes the lowest percentage increase in emergency hospital admissions due to air pollution growth. On the other side, Odivelas and Lisbon seem to be affected by the inverse situation, as consistently reveal the biggest increases in emergency hospital admissions due to rises in air pollution. The distinction of values in quantity and impact of effects is somewhat understandable, as the greater influences are felt in the municipality with the highest vulnerability. Lisbon municipality is the focus of daily commuting in LMA, being where most of employment (besides population) is located, and, consequently where the traffic is more intense [103]. Therefore, the air pollution concentration is generally higher for Lisbon, but, more importantly, this municipality registers the highest number of limits exceedances. Thus, the relation between air pollution and emergency hospital admissions is different, suggesting an urban/suburban areas effect [74], where the core urban region has a greater number of associations and many of the top effects, as is indicated to happen with Lisbon in the LMA region. Following many other international findings, this also suggests that higher exposure to traffic is closely related to higher numbers of admissions in the observed diseases [28,109,110]. Ultimately, the vulnerability to air pollution accessed (see the synthesis presented in Table 3) is coherent with the findings, as greater vulnerability conduces to more and higher impacts on population health.

The considerable amount of associations between CO and emergency hospital admissions in all study areas brings a renovated interest for this pollutant. Although counting no exceedances in the 2005-2015 period, the fact is that its effect is still noticeable. Cruz et al. also found associations with CO and hospital admissions in LMA, however in much smaller numbers and impacts [41]. This makes the "silent killer" an actually "silent killer", as it poses—supposedly—minor threats due to the compliance with legal limits, yet the health effects seem to still be there and in great number. In this study we assessed that CO's greatest effects are felt by the 15–64 and >64 age groups in cerebrovascular diseases and acute upper respiratory infections, reaching values over 2% increase in emergency hospital admissions per 10 μg $m^{-3}$ increase. So, CO appears to be a great concern for both respiratory and circulatory diseases, and due to its larger normal quantity in air (when compared to other pollutants), the 10 μg $m^{-3}$ increase occurs more easily.

As in other studies, we have found that even when the legal limits for air quality are not surpassed, air pollution seems to have an adverse effect on health. This finding calls for the continuous study of its relationship with health and for the rethinking of pollution limits.

Although having only a few associations, $NO_2$ registered the biggest average increase in emergency hospital admissions per 10 μg $m^{-3}$ rise across all models. This was fairly expected due to its prevalence in traffic-congested areas, as in the case of LMA [61].

$O_3$ showed not only high correlation levels with respiratory diseases but also with circulatory diseases, like other international studies have pointed out [54,55], in fact the emergency hospital admissions increase for Lisbon is very similar in all circulatory diseases and all respiratory diseases. Most studies do not find such a significative relation with admissions, but the lag used in them amounts only to a few days. We also found fewer associations in the day models. However, when using a lag of a week or more—as was used here—the associations increase, not only in number but in power—for instance the temporal model WW's associations almost double the ones found in model D. So, it seems that $O_3$ may have a somewhat retarded effect in admissions, following such findings in Europe [53]. This is the first study expressing such an association in this territory. Also, the greater number of associations in Lisbon suggests that ozone affects emergency hospital admissions mainly in the urban areas with greater traffic levels, as opposed to the suburban areas. This delay may be justified by the land and sea breeze circulation that occurs in many large cities built near the coast, which see their pollutants issuing into the atmosphere [111].

A reduced number of relations between $PM_{10}$ and emergency hospital admissions were found, just in Lisbon and Amadora, and never with the 65 and over age group. This runs along with other studies that show that particle matter may not be the best predictor for hospitalization in LMA [41,52]. Nevertheless, even if reduced, its impacts appear to be considerably powerful. In this study we found that $PM_{10}$ may not have a perfect association with the total admissions (all age groups) but is of greater importance in the under-15 age group, being its major impactor.

We may then infer that ozone and particulate matter are important for emergency hospital admissions in different manners, although the main difference in function is the prediction—the former is a good predictor for the older population and the latter for the younger population.

## 5. Conclusions

In this study we found a considerable number of associations between air pollution and emergency hospital admissions across all analyzed diseases, no matter if circulatory or respiratory. We also found that municipalities with higher levels of vulnerability to air pollution (traffic, population density, socioeconomic characteristics, climate change) present more relationships between air pollutants and hospital emergency admissions. The total number of CO relations with emergency hospital admissions, although not having surpassed any air quality limits, draws attention to the importance of air pollution even when its levels are below such limits. We conclude that $O_3$ is a good predictor for emergency hospital admissions but not for the under-15 year-old group, and $PM_{10}$ has the contrary characteristic, being a good predictor for that group. Also, our findings suggest that a considerable distinction amidst the urban city core and its suburban areas exists in terms of air pollution and its emergency hospital admissions effects. Finally, the senior age group is the one with the most total associations and the under-15 group the one with the least.

In the future, we want to analyze the autumn season—mainly due to the higher concentration of pollens in October—and explore the effects of secondary pollutants whenever possible, consequently better to understand the relationship between the concentration of pollutants and the emergency hospital admissions in this season.

**Author Contributions:** All authors made substantial contributions to the conception and design of the study and were involved in critically revising the manuscript in terms of intellectual content. In addition, P.F. and C.G. formulated the idea, research goals, and aims. P.F. and C.G. performed data collection, analysis, and developed the methodology. P.F. and C.G. wrote the manuscript. E.M.d.C. and A.L. supervised the study and critically revised the manuscript. All authors have read and agreed to the published version of the manuscript.

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## Appendix A

**Table A1.** Significant statistical relationship between air pollutants (with substantial associations, CO and $O_3$) and emergency hospital admissions per municipality and age group (observed in at least two of the temporal modelling strategies, D, W, WD, WW).

| | | | **Amadora** | | | **Lisbon** | | | **Odivelas** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AP | Disease | Model | <15 | 15–64 | >64 | <15 | 15–64 | >64 | <15 | 15–64 | >64 |
| CO | ACD | D | | 0.19 | 0.39 | | | | | | |
| | | W | | 0.32 | 0.41 | | | 0.51 | | | 0.85 |
| | | WD | | 0.20 | 0.43 | | 0.02 | 0.45 | | 0.83 | 0.85 |
| | | WW | | 0.25 | 0.41 | | 0.17 | 0.40 | | 0.88 | 0.90 |
| | ARD | D | | | 0.23 | | | 0.33 | | 0.25 | |
| | | W | | | 0.26 | | | 0.65 | | 1.16 | 1.04 |
| | | WD | | | 0.27 | 0.53 | | 0.60 | | 0.74 | 0.70 |
| | | WW | | 0.09 | 0.25 | 0.69 | 0.53 | | | 1.12 | 1.03 |
| | AURI | D | | | 0.12 | | | 0.73 | | | |
| | | W | | 0.39 | 0.91 | | 2.21 | 1.70 | | | |
| | | WD | | 0.11 | 0.10 | 0.76 | 0.47 | 1.16 | | | |
| | | WW | | 0.36 | 0.93 | 1.29 | 1.88 | 1.49 | | | |
| | CARD | D | | 0.23 | 0.44 | | | 0.26 | 0.08 | | |
| | | W | | 0.41 | 0.47 | | | 0.54 | | | 0.81 |
| | | WD | | 0.24 | 0.49 | | | 0.51 | | | 0.95 |
| | | WW | | 0.34 | 0.48 | 0.82 | 0.19 | 0.43 | | 0.80 | 0.89 |
| | CD | D | | | 0.09 | | | 0.62 | | | |
| | | W | | | | | | 0.97 | | 2.38 | |
| | | WD | | | | | | 1.02 | | 0.12 | 0.83 |
| | | WW | | | | | | 0.83 | | 1.11 | 1.12 |
| | CLRD | D | 0.09 | 0.05 | | | 0.48 | 0.44 | | | |
| | | W | 0.10 | 0.48 | 0.23 | | 0.80 | 0.83 | | 1.72 | |
| | | WD | 0.10 | 0.09 | 0.15 | | | 0.86 | | | |
| | | WW | 0.11 | 0.54 | 0.28 | | 0.72 | 0.79 | | 1.91 | |
| | IHD | D | | | 0.10 | | | | | | |
| | | W | | 0.21 | | | | 0.36 | | | |
| | | WD | | | 0.14 | | | | | | 0.38 |
| | | WW | | | 0.28 | | | | | | 1.27 |

**Table A1.** *Cont.*

| | | | Amadora | | | Lisbon | | | Odivelas | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NO | ACD | W | | | | | 3.17 | | | | |
| | | WW | | | | | 1.49 | 1.78 | | | |
| | ARD | W | 3.19 | | | | | | | | |
| | | WD | 0.57 | | | | | | | | |
| | | WW | 3.75 | | | | 2.18 | 1.88 | | | |
| | CARD | W | | | | | 3.33 | | | | |
| | | WW | | | | | 1.93 | 2.01 | | | |
| | CD | WW | | | 1.89 | | | 1.38 | | | |
| | CLRD | WW | | | | 6.80 | 3.33 | 2.41 | | | |
| | IHD | D | | | | | 1.75 | | | | |
| | | W | | | | | 9.18 | | | | |
| | | WW | | | | | 3.70 | | | | |
| $NO_2$ | ACD | D | | | | | | | | | 2.61 |
| | | W | | | | | | | | | 4.12 |
| | | WD | | | | | | | | | 4.51 |
| | | WW | | | | | | | | | 3.78 |
| | ARD | D | | | | | | | 0.88 | | 1.62 |
| | | W | | | | | | | | | 4.68 |
| | | WD | | | | | | | 3.29 | | 1.76 |
| | | WW | | | | | | | 10.16 | | 3.47 |
| | AURI | WD | | | | | | | 1.78 | | |
| | | WW | | | | | | | 6.71 | 8.50 | 5.18 |
| | CARD | D | | | | | | | | | 3.15 |
| | | W | | | | | | | | | 4.53 |
| | | WD | | | | | | | | | 6.10 |
| | | WW | | | | 0.12 | | | | | 4.30 |
| | CD | WD | | | | | | | | | 3.47 |
| | | WW | | | | | | | | 4.26 | 6.89 |
| | CLRD | WD | | | | | | | | 3.10 | |
| | | WW | | | | | | | | | 8.87 |
| | IHD | W | | | | | 9.18 | | | | |
| | | WW | | | | | | | | 2.77 | |
| $O_3$ | ACD | W | | | | | 1.94 | 3.28 | | | |
| | | WD | | | | | | 3.41 | | | |
| | | WW | | | | | 1.50 | 3.45 | | 1.46 | |
| | | D | | | | | 1.36 | 1.42 | | | 1.46 |
| | ARD | W | | | | | 2.96 | 3.63 | | | |
| | | WD | | | | | 2.71 | 3.73 | | | |
| | | WW | | | | | 2.42 | 3.90 | | | |
| | AURI | D | | | | | 0.92 | 1.90 | | | 1.94 |
| | | W | | | | | 10.38 | 5.53 | | | |
| | | WD | | | | | 1.19 | 5.13 | | | 3.26 |
| | | WW | | 3.13 | | | 5.00 | 7.20 | | | 4.60 |
| | CARD | D | | | | | | 1.26 | | | |
| | | W | | | | | 2.01 | 3.47 | | | |
| | | WD | | | | | 1.48 | 3.32 | | | |
| | | WW | | | | | 1.72 | 3.79 | | 2.15 | |
| | CD | D | | | 1.45 | | | 2.48 | | | |
| | | W | | | 4.55 | | | 5.05 | | | |
| | | WD | | | 2.39 | | | 5.90 | | | |
| | | WW | | | 4.30 | | 1.54 | 5.78 | | | |
| | CLRD | D | | | | | 3.01 | 2.02 | | | |
| | | W | | | | | 7.54 | 5.85 | | 3.33 | |
| | | WD | | | | | 4.51 | 5.80 | | | |
| | | WW | | | | | 7.08 | 5.66 | | 3.24 | |
| | | WW | | | | | | 0.70 | | 2.03 | |
| | IHD | D | | | | 3.62 | | | | | |

**Table A1.** *Cont.*

| | | | Amadora | | | Lisbon | | | Odivelas | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $PM_{10}$ | ARD | W | 3.62 | | | 7.34 | | | | | |
| | | WD | | | | 5.61 | | | | | |
| | | WW | 2.30 | | | 4.65 | | | | | |
| | | D | | | | 3.08 | | | | | |
| | AURI | WW | | | 3.54 | 1.78 | | | | | |
| | | W | | 3.69 | | | | | | | |
| | CARD | WW | 4.07 | | | | | | | | |
| | | D | | | | | | 2.30 | | | |
| | IHD | W | | 9.48 | | | | 2.66 | | | |
| | | WD | | 1.83 | | | 2.59 | 1.61 | | | |
| | | WW | | 5.47 | | | 4.30 | 1.32 | | | |

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