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Investigation into Atmospheric Pollution Impacts on Hospital Admissions in Attica Using Regression Models †

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Abstract: Research in the field of air pollution epidemiology is crucial for identifying and enhancing quality of life by taking measures to manage adequately related medical emergencies. The aim of this paper is to investigate how the occurrence of certain respiratory and cardiovascular diseases in the urban population of the Attica region is affected by the existence of air pollution. The study takes into consideration the daily hospital admissions from two hospitals in central and western Attica as well as the air quality status from the neighboring monitoring stations. The Generalized Linear Models with Poisson Distribution were applied because of the distribution followed by the medical data. Preliminary results from the regression analysis revealed the relationship between pollutants' concentrations and the associated health effects derived from public hospitals in Attica. The effects of the pollution episodes on health are closely related to factors such as the gender and age of patients, as well as the length of their hospital stays.

Keywords: air pollution; health impacts; Generalized Linear Models; Athens; Greece

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1. Introduction

The World Health Organization stated in 2017 that globally around 7 million premature deaths are linked to air pollution [1]. In addition, nine in ten individuals inhale air containing significant amounts of pollutants. Several studies revealed that particulate matters (PM) are among the primary pollutants that have harmful effects on human health. Being exposed to PM for both short and extended periods is linked to increased morbidity and mortality, such as acute respiratory illness, chronic obstructive pulmonary disease, cardiovascular disease and others [2,3]. Governments spend billions annually on public health systems to tackle the severe impacts of air pollution on human health. This is particularly crucial in densely populated urban areas with high levels of particulate matter (PM) [4]. In the past decades, research on environmental issues has seen a significant statistical advancement with the introduction of Generalized Linear Models (GLMs). To estimate the effects of air pollution on health, GLMs are commonly utilized considering the non-linearity of air pollution data and the response variable, which is usually hospital admissions or mortality [5,6].

2. Data and Methodology

When analyzing epidemiological time series data that involve counts, the Poisson process with a homogeneous risk (λ) is typically used to model the underlying mechanism. This process assumes the expected number of counts on a given day (t) for the underlying population. The probability of y occurrences on day t is defined by the equation

$$\mathrm{prob}(y|\lambda) = \frac{e^{-\lambda}\lambda^{y}}{y!} \tag{1}$$

The Poisson regression model is based on the assumption that

$$E(y|x) = e^{(\alpha+\sum \beta x)} \tag{2}$$

In the context of Poisson regression, variable x refers to a column vector that contains the independent variables (also called covariates) on day t. The regression coefficients β represent the effect of each independent variable on the expected value of the dependent variable y on day t. The dependent variable y is the count variable being modeled, and its value depends on those of the independent variables in x. The latter equation could also be formulated as (GLM) [7]. In epidemiology, Poisson regression is valuable because it allows for the estimation of the relative risk (RR) associated with a unit increase in a pollutant. This estimation is obtained through the calculation of the exponential value of the regression coefficient β for that pollutant. In other words, the relative risk is equal to the exponential of the regression coefficient associated with the pollutant, leading to the function

$$RR(x) = e^{\beta x} \tag{3}$$

This study utilized medical data collected from hospitals in the Greater Athens Area, in particular Evangelismos and Pamakaristos hospitals (Central Athens) and Attiko hospital (West Athens). Daily hospital admissions were collected from 2018 to 2020 for cardiovascular and respiratory diseases as the response variable for the GLM model. In addition, PM_{10} hourly concentrations from Peristeri Station (West Athens), and Aristotelous station (Central Athens) were used for the same period, obtained from the Greek Ministry of Environment and Energy (MEEN). To enhance the accuracy of the results, medical data from the municipality of Athens and Galatsi were exclusively used for the Central Athens area. This was implemented to guarantee that the medical data utilized in the study were in close proximity to the air pollution monitoring station. The Greater Athens Area as well as the Central and Western Athens regions, the two monitoring stations and the location of the three hospitals are presented in Figure 1. To create the x variable in the GLM model, the maximum daily number of consecutive hours of exceedances (CHE) was calculated, based on the EU threshold for PM_{10} (50 $\mu g/m^3$). During the regression analysis, the β coefficient was determined to detect the time lag between PM_{10} CHE and hospital admissions. This coefficient represents the best estimate for the magnitude and direction of the association between the two variables. The Poisson regression model was performed using the GLM function in R environment, which allowed for the estimation of the relative risk associated with an increase in PM_{10} CHE.

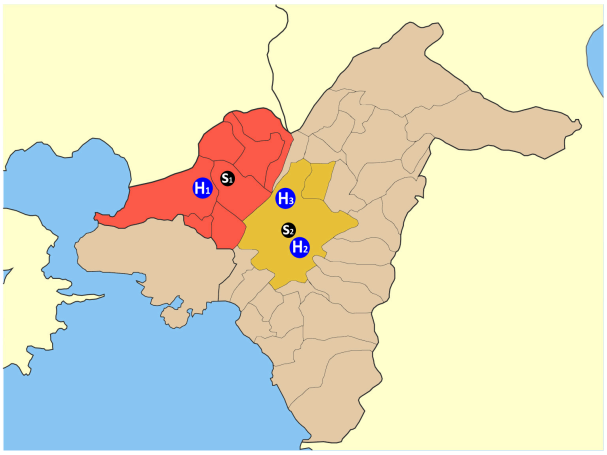


Figure 1. Map of the study area: West Athens (red) and Central Athens (orange). Hospitals are marked in blue circles: Attiko (H_1), Evangelismos (H_2) and Pamakaristos (H_3). Monitoring stations are marked in black circles: Peristeri (S_1) and Aristotelous (S_2). The rest of the Greater Athens Area is colored in light brown.

3. Discussion and Results

In both municipalities, the lagged effects of PM_{10} exposure on hospitalizations were examined by considering the daily PM_{10} CHE as a proxy for exposure and the hospital admissions for the health outcome. The results of the Poisson regression model for PM_{10} pollution and hospital admissions in both locations (West Athens and Central Athens) are presented in Tables 1–4. The estimates, standard errors and p-values for different lag days (0–5) between PM_{10} exposure and hospital admissions are displayed. The estimates represent the change in hospital admissions associated with a unit increase in PM_{10} CHE. The standard errors provide a measure of the precision of the estimates, and the *p*-values (Pr) indicate the significance of the estimates. A *p*-value less than 0.05 suggests statistical significance, indicating that the association between PM_{10} exposure and hospital admissions is unlikely to be due to chance.

Table 1. Results analysis of hospital admissions for 0–5 lag days (best parameters in bold).

	West Athens			Central Athens		
Lag Days	**Estimate**	**Std. Error**	**Pr.**	**Estimate**	**Std. Error**	**Pr.**
0	0.042	0.012	4.17×10^{-4}	0.027	0.012	2.84×10^{-2}
1	0.044	0.012	2.15×10^{-4}	0.040	0.012	5.19×10^{-4}
2	**0.072**	**0.010**	$\mathbf{3.30 \times 10^{-12}}$	**0.045**	**0.011**	$\mathbf{6.23 \times 10^{-5}}$
3	0.040	0.012	9.73×10^{-4}	0.014	0.013	2.84×10^{-1}
4	0.019	0.013	1.47×10^{-1}	0.002	0.014	8.94×10^{-1}
5	0.011	0.014	4.33×10^{-1}	0.008	0.014	5.78×10^{-1}

The analysis revealed a statistically significant association between hospital admissions due to respiratory and cardiovascular diseases and air pollution levels in the region. The results indicate that the coefficients were significant at two lag days, with the exception of males in Central Athens, where only one lag day was observed. This may suggest that there are unique behavioral factors that account for this different pattern of results. The higher coefficients in the West Athens area compared to Central Athens suggest that the air quality in West Athens may be worse. This is supported by the mean daily value of maximum consecutive hours of PM_{10} excess cases, which is approximately 2.3 in West Athens compared to 1.8 in Central Athens for days with non-zero CHE. Greater coefficients, particularly among males compared to females, suggest that there may be differences in vulnerability and responses to PM_{10} CHE between the two locations. This is in contrast to Central Athens, where the opposite pattern was observed regarding the genders. Such disparities in demographics and health status could potentially contribute to the variations in the coefficient estimates. In addition, the findings suggest that older individuals (aged over 70) in both areas are more susceptible to the impacts of PM_{10}. Moreover, there is an indication that the potential cost of hospitalization increases significantly with the occurrence of PM_{10} CHE, while the RR of hospital admissions due to respiratory and cardiovascular diseases increases, with a two-day lag, by a factor of approximately 1.074 and 1.046, respectively, for every unit of PM_{10} CHE for both West Athens and Central Athens. Based on Equation (3) and the data derived from the aforementioned tables, Figures 2–5 illustrate the best associations between RR and PM_{10} CHE. The observed associations between air pollution and hospital admissions due to relative diseases call for urgent measures to reduce air pollution levels and protect public health.

Table 2. Results analysis of male hospital admissions for 0–5 lag days (best parameters in bold).

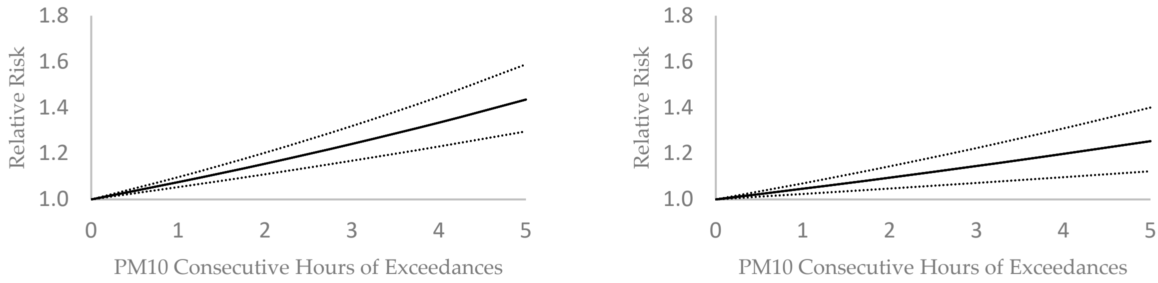
	West Athens			Central Athens		
Lag Days	**Estimate**	**Std. Error**	**Pr.**	**Estimate**	**Std. Error**	**Pr.**
0	0.052	0.015	6.11×10^{-4}	0.022	0.016	1.76×10^{-1}
1	0.043	0.016	6.92×10^{-3}	**0.045**	**0.014**	$\mathbf{1.93 \times 10^{-3}}$
2	**0.076**	**0.014**	$\mathbf{2.23 \times 10^{-8}}$	0.040	0.015	7.36×10^{-3}
3	0.044	0.016	5.17×10^{-3}	0.016	0.017	3.35×10^{-1}
4	0.027	0.017	1.09×10^{-1}	0.011	0.017	5.22×10^{-1}
5	−0.008	0.020	7.00×10^{-1}	0.009	0.017	5.82×10^{-1}

Table 3. Results analysis of female hospital admissions for 0–5 lag days (best parameters in bold).

	West Athens			Central Athens		
Lag Days	**Estimate**	**Std. Error**	**Pr.**	**Estimate**	**Std. Error**	**Pr.**
0	0.028	0.020	1.50×10^{-1}	0.035	0.019	6.77×10^{-2}
1	0.046	0.018	1.13×10^{-2}	0.032	0.020	1.07×10^{-1}
2	**0.068**	**0.016**	$\mathbf{2.90 \times 10^{-5}}$	**0.055**	**0.017**	$\mathbf{1.43 \times 10^{-3}}$
3	0.034	0.019	7.01×10^{-2}	0.011	0.022	6.15×10^{-1}
4	0.008	0.021	7.11×10^{-1}	−0.012	0.024	6.25×10^{-1}
5	0.031	0.019	1.02×10^{-1}	0.001	0.023	9.53×10^{-1}

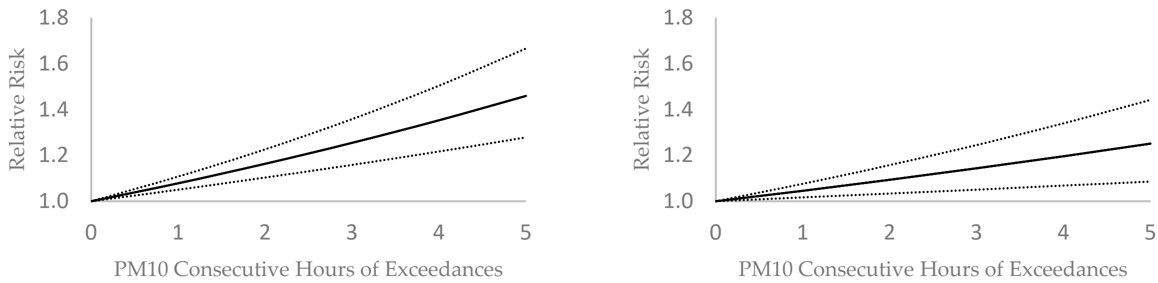
Table 4. Results analysis of hospital admissions (≥70 years old) for 0–5 lag days (best parameters in bold).

	West Athens			Central Athens		
Lag Days	**Estimate**	**Std. Error**	**Pr.**	**Estimate**	**Std. Error**	**Pr.**
0	0.060	0.015	3.41×10^{-5}	0.031	0.016	5.50×10^{-2}
1	0.058	0.015	8.73×10^{-5}	0.054	0.014	1.41×10^{-4}
2	**0.049**	**0.013**	$\mathbf{1.80 \times 10^{-9}}$	**0.060**	**0.014**	$\mathbf{1.36 \times 10^{-5}}$
3	0.01	0.015	7.68×10^{-4}	0.027	0.016	1.03×10^{-1}
4	0.021	0.017	2.20×10^{-1}	0.013	0.018	4.56×10^{-1}
5	0.029	0.017	8.46×10^{-2}	0.026	0.017	1.22×10^{-1}



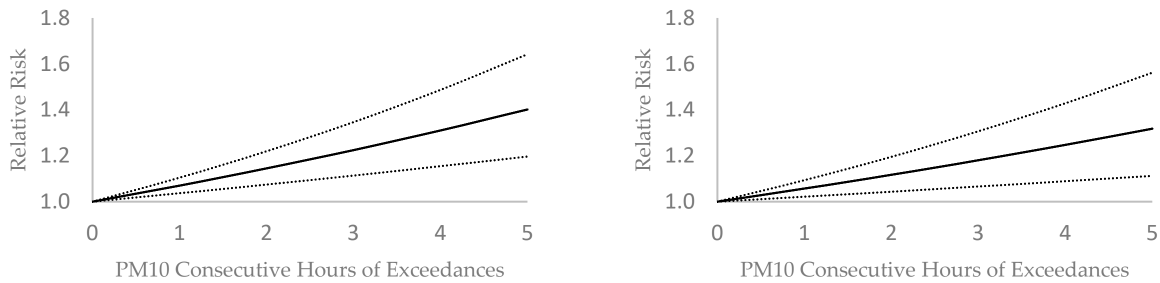
(**a**) (**b**)

Figure 2. Estimates of RR for the model considering the lag effect, according to the increase in PM_{10} CHE (the dashed lines are the confidence interval upper and lower RR, respectively): (**a**) hospital admissions RR in West Athens; (**b**) hospital admissions RR in Central Athens.



(**a**) (**b**)

Figure 3. Estimates of RR for the model considering the lag effect, according to the increase in PM_{10} CHE (the dashed lines are the confidence interval upper and lower RR, respectively): (**a**) male hospital admissions RR in West Athens; (**b**) male hospital admissions RR in Central Athens.



(**a**) (**b**)

Figure 4. Estimates of RR for the model considering the lag effect, according to the increase in PM_{10} CHE (the dashed lines are the confidence interval upper and lower RR, respectively): (**a**) female hospital admissions RR in West Athens; (**b**) female hospital admissions RR in Central Athens.

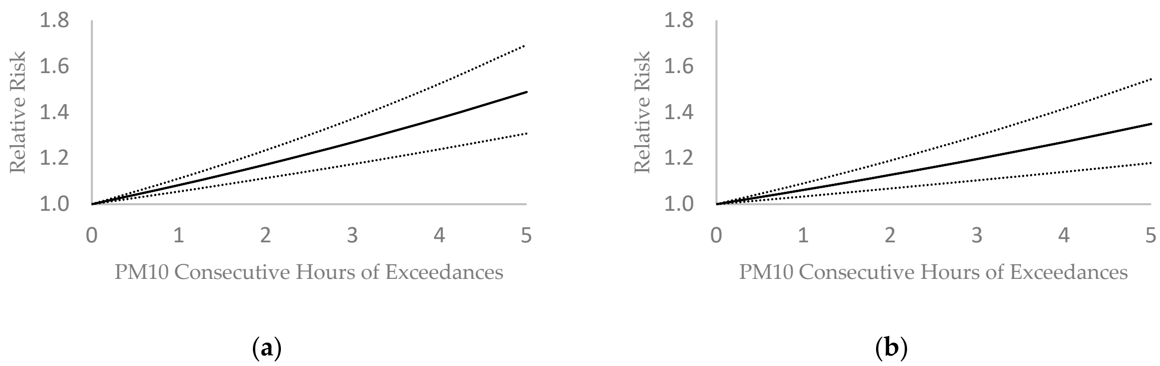


Figure 5. Estimates of RR for the model considering the lag effect, according to the increase in PM_{10} CHE (the dashed lines are the confidence interval upper and lower RR, respectively): (**a**) hospital admissions RR (≥70 years old) in West Athens; (**b**) hospital admissions (≥70 years old) RR in Central Athens.

4. Conclusions

A study on the atmospheric pollution impacts on hospital admissions in Attica using regression models was performed. The findings suggest that short-term exposure to PM_{10} pollution may increase the risk of hospitalization due to respiratory and cardiovascular diseases, highlighting potential significant expenses, as well. In most cases, the highest associations were found with a lag of two days, indicating a delayed effect of PM_{10} exposure on health. Impacts were stronger for older age groups, whereas differences in demographics and health status among cities and genders can affect vulnerability and responses to environmental exposures, such as air pollution. These findings have important implications for public health policies and underscore the need for continued efforts to improve air quality and reduce exposure to particulate matter.

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