EFFECTS OF AIR POLLUTION AND WEATHER PARAMETERS ON HUMAN HEALTH IN THE CITY OF ATHENS, GREECE

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INTRODUCTION

Health and air pollution

The adverse effects of air pollution on human health have become widely acknowledged over the last decades and a wide variety of epidemiological studies (Schwartz, J and A. Marcus, 1990; Schwartz, J. and B. Morris, 1995; Katsouyanni, K. *et al.,* 1997) have quantified these effects for a number of regions, countries and time periods, showing harmful effects even for low concentration levels (Brunekreef, B and S.T. Holgate, 2002).

Health and climate

However, mortality and morbidity are also affected by extreme and moderate weather phenomena, including heat waves and cold spells (Braga, A.L.F. *et al.,* 2002; Patz, J.A. and R.S.Kovats, 2002; Pattenden, S. *et al.,* 2003; Kalkstein, L.S, 1993). Thermal stresses contribute to the aggravation of cardiovascular and respiratory diseases or even deaths by these causes (Haines, A. *et al.,* 2000; Martens, W.J.M, 1996). Additionally, The International Panel on Climate Change (1996) issued a warning about potential further effects of climate change, including raised occurrence of skin cancer and glaucoma.

Present study

The great variety of statistical tools and approaches can influence the outcome of each study. In this study, we refer to the widely accepted Generalized Additive Models (GAMs), which allow for non-linearities and to Linear Models with Poisson and normal distribution (GLM). Additionally, we use monthly data to display aggregated effects over the period of a month or of adjacent months, which escape investigation in short and long-term studies.

DATA

The Department of Air Quality operated by the Ministry for the Environment, Physical Planning and Public Works provided the pollution data (CO, NO_2, NO, SO_2, O_3). The values of the pollutants come from the station Patision, measured on an hourly basis. The weather data, provided by the National Meteorological Service and collected from the station 701, located in Nea Philadelfia, include average daily figures for average/maximum/minimum temperature, precipitation, wind strength, relative humidity and atmospheric pressure. Finally, morbidity data were proxied by "number of patients discharged by main categories of diseases and place of permanent residence" collected from hospital records from the area of greater Athens. Three conditions were considered: "diseases of the circulatory system"[9], "diseases of the respiratory system"[10] and "diseases of the skin and subcutaneous tissue"[11]. The period analysed is 01/01/1986- 31/12/1999.

[9] ICD-9: 390-398, 401-405, 410-417, 420-438, 440-448 and 451-459.
[10] ICD-9 460-466, 470-478, 480-487, 490-496, 500-508 and 510-519.
[11] ICD-9: 680-686, 690-698 and 700-709.

METHODS

We evaluated the effects of pollution and climate parameters on human health and tested the sensitivity of the results under different model specifications. Three models were used: Linear models assuming normal distribution, Generalised Linear Models (GLM) assuming Poisson distribution and Generalised Additive Models (GAMs) assuming Poisson distribution. As Schwartz, J. *et al.* (1996) argue, the difference in the results between modelling count data as Poisson or Gaussian is not significant.

A major issue in the epidemiological literature is the control for serial correlation, seasonality and other cyclical patterns. As it was argued in the APHEA project (Schwartz, J. *et al.,* 1996) parametric approaches can be applied using sine and cosine terms with different wavelengths in order to capture distinct shapes and patterns (Katsouyianni, K. *et al.,* 1996). Our choice of order was decided upon minimisation of the Akaike's Information Criterion, AIC (Akaike, H., 1973). Additionally, a time trend and its square were introduced in the models as well as a dummy variable for each month in order to account for the systematic differences among months (Wooldridge, J.M., 2003). If it was needed, autoregressive terms were included. Our purpose was to obtain white noise for all the models' residuals, observing through correlograms and formally testing using the Portmanteau (Q) statistic for white noise.

First and second order lags of all the explanatory variables were included in all the models apart from the GAMs, where first order lags were used. First or second order lags are more than sufficient since the short/medium term effects of air pollution and weather do not last longer than a month (Laschewski, G. and G. Jendritzky, 2002; Pattenden, S. *et al.,* 2003).

Gaussian Linear Model

For the Gaussian linear model with a log link function, the specified expectation of the random variable Y_t is

$$E(Y_t / X_t) = \exp(\beta_0 + \sum_{i=1}^{n} \beta_i X_{i,t} + \ln(WMA(Y)) \qquad (1)$$

Here Y_t denotes the monthly interval values of the circulatory, respiratory and skin diseases. $X_t = (X_{1,t},..., X_{i,t})$, where $i=1,\ldots,n$ denotes all the explanatory variables and $\ln(WMA(Y))$ the logarithm of the weighted moving average of *Y*. Additionally, models with the logarithms of the explanatory variables, instead of the linear forms, were specified.

Generalised Linear Model

For the GLM we used the same specification and procedure as above while, a Poisson distribution was assumed instead (McCullagh, P. and J.A. Nelder, 1989).

Generalised Additive Model

GAMs are a nonparametric alternative to the GLM and allow for non-linear relationships between the response variable and the control variables (Hastie, T.J. and R.J. Tibshirani, 1990). However, a GAM can be turned into a semi-parametric model including some variables as smooth functions and some others as linear. This can be done by adjusting the degrees of freedom of the specific smooth functions to one. Therefore, this would give us a different specification

$$E(Y_t / X_t) = \exp(\beta_0 + \sum_{r=1}^{p} \beta_r X_{r,t} + \sum_{i=1}^{n} g_i(X_{i,t})) \qquad (2)$$

Every g_i denotes a smooth function that is used in the model. We used cubic smooth splines to estimate the non-parametric functions g_i (Dominici, F. *et al.,* 2002) while all the $X_{r,t}$ where $r=1,...,p$ are introduced as linear. The appropriate amount of degrees of freedom was decided using two approaches: primarily, the AIC, which penalizes the amount of degrees of freedom used and secondarily the deviance.

RESULTS

For the indicator of circulatory diseases the results are fairly consistent throughout the study and despite the several model specifications. NO and SO_2 were persistently significant in all models with a 10μgr/m^3 increase leading to a 0.2%-0.6% and a 0.5%-1.6% respectively, increase in circulatory diseases. Similarly, an increase of 1^0C in mean temperature resulted in a 2.5%-6% increase, while for the increase of the minimum temperature by 1^0C lead to a 2.7%-7.7% decrease in the numbers of occurrence.

For the indicator of respiratory diseases the most useful results were obtained from the GAMs, where a 10μgr/m^3 increase in NO_2 and O_3 was to be followed by a 1.3 to 2% and 1.7%-1.8% increase, respectively. Again, raising maximum temperature by 1^0C would result in a 7%-16% increase in respiratory diseases, while for an increase of the same amount for the minimum temperature the effect would be a 2%7% decrease in the same values. For the rest of the specifications the effects of pollution and weather were either insignificant or not existent at all.

Finally, for the diseases of skin and subcutaneous tissue, CO was highly significant for linear models with normal and Poisson distribution showing a negative effect and increasing the number of diseases by 0.5%-3.3% for every additionally unit (mgr/m^3) of CO. For GAMs the results suggested that NO_2 and O_3 were the most harmful with a 1.5%-1.7% increase for every additional 10 μgr/m^3. However, the results for temperature were more consistent showing a decline (1.6%-3.5%) in the numbers of diseases for every unit increase of minimum temperature and an increase (3.5%-7%) for the same change in maximum temperatures.

Additionally, throughout the study humidity was significantly positively correlated with all of health indicators, while the months that appeared to have mainly persistent negative effects were May and March.

DISCUSSION

Our results confirmed what has already been argued in the literature. The analysis certifies the harmful effects of air pollution and weather parameters, mostly temperature. In two previous studies in Athens (Touloumi, G. *et al.*, 1996; Katsouyianni, K., 1995) SO_2 was positively correlated with health showing a 3% to 8% increase in daily deaths and a 6% increase in hospital admissions for every additional 100 μgr/m^3 and 25μgr/m^3, respectively. Significant also seemed to be the results for other pollutants, such as NO_2 and CO. In other studies (Linn, W.S. *et al.,* 2000; Saez, M. *et al.,* 2002) NO_2 was positively associated with cardiovascular admissions and deaths increased risk ranging from 14%(admissions for every 10pphm) to 1% (deaths for every 10μgr/m^3).

In our study O_3 resulted to be irrelevant for circulatory diseases, something that was also confirmed by Anderson, R.H. *et al.* (1996). The impact of O_3 in respiratory diseases was, similarly, obtained by other studies (Brunekreef, B. and S.T. Holgate, 2002). Desqueyroux, H. *et al.* (2002) reported that a 10mgr/m^3 increase was associated with an increase in the relative risk (OR= 1.20, 95% CI) of asthma attack. Moreover, the relation of pollution and skin diseases is not a common finding in the literature (Mar, A. and R. Marks, 1999; Polosa, R. 1999). Yet, ground-level ozone is inseparably connected to sun and sunlight. Brunekreef, B. and S.T. Holgate (2002) confirm “high ozone concentrations during warm and sunny weather” (p. 1233). This could create a combined effect responsible for skin diseases. Finally, our results for temperature also comply with the literature. As already pointed out (Patz, J.A. and R.S. Kovats, 2002), populations in warmer and temperate climates tend to be more sensitive to low temperatures, while populations of colder climates are more vulnerable to heat.

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