Effect of socioeconomic status on the association between air pollution and mortality in Bogota, Colombia

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Abstract

Objective. To evaluate the modification effect of socioeconomic status (SES) on the association between acute exposure to particulate matter less than 10 microns in aerodynamic diameter (PM_{10}) and mortality in Bogota, Colombia. **Materials and methods.** A time-series ecological study was conducted (1998-2006). The localities of the cities were stratified using principal components analysis, creating three levels of aggregation that allowed for the evaluation of the impact of SES on the relationship between mortality and air pollution. **Results.** For all ages, the change in the mortality risk for all causes was 0.76% (95%CI 0.27-1.26) for SES I (low), 0.58% (95%CI 0.16-1.00) for SES II (mid) and -0.29% (95%CI -1.16-0.57) for SES III (high) per 10µg/m^3 increment in the daily average of PM_{10} on day of death. **Conclusions.** The results suggest that SES significantly modifies the effect of environmental exposure to PM_{10} on mortality from all causes and respiratory causes.

Key words: mortality; socioeconomic status; particulate matter; Bogota; Colombia

Blanco-Becerra LC, Miranda-Soberanis V, Barraza-Villarreal A, Junger W, Hurtado-Díaz M, Romieu I. Efecto del nivel socioeconómico sobre la asociación entre contaminantes atmosféricos y mortalidad en Bogotá, Colombia. Salud Publica Mex 2014;56:371-378.

Resumen

Objetivo. Evaluar el efecto modificador del nivel socioeconómico (NSE) sobre la asociación entre la exposición aguda a partículas menores de 10 micras de diámetro aerodinámico (PM_{10}) y la mortalidad en Bogotá, Colombia. **Material y métodos.** Se realizó un estudio ecológico de series de tiempo (1998-2006). Mediante análisis de componentes principales se estableció una estratificación de las localidades de la ciudad, de lo que se generaron tres niveles de agregación que permitieron evaluar el impacto de la variable NSE en la relación mortalidad-contaminación atmosférica. **Resultados.** En todas las edades, para la mortalidad por todas las causas, el porcentaje de cambio en el riesgo fue 0.76% (IC95% 0.27-1.26) en el NSE I (bajo), 0.58% (IC95% 0.16-1.00) en el NSE II (medio) y -0.29% (IC95% -1.16-0.57) en el NSE III (alto), por incremento de 10µg/m^3 en el promedio diario de PM_{10} en el día del deceso. **Conclusiones.** Los resultados sugieren que el NSE modifica de manera significativa el efecto de la exposición ambiental a PM_{10} sobre la mortalidad por todas las causas y causas respiratorias.

Palabras clave: mortalidad; nivel socioeconómico; partículas; Bogotá; Colombia

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Urban growth in developing countries has been characterized by informality, illegality and the lack of settlement planning. Urban development has also been associated with an increase in poverty as well as low socioeconomic status (SES) areas.[1] Income inequality is higher in the developing world than developed countries, as seen in Latin America and the Caribbean (LAC).[1] One way to measure the inequality of incomes between countries is the Gini coefficient,[2] which takes values between 0 and 1, 0 being perfect equality and 1 perfect inequality.

LAC has one of the highest rates of urbanization, where 75% of the population lives in urban areas. Many cities in this region have poor air quality as a result of unplanned urbanization, augmented vehicular fleets and obsolete industrial technologies.[3] Epidemiological studies conducted in developed and developing countries worldwide have reported an increase in mortality from all causes, and particularly from cardiopulmonary causes, as a result of exposure to air pollution, and especially from particulate matter smaller than 10 microns (PM_{10}).[4-7] Although SES can modify the effect of air pollution on mortality,[8] available studies do not allow for either confirming or completely discarding the influence of SES on this association.[9-14] Groups with low SES tend to live in areas where they are exposed to high concentrations of air pollutants, compared to those groups with high SES.[10,14,15]

Air pollution affects a large number of inhabitants[3] in Bogota, the capital district (DC, abbreviation in Spanish) of Colombia.[16] PM_{10} concentration maps show how the distribution of this contaminant more greatly affects poor social groups. The greatest concentrations of PM_{10} are located in the south and southwest portions of the DC, areas where a large proportion of people of low SES reside.[17]

Bogota has a Gini coefficient between 0.60 and 0.69, which is higher than that estimated for similar cities in the region (0.52),[1] thus showing greater inequality. This research aims to evaluate the modification effect of socioeconomic status (SES) on the association between acute exposure to PM_{10} and daily mortality from all causes, and specifically from cardiopulmonary diseases, in the general population and among those over 65 years old in Bogota, Colombia.

Materials and methods

Study design: An ecological study was conducted using a time-series analysis from April 1998 to December 2006. This study was based on the methodology applied in the "Multi-City Study of Air Pollution and Health Effects in Latin America."[18] The study protocol was reviewed and approved by the ethic committee of the National Institute of Public Health (INSP, Spanish acronym). Bogota is divided into 20 administrative units or localities. For the purpose of the SES analysis, the localities were stratified based on three levels of aggregation, which enabled evaluating the effect on mortality and air pollution (figure 1). The Sumapaz locality was omitted from the analysis because it is a rural area that represents only 1% of the total city population (n = 5 792). Therefore a total of 19 municipalities were included in the analysis.

Mortality data: Information regarding the total number of daily deaths registered in Bogota DC was obtained from death certificates. The basic cause of death provided by the Bogota District Secretary of Health (DSH) was used, and only information about the deaths of those who were residents at the time of death in any of the 19 localities in DC was included in the study. The outcomes analyzed were all causes of death (ICD: A00-T98), respiratory (ICD: J00-J98) and cardiovascular causes (ICD: I00-I99), according to the 10th International Classification of Diseases (ICD).

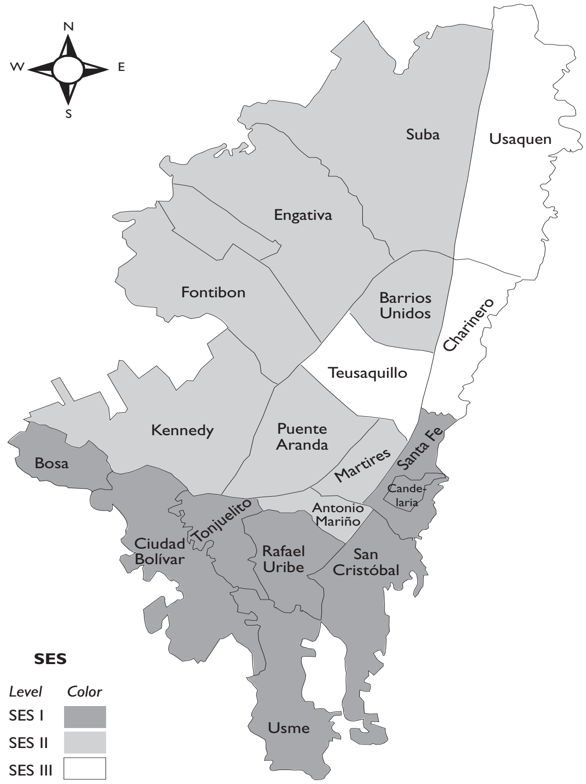


Figure 1. Stratification of the 19 localities by socioeconomic status SES I (low), SES II (mid) and SES III (high) in Bogota D.C. Colombia. 1998-2006

Socioeconomic strata to evaluate SES were generated by grouping localities with similar socioeconomic characteristics; daily mortality for each level was assigned according to the daily death counts in each stratum.

Meteorological, air pollution and SES data: Hourly data for air pollutants were obtained from the Bogota Air Quality Monitoring Network (BAQMN). Temperature and relative humidity (RH) registries were obtained from the BAQMN and the Institute of Hydrology, Meteorology and Environmental Studies (IHMES) stations. Information for constructing the SES stratification of the city was obtained from the 2005 census and the 2007 Bogota Quality of Life Survey conducted by the National Administrative Department of Statistics.

Exposure assessment: Daily (24-hr) averages of PM_{10} were calculated for all monitoring stations, considering a sufficiency criterion of 75% of data. The same procedure was carried out for temperature and RH. In order to assign exposure for each SES, daily average PM_{10} was calculated using the daily registries of the stations located within the localities of each SES. When stations were not available within the locality, the values of the closest air quality monitoring station were assigned, considering a distance between the monitoring station and locality of less than 5km.

Statistical analysis

SES: The SES of the deceased were defined by applying multivariate techniques for each locality based on four-dimensional indicators related to SES: income (Gini coefficient,[2] percentage of households with high economic level), housing conditions (percentage of households with inadequate housing services), living conditions (percentage of households in indigence, poverty and critical overcrowding)[11] and educational level (percentage of households with school non-attendance). These indicators or similar ones have been used in other studies.[2,8,12,13,15,19,20] Prior to analysis, all indicators were standardized to avoid the influence of measurement units and to provide the same weight in the analysis. In order to obtain the SES stratification, first, biplots were generated to graphically observe the relation between localities and indicators.

Subsequently, a cluster analysis was performed to build hierarchies, a K-means algorithm was applied for data partitioning and groups were randomly selected. Although these analyses indicated three to four SES levels, there was greater uniformity and consistency when localities were grouped into just three levels, therefore three was the final number of socioeconomic levels used in the study (figure 1). To assign high (SES III), middle (SES II) and low (SES I) levels, a factor analysis using principal components was performed, in which the first component explained 84% of the total variability. This analysis was used in other studies.[10,13] The above assignation was based on sorting scores by locality. Finally, to validate the results, a discriminate analysis was conducted on all three predefined locality groups.

The levels generated are as follows:

- SES I (low): Bosa, Ciudad Bolívar, Rafael Uribe, San Cristóbal, Santa Fe, Tunjuelito y Usme.
- SES II (mid): Antonio Nariño, Barrios Unidos, Candelaria, Engativá, Fontibón, Kennedy, Mártires, Puente Aranda y Suba.
- SES III (high): Chapinero, Teusaquillo y Usaquén.

Time series analysis: The Generalized Additive Model (GAM) with Poisson regression[21] was used to model the relationship between the daily number of deaths and PM_{10} levels. Short-term fluctuations were controlled using variables that indicated days of the week, long weekends and holidays. With respect to the adjustment of meteorological factors, temperature and RH variables were taken into account, including functions, considering the effect on daily average with a 1-day lag, and with 4 and 2 *df* per year, respectively.

The baseline was as follows:

$$Ln\ (E(Yt)) =$$
$$\beta 1 * DF\ national + \beta 2 * DF\ religious + \beta 3 * DS + \beta 4 * FS + ns\ (Temp,\ gi1,1) + (Hum,gi2,1) + ns\ (time,\ gi3)$$

where *Yt* is the number of deaths in a day *t*, $DF_{national}$ and $DF_{religious}$ are holidays categorized as *national* and *religious*, *DS* is the days of the week, *FS* is long weekends, *ns* is natural smooth functions of temperature (*Temp*), RH (*Hum*) and time (*time*), and g_i is the *df* for each function.

An independent model was generated for each cause of death studied, according to the groups *all ages* and *over 65 years old*. To calculate the percentage change in risk of mortality attributed to each increase of $10\mu g/m^3$ in PM_{10} average levels, single lag models (SLM), moving average models (MA) and distributed lag models (DLM) were adjusted, the SLM having a simple lag factor from 0 to 3 days, the MA having an average of up to 3 days lag and the DLM an evaluation of cumulative periods of 3 and 5 days prior to the event.

For more detailed information about the topics covered in the materials and methods section, see the study by Blanco *et al*.[22]

Results

During the period of time studied, 76 404 deaths were registered for SES I (low), 106 704 for SES II (middle) and 24 632 for SES III (high) for all causes, with a daily average of 24 (standard deviation SD = ± 5.38), 33 (SD = ± 6.42) and 8 (SD = ± 2.78) deaths, respectively. A total of 53% (n= 109 775) of the deceased were people over 65 years old, of which 54% (n= 59 364) was observed to be in SES II. The average mortality for respiratory and cardiovascular diseases was higher for SES II (table I).

The daily average PM_{10} was 60.12$\mu g/m^3$ (SD= ± 18.78) for SESI, 71.05$\mu g/m^3$ (SD= ± 19.44) for SES II and 36.95$\mu g/m^3$ (SD= ± 17.10) for SES III, with daily maximum values for each SES greater than or equal to 123$\mu g/m^3$, which exceeds the World Health Organization (WHO)[23] daily guideline. The mean difference between SES for PM_{10} concentration and the number of deaths was statistically significant (table I).

A statistically significant association was observed for acute mortality from all causes for SES I and SES II. The percentage change in risk of mortality from all causes and for all ages was 0.76% (95%CI 0.27-1.26) for SES I, 0.58% (95%CI 0.16-1.00) for SES II and -0.29% (95%CI -1.16-0.57) for SES III, per 10$\mu g/m^3$ increase in average PM_{10} levels on the day of the event (lag 0), showing a larger effect for SES I (low). The MA, considering a two-day average (MA01), showed a larger effect for SES I compared with the remaining SES. The estimated mortality due to all causes for those over 65 years old was similar to that observed for all ages (figure 2).

Using the DLM for a three-day period prior to death (DLM0-3) and a 10$\mu g/m^3$ increase in PM_{10} concentration (24-hr average), the risk of mortality from all causes and for all ages increased by 0.62% (95%CI 0.25-1.00) for SES I, 0.87% (95%CI 0.55-1.20) for SES II and -0.47% (95%CI -1.25-0.31) for SES III; the first two SES groups were statistically significant. Those over 65 years old showed similar differences among SES strata (figure 2).

As for respiratory mortality for all ages, a significant change in risk of 1.30% (95%CI 0.35-2.26) at lag 0 and 1.52% (95%CI 0.45-2.60) at MA01 was observed for SES II. The risk was always higher for SES II than for the remaining SES. A similar behavior of mortality was observed for the group of people over 65 years old. Using the DLM0-3, a statistically significant effect was found only for SES II for all ages and for those over 65 years old, compared with the other levels (figure 3).

For all age groups and people over 65 years old, no significant association was found between cardiovascular causes and PM_{10} exposure in terms of risk of mortality, although a larger effect was generally observed for SES I (figure 4).

Discussion

Our study suggests that SES significantly modifies the effect of exposure to daily PM_{10} concentrations on daily mortality from all causes and respiratory causes. To our knowledge, this study is the first carried out in Bogota to evaluate this effect. The percentage change in the es-

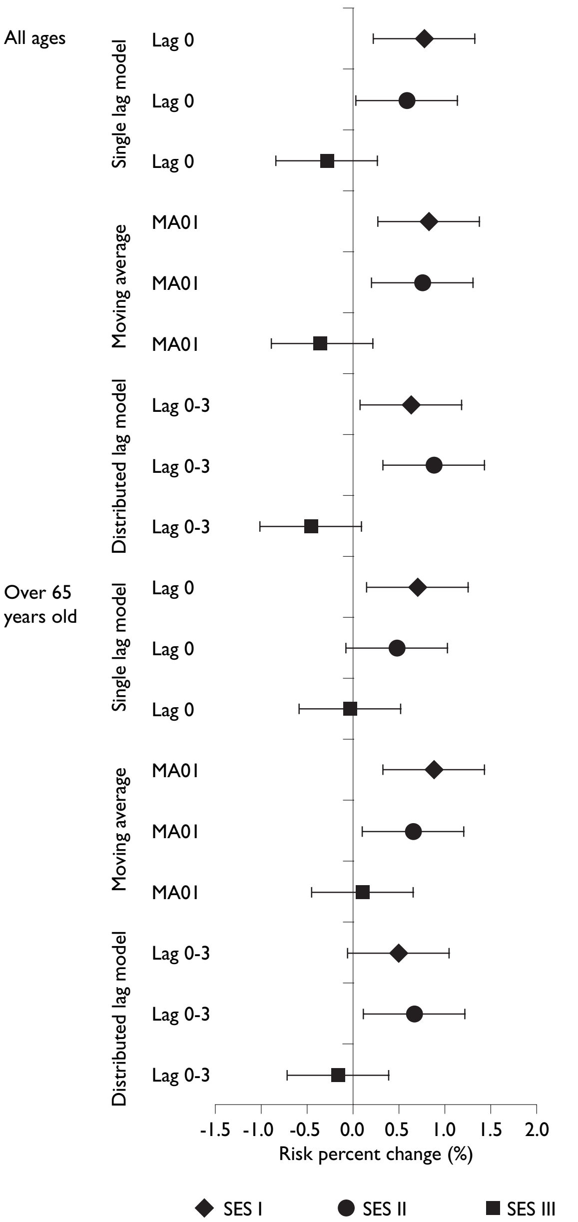
Table I

DISTRIBUTION OF PM_{10} CONCENTRATIONS AND MORTALITY FOR DIFFERENT CAUSES IN BOGOTA, DC STRATIFIED BY SOCIOECONOMIC STATUS (SES) DURING THE PERIOD 1998 TO 2006

Variable	*Observations*			*Mean*			*SD*			*Maximum*		
	I	*II*	*III*	*I*	*II*	*III*	*I*	*II*	*III*	*I*	*II*	*III*
PM_{10} ($\mu g/m^3$)*	3 056	3 167	2 877	60.12	71.05	36.95	18.78	19.44	17.10	147	179	123
All causes*	3 197	3 197	3 194	23.90	33.38	7.71	5.38	6.42	2.78	44	71	21
All causes> 65*	3 197	3 197	3 169	10.88	18.57	4.90	3.63	5.02	2.27	27	39	15
RESP*	3 145	3 186	2 511	4.25	6.39	1.57	2.20	2.80	1.30	14	18	9
RESP > 65*	2 877	3 115	2 094	2.43	4.16	1.12	1.67	2.31	1.11	10	16	8
CVC*	3 185	3 197	2 907	6.04	9.50	2.41	2.60	3.19	1.55	16	22	10
CVC > 65*	3 126	3 191	2 705	3.97	6.83	1.84	2.07	2.72	1.36	13	19	9

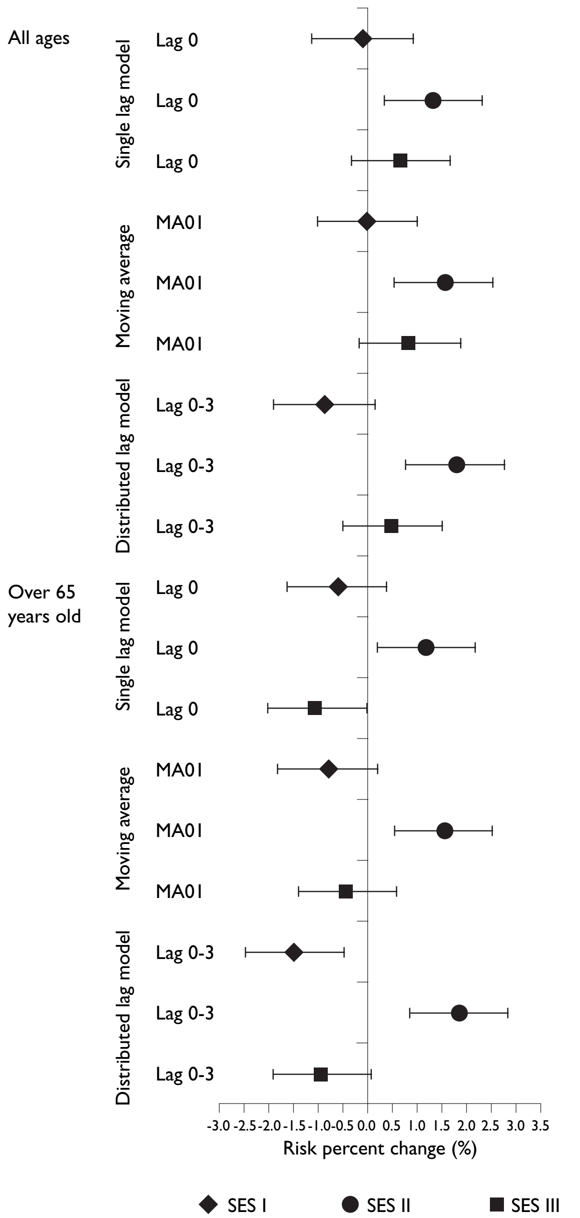
RESP: Respiratory, CVC: Cardiovascular, SES: socioeconomic status, SD: Standard Deviation

* Significant mean difference ($p<0.05$)



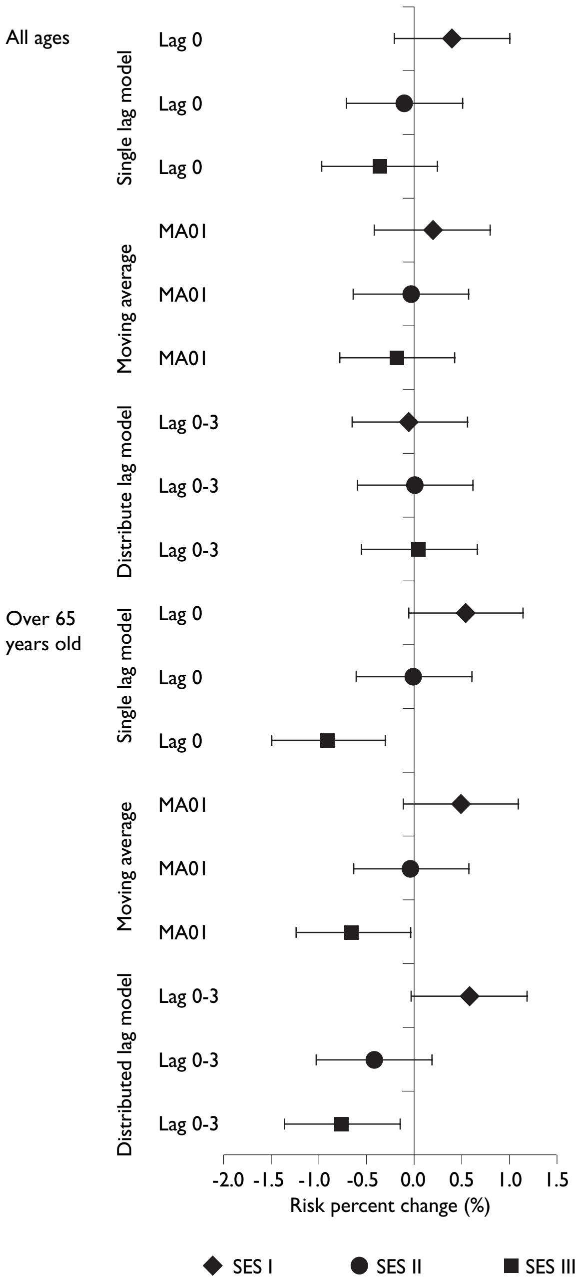
* Percentage change in risk per 10μg/m³ increase in daily air concentrations of PM_{10} using single lag models on the same day of the event (lag0), moving average models considering 2-day average (MA01) and distributed lag models with period of 3 days prior to death(Lag0-3), in Bogota DC

Figure 2. Percentage change in risk of overall mortality* for all ages and those over 65 years old, associated with acute PM_{10} exposure, stratified by socioeconomic status (SES) in Bogota DC, Colombia. 1998-2006



* Percentage change in risk per 10μg/m³ increase in daily air concentrations of PM_{10} using single lag models on the same day of the event (lag0), moving average models considering 2-day average (MA01) and distributed lag models with period of 3 days prior to death(Lag0-3), in Bogota DC

Figure 3. Percentage change in risk of respiratory mortality* for all ages and those over 65 years old, associated with acute PM_{10} exposure, stratified by socioeconomic status (SES), in Bogota DC, Colombia. 1998-2006



* Percentage change in risk per 10µg/m^3 increase in daily air concentrations of PM_{10} using single lag models on the same day of the event (lag0), moving average models considering 2-day average (MA01) and distributed lag models with period of 3 days prior to death (Lag0-3), in Bogota DC

Figure 4. Percentage change in risk of cardiovascular mortality* for all ages and those over 65 years old, associated with acute PM_{10} exposure, stratified by socioeconomic status (SES), in Bogota DC, Colombia. 1998-2006

timated risk of daily mortality for all causes and all ages was 0.76% at lag 0 and 0.83% at MA01 for SES I (low), decreasing to a value of -0.29% and -0.58% for SES III (high), respectively. When change in risk was estimated using DLM0-3, there was an increased risk for SES II (mid), with a value of 0.87%, compared to 0.63% for SES I and -0.47% for SES III. Our results are consistent with other authors. Forastiere *et al.*[11] found an increase of 1.4% in overall mortality for low SES for those over 35 years old, compared with 0.1% for the high SES, per 10μg/m^3 increase in PM_{10} concentrations at MA01. Wong *et al.*[19] constructed a social deprivation index (SDI), finding a significant excess in non-accidental risk of mortality for all ages – 0.70% per each 10μg/m^3 increase in PM_{10} concentration at lag 0 for the middle SDI, compared with low and high SDI.

One possible explanation for our results is that the population that lives in the low SES is associated with a high prevalence of preexisting diseases, limited or poor quality medical services and deficient consumption of polyunsaturated fatty acids and vitamins, all of which increases their susceptibility and conditions of vulnerability to the effects of air pollutants.[19,23] Another factor that may be associated is race and ethnicity; U.S. studies have shown a larger risk of mortality for the Hispanic population compared to white and black populations.[25,26]

When estimating the risk of mortality for the group over 65 years old, a risk of 0.88% at MA01 and 0.96% at MA02 was found for SES I, which decreases to 0.09% and -0.27% for SES III, respectively, following the trend observed in the general population. The result for this group can be explained by mobility, as those over 65 years old spend more time at home and therefore are largely exposed,[12,15] as well as by a high prevalence of preexisting conditions[24] that make them more susceptible to the effects of PM_{10}.

Mortality due to respiratory disease was always higher and statistically significant for SES II (middle) compared with SES I and SES III groups, with values of 1.31% (lag 0), 1.53% (MA01) and 1.77% (DLM0-3) for all ages, respectively, and 1.18, 1.54 and 1.83% respectively, for those over 65 years old. Our results coincide with those established by other authors. Wong *et al.*[19] identified a significant excess in – risk 1.46% (lag 2) for the high SDI, decreasing to 0.36% for the low SDI. Martins *et al.*[12] determined that areas with a lower socioeconomic profile showed the highest coefficient of association between PM_{10} exposure and respiratory mortality among the elderly. The authors state that low income and low education levels are factors that explain the relationship found.

In our study, respiratory mortality was always higher for SES II, the area in the city with the highest daily average of PM_{10} (71μg/m^3). This shows a dose-response relation for this cause, since the SES II population is exposed to daily PM_{10} concentrations that exceed WHO[22] guidelines, increasing the risk of mortality as compared with SES I and SES III, which have lower concentrations of PM_{10} (60μg/m^3 and 37μg/m^3, respectively).

Although cardiovascular mortality showed no significant values, SES I was observed to have the highest percentage change in risk at lag 0, MA01 and DLM0-3 for all ages and those over 65 years old. Our results agree with those found by Finkelstein *et al*.[10] who confirmed the hypothesis that part of the deprivation or inequity associated with mortality from cardiovascular disease is related to differences in exposure to environmental pollutants.

O'Neill *et al*.[2] propose three hypotheses for which low SES groups are more vulnerable to the effects of air pollution: 1) low-income people may receive greater exposure to air pollution,[19] 2) these groups may be more susceptible because they have a compromised health status due to limited financial resources, and 3) they are more likely to suffer health effects due to the combination of increased exposure and susceptibility. The latter hypothesis is more accurate and fits the reality of Bogota[17] and other cities in LAC. Nevertheless, it is important to highlight that health inequality impacts this relationship and may explain the effect on the population.[27] Bartley[28] proposes the material/neo-material model as an explanatory model of health inequality, which postulates that people of relatively low incomes have poorer health and lower life expectancy, and which combined with increased exposure to a contaminant results in the situation studied in our work.

The strengths of our study were: 1. The use of the GAM[21] model enabled the adjustment of linear and non-linear associations, as well as short- and long-term fluctuations. 2. The use of different indicators related to SES, recommended in other studies,[9,29,30] with principal component analysis made it possible to obtain a socioeconomic division which, although not entirely homogenous within the localities, enabled obtaining estimates that reflected the socioeconomic reality of the localities of Bogota. 3. With the use of localities as units of stratification and relevant information about each of them, it was possible to establish the effect of SES on the air pollution–mortality relationship; this approach has been used or suggested by other studies.[12,29]

It is also important to mention the possible limitations of the study that may influence the results. First, there were some problems measuring exposure for SESI (low) because many of the localities belonging to this SES did not have air quality monitoring stations, therefore concentrations from stations at nearby locations belonging to other SES were assigned. This may have affected the estimate of the percentage change in risk for the different causes of death studied at this SES level. Nevertheless, the measurement of PM_{10} for SES II represents the real situation of the city, as winds concentrate pollutants in the localities that make up this SES and, therefore, taking into account the direction of the winds, the areas next to these localities should exhibit lower concentrations than those registered for SES II.[16] Second, information about temperature and RH was available only in one SES of the city, since the majority of localities did not have instruments to measure meteorological variables; the percentage change in risk was estimated with and without adjusting the weather variables, no significant difference in values was noted. Third, the ozone time series showed a change in the value of the daily 8-hour average concentration after 2002, the year in which maintenance of the BAQMN was performed. Unable to establish whether the measurements recorded before or after 2002 were correct, it was decided not to adjust for this pollutant; the estimates were calculated with and without adjustment for ozone, which showed no significant difference in values.

In summary, our results support the hypothesis proposed and observed by other studies that SES has a modifier effect on the relationship between air pollution and mortality.[30] Thus, addressing this relationship must take into account the socio-economic component, which may help to decrease deaths in Bogota. Therefore, promotion and prevention programs established by the DSH of Bogota in the localities considered vulnerable should tend to reduce these weaknesses, which would ultimately affect the health of the people in the capital, especially the elderly.

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