

Air Pollution and Infant Mortality from Pneumonia in the Rio de Janeiro Metropolitan Area¹

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The authors report the results of an investigation into the possible association between air pollution and infant mortality from pneumonia in the Rio de Janeiro Metropolitan Area. This investigation employed multiple linear regression analysis (stepwise method) for infant mortality from pneumonia in 1980, including the study population's areas of residence, incomes, and pollution exposure as independent variables.

With the income variable included in the regression, a statistically significant association was observed between the average annual level of particulates and infant mortality from pneumonia. While this finding should be accepted with caution, it does suggest a biological association between these variables. The authors' conclusion is that air quality indicators should be included in studies of acute respiratory infections in developing countries.

In 1978 Bulla and Hitze (1) pointed out the strong significance of pneumonia as a cause of death among children under five years of age in developing countries, a circumstance demanding preventive action. Preventive measures that have been proposed include applying the norms for adequate treatment of acute respiratory infections (ARIs), so as to prevent ARI cases from worsening; vaccination against measles, whooping cough, and diphtheria; and control of risk factors such as indoor pollution (2).

In the state of Rio de Janeiro, respiratory diseases were the second major cause of infant mortality in 1985, account-

ing for 18.5% of all deaths. Respiratory disease mortality followed mortality from causes originating in the perinatal period (46.5%) and exceeded mortality caused by infectious and parasitic diseases, including diarrheal diseases, which accounted for 16.7%. Pneumonias were the main cause of respiratory disease deaths, accounting for 77% of the total within this category. The relevance of these figures is increased by the fact that causes of death in the population covered appear relatively well-defined, only 2.2% of the state's deaths being ascribed to poorly defined causes (as compared to 22% of the mortality in Brazil as a whole).

National and international recommendations for controlling ARI in developing countries have devoted relatively little attention to air pollution. For instance, the preventive measures cited by a Brazilian Health Ministry guidebook on control and care of acute respiratory infections (6) include only immunizations required in the first year of life and a proposal to

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"avoid leaving the infant in environments polluted by smoke from fires or cigarettes" (p. 13).

However, laboratory and population surveys (4, 5) have indicated that air pollution can have harmful effects. Indeed, studies associating increased death rates with air pollution have been carried out in many countries. In general, such studies have investigated increased mortality from chronic respiratory diseases, cardiovascular diseases, and cancer, mainly in adults and older people (7-9). There are also several studies concerned with alterations in lung function after acute and chronic exposure to pollution, primarily in school-age children (10-11). In addition, a number of recent studies have sought to evaluate the relationship between air pollutants and acute upper and lower respiratory tract infections (12-14), mainly in adults and school-age children.

Such surveys are not yet common in Latin America, even though in recent decades the area's economic development process has been characterized by rapid industrialization and urbanization accompanied by acute socioenvironmental problems. Today, some of the world's greatest urban conglomerates, including centers like Mexico City and São Paulo, are found in Latin America. (Among these, the Rio de Janeiro Metropolitan Area, with a territory of 6,464 km², includes about 10 million inhabitants living in the city of Rio de Janeiro proper and 12 peripheral cities.) Nevertheless, air pollution is not so rigorously controlled as it is in the developed countries, and government authorities are only slowly becoming concerned with the environmental problems involved.

The aim of the study reported here was to investigate possible associations between air pollution in the metropolitan area of Rio de Janeiro, as indicated by the amount of suspended particulate matter

in the atmosphere, and pneumonia mortality among children under one year of age.

MATERIALS AND METHODS

The Rio de Janeiro Metropolitan Area consists of 24 administrative regions pertaining to the city of Rio de Janeiro and 13 outlying municipalities. Detailed information about socioeconomic indicators for each of these regions and municipalities (15) was available from the Brazilian Institute of Geography and Statistics for 1980, a census year, and so that year was selected for this work.

The socioeconomic indicators used in the study were (1) the proportion of households with a total income lower than two minimum wages, and (2) the proportion of households with a total income between two and five minimum wages. Since the minimum wage in 1980 was under US\$30 per month, we used the first indicator to select families living in dire poverty and the second to select mainly poor families of semiskilled workers.

Data on the number of deaths among children under one year old, by cause and area of residence, were provided by the State Secretariat of Health, which is the agency responsible for collecting death certificates throughout the state and for codifying the underlying cause of death according to the rules of the IX International Classification of Diseases.

In order to estimate the number of live births occurring in the year of the study, we applied a correction factor to the statistics provided by the Civil Register. This was necessary; for although birth registration is mandatory in Brazil, cost considerations typically cause it to be carried out with some delay among the more impoverished segments of the population. Using birth data from Civil Registry statistics published up to 1988 (16), which

cited registered births reported in the year of the infant's birth and in all subsequent years (allowing for up to eight years' delay in birth registration), we employed the method proposed by Sczwarzwald (17).

The correction factor calculation is based on the premise that after the third year of delay, the number of records will decrease in accordance with a geometric progression. By means of log-linear regression analysis of the available data, the proportion of underrecording was estimated. The results seemed to agree with those of Brass, which were derived from census information (17).

Estimates of exposure to air pollution were based on the total amount of suspended particulates ($\mu\text{g}/\text{m}^3$) in the surveyed areas. The data on particulates were provided by the State Foundation of Environmental Engineering (Fundação Estadual de Engenharia do Meio Ambiente—FEEMA), which has 22 stations monitoring suspended particulates by collecting air samples over a 24-hour period every six days using the high-volume sampler method (Hi-vol). These data indicate the air quality of 27 regions, because the metropolitan area's geographic characteristics delimit different basic zones, and so some stations measure air quality for more than one region (18). Our analysis of these data included both the annual geometric mean for each region (average pollution) and the year's maximum 24-hour concentration (maximum pollution), since if there were a threshold for the existence of some biological effect, the maximum figure should correlate better than the average figure with occurrence of that effect.

The data were examined by multiple linear regression analysis, using the stepwise method. The dependent variable was infant mortality due to pneumonia per 10,000 live births, while the independent variables were the percentage of

households with a total income lower than two minimum wages, the percentage of households with total income between two and five minimum wages, average pollution in 27 administrative regions and municipalities of the Rio de Janeiro Metropolitan Area, and maximum pollution in the same places (Table 1).

The weighted least squares method was used to deal with the variance heterogeneity of the data. The weights were the number of live births, which were assumed to be proportional to the reciprocal of mortality variances.

We then repeated the analysis, employing as the dependent variable infant mortality from all causes per 1,000 live births, and also infant mortality from diarrhea per 10,000 live births. This last analysis was done to see if air pollution could be associated with diarrhea mortality—which would indicate an ecologic fallacy. All the analyses were carried out using the "Statistical Analysis System" (SAS) (19).

RESULTS

It was observed that of the 22 stations studied, 20 exceeded the quality standard in force (an average particulate pollution of $80 \mu\text{g}/\text{m}^3$), while 15 exceeded the daily maximum concentration standard of $240 \mu\text{g}/\text{m}^3$, some doing so more than once a year.

The above-mentioned standards conform with those used in the United States, making it appear that the populations involved were subjected to high concentrations of air pollutants. The analysis (Table 2) yielded statistically significant regression coefficients for the proportion of households with a total income inferior to two minimum wages ($t = 7.555$, $p = 0.0001$), the proportion of households with a total income between two and five minimum wages ($t =$

Table 1. Aggregate data for the 27 study areas, showing average and maximum particulate concentrations, family income levels (< 2 and 2–5 times the minimum wage), and infant mortality from pneumonia per 10,000 births.

Area ^a	Pollution		Income		Pneumonia death rate per 10,000 live births
	Average $\mu\text{g}/\text{mm}^3$	Maximum $\mu\text{g}/\text{mm}^3$	< 2 min. wage (%)	2–5 min. wage (%)	
AR #1	109	255	25.00	41.81	89.04
AR #2	109	255	13.54	35.49	68.41
AR #3	104	244	21.58	34.63	91.24
AR #4	109	255	8.57	18.13	14.09
AR #5	110	216	6.61	14.85	9.32
AR #7	130	323	24.62	39.01	105.94
AR #8	141	296	10.92	17.73	27.64
AR #9	141	296	11.38	20.43	65.36
AR#10	206	516	22.43	39.31	64.17
AR#11	154	444	21.68	41.33	45.01
AR#12	175	430	19.19	34.2	39.33
AR#13	115	222	13.94	27.87	22.56
AR#14	180	589	19.38	37.68	30.69
AR#15	175	430	18.41	37.78	43.86
AR#17	97	198	25.56	45.23	47.35
AR#18	85	152	28.56	44.98	50.27
AR#19	85	152	34.53	44.65	62.78
AR#20	104	299	15.45	29.75	34.11
AR#22	145	308	23.05	44.26	37.76
AR#23	80	201	16.08	33.19	46.82
D. Caxias	150	359	33.67	46.02	120.64
Itaguaí	74	167	39.40	41.53	95.51
N. Iguaçu	157	437	35.87	45.86	124.41
Nilópolis	145	308	25.42	46.55	86.31
Niterói	104	407	19.67	27.42	75.85
S. Gonçalo	227	491	29.26	45.05	96.41
S. J. Meriti	157	363	30.65	48.44	87.96

^aThe letters "AR" refer to administrative regions of the city of Rio de Janeiro, while the names refer to municipalities. Four administrative regions and seven municipalities were excluded from the study for lack of pollution data.

–3.412, $p = 0.0024$), and average pollution ($t = 2.670$, $p = 0.0137$).

Maximum pollution was not included in the best model. The best model explains 83% ($R^2 = 0.83$) of the overall variation in infant pneumonia mortality, but only 5.27% of the total variation can be explained by pollution (squared semi-partial correlation coefficient = 0.0527). However, pollution explains 23.7% (squared partial correlation coefficient = 0.2366) of the residual variation after including in the model the two above-mentioned socioeconomic variables.

Table 2 also shows the maximum

model. The inclusion of maximum pollution resulted in loss of precision, with no significant regression coefficients for average pollution and maximum pollution. The squared partial correlation coefficients were 0.02351 for average pollution and 0.0221 for maximum pollution.

It is interesting to note that although maximum pollution exhibited a higher correlation coefficient with infant pneumonia mortality than did average pollution (Table 3), its relationship with pneumonia deaths adjusted for all the other variables, expressed in terms of a partial regression coefficient, is weaker.

Table 2. Regression coefficients for the best and maximum models with infant pneumonia mortality as the dependent variable.

	Coefficient	Value of:	
		t for H ₀ (parameter = 0)	p
<i>Best model (F = 37.423, p < 0.001):</i>			
Intercept	-9.3970	-0.533	0.5990
Income less than 2 minimum wages	5.8684	7.755	0.0001
Income from 2 to 5 minimum wages	-2.4921	-3.412	0.0024
Average pollution	0.2208	2.670	0.0137
R ² = 0.8300, Adjusted R ² = 0.8078			
n = 27 areas			
<i>Maximum model (F = 27.577, p < 0.001):</i>			
Intercept	-11.5489	-0.639	0.5295
Income less than 2 minimum wages	5.7134	7.176	0.0001
Income from 2 to 5 minimum ages	2.3284	3.008	0.0065
Average pollution	0.1204	0.728	0.4744
Maximum pollution	0.0396	0.705	0.4884
R ² = 0.8337, Adjusted R ² = 0.8035			
n = 27 areas			

When the dependent variable (infant pneumonia mortality) was replaced in turn with infant mortality from all causes and infant diarrhea mortality (Table 4), the only independent variable accepted by the model was the proportion of households with a total income below two minimum wages, which explains

51.9% and 52.2% of the variation in diarrhea and general mortality, respectively ($R^2 = 0.5185$, $R^2 = 0.5221$).

DISCUSSION

These results agree with previous findings that attribute an increase in lower

Table 3. Correlation matrix for variables used in the analysis.

	Income		Pollution		Mortality from:		
	< 2 min. wages	2-5 min. wages	Average	Maximum	Pneumonia	Diarrhea	All causes
<i>Income:</i>							
< 2 min. wages	1.000						
2-5 min. wages	0.8597	1.000					
<i>Pollution:</i>							
Average	0.1637	0.2500	1.0000				
Maximum	0.1563	0.1488	0.8518	1.0000			
<i>Death rate:</i>							
From pneumonia	0.8456	0.5995	0.3061	0.3512	1.0000		
From diarrhea	0.7201	0.6161	0.2121	0.1083	0.7060	1.0000	
From all causes	0.7226	0.6071	0.1781	0.1287	0.7922	0.8852	1.0000

Table 4. Regression coefficients for the models with infant diarrhea mortality and mortality from all causes as the dependent variable.

		Value of:	
	Coefficient	t for H ₀ (parameter = 0)	p
<i>All causes:</i>			
Intercept	135.8806	2.238	0.0343
Income < 2 min. wages	11.6104	5.227	0.0001
R ² = 0.5221			
Adjusted R ² = 0.5030			
n = 27 areas			
<i>Diarrhea:</i>			
Intercept	-3.5936	0.226	0.8231
Income < 2 min. wages	3.0199	5.189	0.0001
R ² = 0.5185			
Adjusted R ² = 0.4992			
n = 27 areas			

respiratory disease morbidity and mortality in children to pollutants of the SO₂—suspended particulates complex (5). After the 1952 smog in London, the direct biologic impact on the respiratory tract was attributed to suspended particulate matter, but today we cannot regard such effects as being due to nonspecific particulates. Instead it is felt that measures of suspended particulate matter concentrations in the atmosphere function as a substitute for measures of other substances, probably acid aerosols, that are responsible for the biologic effects (20).

Working with a measure of exposure that actually is a proxy variable for causal exposure tends to weaken the observed association, increasing our confidence in the observed results. On the other hand, we used routine air pollution control data. These data are collected at monitoring sites whose locations tend to be selected for regulatory purposes; that is, they tend to be near sources of emission rather than near places receiving average exposures, and so they tend to reg-

ister relatively high concentrations of pollutants (21). However, if this tendency toward overestimation of exposure were uniform, it would not introduce any bias into the type of analysis performed.

Among the difficulties involved in attributing infant pneumonia mortality to air pollution is one revealed by the literature (9), which points out an association between the air pollution and socioeconomic conditions, which in turn are associated in a causal way with infant mortality from pneumonia. This double association transforms socioeconomic conditions into a confounding variable, requiring some control.

Among socioeconomic indicators for which data are available, the one most closely related to pollution would appear to be income, which is also the one most closely associated with infant mortality. Hence, failure to include income in the model would probably lead to bias, whereas its inclusion could result in over-control, thus making the actual association appear weak. In this light, the association found between infant pneumonia mortality and air pollution could be underestimated because of the model selected.

Indoor air pollution constitutes another possible confounding variable, one not subject to control in studies with aggregate data. However, for indoor pollution to become a confounding variable in this present study (responsible for bias in the association between air pollution and infant pneumonia mortality), it would be necessary for indoor and outdoor air pollution to also be related, something that could only be explained by association of these two variables with socioeconomic conditions. Hence, control over socioeconomic influences through the variable "income" would also provide some control over the indoor air pollution variable.

In addition, indoor air pollution created by cooking with organic fuels or gas

should not constitute a confounding variable in our study for reasons of climate, dwellings located in the Rio de Janeiro Metropolitan Area generally being well-ventilated. Moreover, organic fuel is rarely used; and, when used, it is traditionally burned in a place outside or well-separated from the main living spaces of the home.

Regarding indoor pollution by cigarette smoke, there are no nationwide data indicating whether smoking prevalence is associated with low income. In the absence of empirical data suggesting a negative association between family income and indoor pollution by cigarette smoke, we presume that although the more privileged classes are more aware of the risks to small children presented by parental (especially maternal) smoking, Brazilian traditions do not encourage smoking among women, and cigarette smoking is not favored by the more impoverished classes because of its high cost.

Our data set shows that average particulate pollution was a better proxy variable for exposure than maximum particulate pollution. Specifically, the confounding effect of the socioeconomic variables was found to be larger for maximum pollution than for average pollution.

The association observed in this study between air pollution and infant pneumonia mortality must be regarded with the same caution reserved for other studies using aggregate data, because such studies are subject to "ecologic fallacy" and fail to provide measures of effect such as relative risk. Nevertheless, the present findings are consistent with available knowledge on the subject; and their biologic specificity is suggested by exclusion of both variables related to air pollution from the regressions when the dependent variable was general infant mortality (all causes) or infant diarrhea

mortality (see Table 4), despite the fact that high correlation coefficients were found between these two air pollution variables and infant pneumonia mortality.

CONCLUSION

The investigation revealed an association between air pollution (measured in terms of the annual average concentration of suspended particulates) and infant pneumonia mortality at the level of aggregate data for each administrative region in the city of Rio de Janeiro and the other cities of the metropolitan area. This association persists even when the model includes the proportion of households with a total income below two minimum wages and the proportion with a total income between two and five minimum wages, which controls for the effects of socioeconomic conditions. The biologic character of this association is indicated by the model's failure to accept pollution as an explanatory variable when dealing with general infant mortality or infant diarrhea mortality.

This result must be regarded with the caution appropriate for findings derived from ecologic studies of this nature. At the same time, detection of this apparent association in combination with findings of other studies—including animal studies indicating changes in pulmonary defense mechanisms caused by exposure to air pollutants—clearly justifies greater involvement with this issue for the purpose of seeking reduced infant mortality from acute respiratory infections. In sum, the results suggest that air pollution measures should be included in studies designed to detect risk factors for serious acute respiratory infections in urban areas of developing countries, where for the most part environmental control is not yet considered a priority matter.

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