

Brief Report

An Ecologic Analysis of County-Level PM_{2.5} Concentrations and Lung Cancer Incidence and Mortality

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Abstract: Few studies have explored the relationship between PM_{2.5} and lung cancer incidence. Although results are mixed, some studies have demonstrated a positive relationship between PM_{2.5} and lung cancer mortality. Using an ecologic study design, we examined the county-level associations between PM_{2.5} concentrations (2002–2005) and lung cancer incidence and mortality in North Carolina (2002–2006). Positive trends were observed between PM_{2.5} concentrations and lung cancer incidence and mortality; however, the R² for both were <0.10. The slopes for the relationship between PM_{2.5} and lung cancer incidence and mortality were 1.26 (95% CI 0.31, 2.21, p-value 0.01) and 0.73 (95% CI 0.09, 1.36, p-value 0.03) per 1 µg/m³ PM_{2.5}, respectively. These associations were slightly strengthened with the inclusion of variables representing socioeconomic status and smoking. Although variability is high, thus reflecting the importance of tobacco smoking and other etiologic agents that influence lung cancer incidence and mortality besides PM_{2.5}, a positive trend is observed between PM_{2.5} and lung cancer incidence and mortality. This suggests the possibility of an association between PM_{2.5} concentrations and lung cancer incidence and mortality.

Keywords: particulate matter; lung cancer; incidence rates; mortality rates

1. Introduction

Although results have been mixed, overall, recent studies have reported an association between PM_{2.5} exposure and lung cancer mortality [1-8]. However, few studies have been conducted to examine the association between PM_{2.5} exposure and lung cancer incidence. Analyses performed on the Netherlands Cohort Study on Diet and Cancer (NCLS) reported no associations between PM_{2.5} and lung cancer incidence [1]. In addition, two recent studies examined the association between PM₁₀ and lung cancer incidence [9,10]. One study conducted in Europe reported no association [10], whereas the other study did find a positive relationship between PM₁₀ and lung cancer incidence among men in California [9]. The objective of this study was to further investigate the association between PM_{2.5} and lung cancer incidence rates, as well as, lung cancer mortality rates, using an ecologic study conducted across North Carolina. This will provide information on the possibility of an association between PM_{2.5} and lung cancer incidence, an association rarely examined.

2. Methods

For this ecologic study, age-adjusted lung cancer incidence and mortality rates from 2002–2006 were obtained for each county in North Carolina (n = 100) from the North Carolina Central Cancer Registry and the State Center for Health Statistics. Predictions of the PM_{2.5} concentrations for the years 2002 through 2005 were determined using a hierarchical Bayesian model that combined monitoring data from the U.S. Environmental Protection Agency's (EPA) Air Quality System (AQS) with numerical output from the EPA's Community Multi-Scale Air Quality (CMAQ) model [11]. The model provides information on areas of the state without monitors by modeling known emissions and meteorological conditions. This is combined with actual monitoring data where available. This method has been validated and provides reliable information on PM_{2.5} [11]. The estimated PM_{2.5} concentrations were reported for a grid consisting of 12 × 12 km cells spanning the spatial extent of North Carolina. We calculated the 24-hour average PM_{2.5} values for each grid cell during the 2002 to 2005 time period. The average across this time period was then calculated for each county using spatial weighting to account for counties that spanned multiple grid cells. The weighting was performed by having each grid cell contribute to the county-wide estimate based on the proportion of the county's area in each cell.

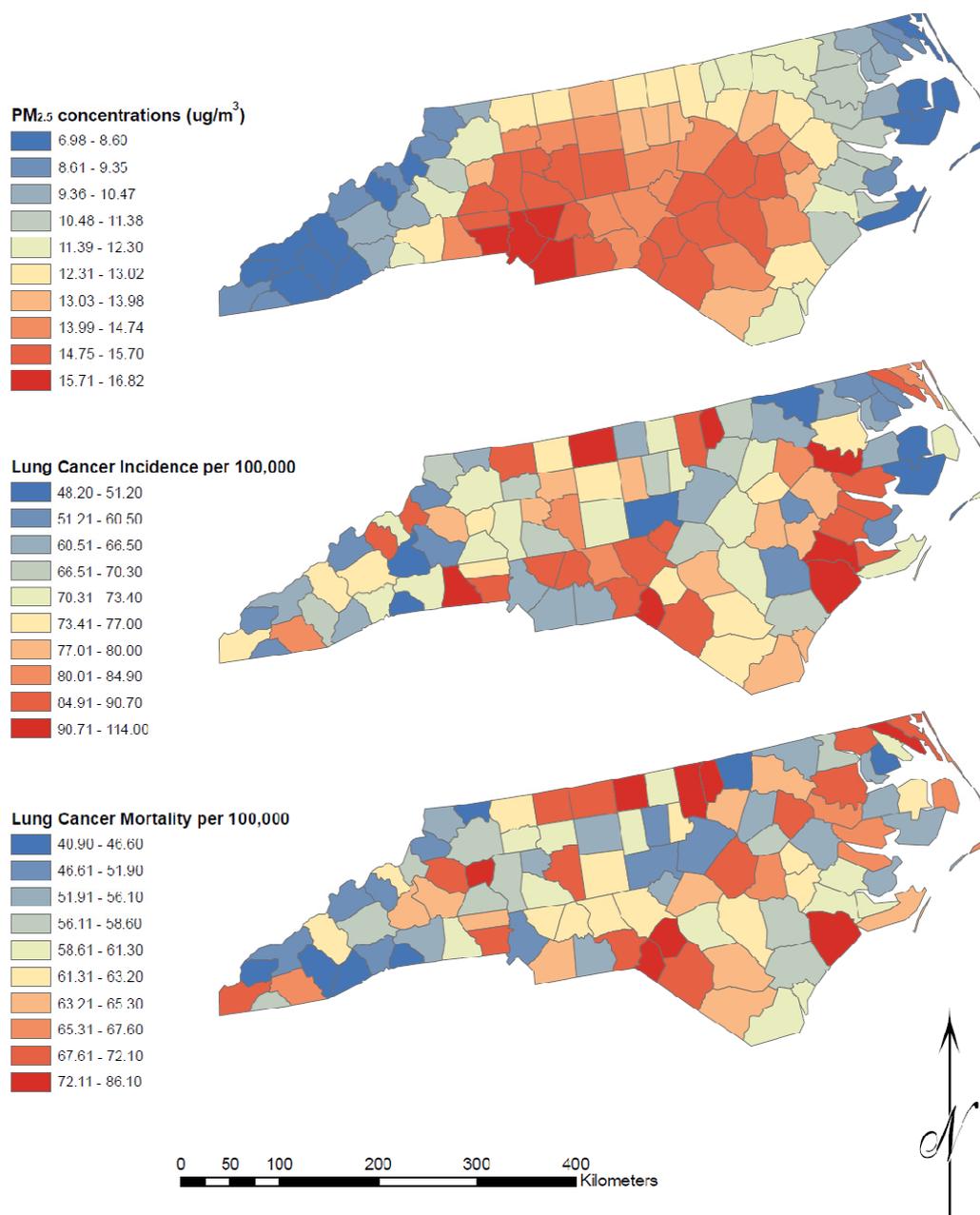
Linear regression was performed in order to estimate the relationship between PM_{2.5} concentration and lung cancer incidence and mortality rates. To adjust for neighborhood socioeconomic status (SES) and smoking, the analyses were repeated with a variable for each included in the models. County-level per capita income estimates were obtained from the North Carolina Comprehensive Assessment for Tracking Community Health (CATCH) system of the State Center for Health Statistics. Smoking statistics were not available for each individual county. However, cigarette smoking prevalence rates from the 2005 North Carolina Behavioral Risk Factor Surveillance System (BRFSS) were available for some single counties (n = 22) and some combined counties (n = 78; 13 groups ranging from 3 to 15 counties with a median of 5 counties per group). Rates for the combined counties were applied to all counties in each grouping.

Linear regression was also used to evaluate if associations exist between PM_{2.5} concentrations and breast and prostate cancers rates from the North Carolina Central Cancer Registry and the State Center for Health Statistics. This additional analysis was undertaken to examine if an association would be prevalent solely for lung cancer or for multiple cancers, including those not thought to be related to air pollutants.

3. Results

Age-adjusted lung cancer incidence and mortality rates, as well as average PM_{2.5} concentrations, are displayed on maps of the 100 counties in Figure 1.

Figure 1. Maps of PM_{2.5} concentrations, lung cancer incidence, and lung cancer mortality for the 100 counties in North Carolina.

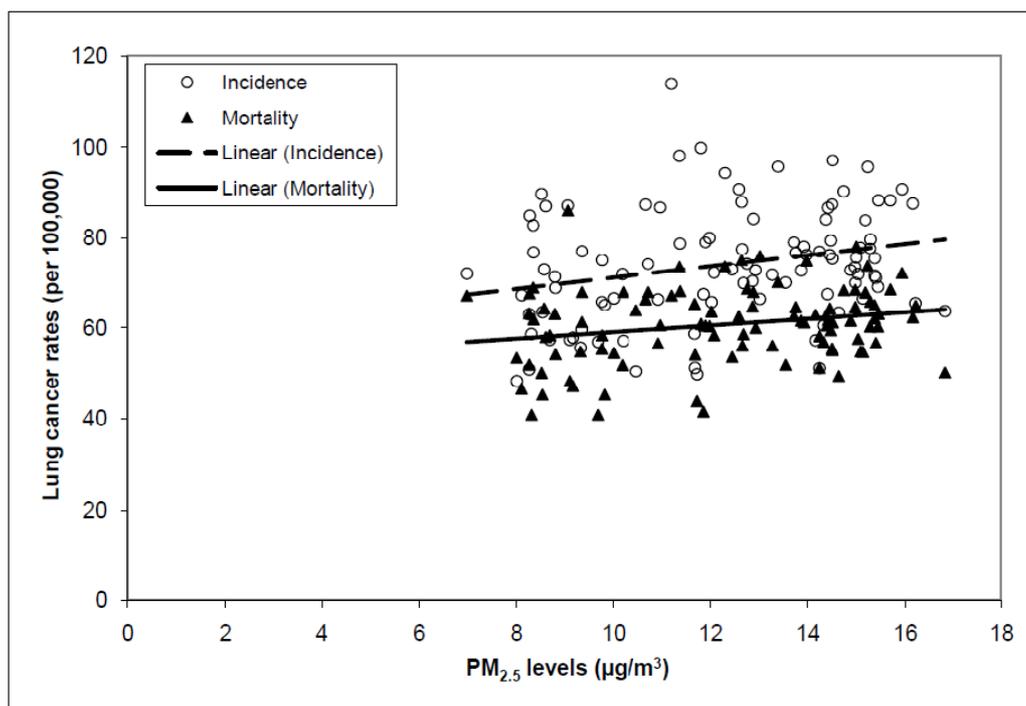


County-wide age-adjusted lung cancer incidence rates for 2002–2006 ranged from 48.2–114.0 per 100,000, with a median of 72.9 per 100,000. For lung cancer mortality, the median rate was 61.3 per 100,000 with a range of 40.9–86.1 per 100,000. The four year average of 24-hour PM_{2.5} concentrations ranged from 7.0 µg/m³ for the county with the lowest concentration to 16.8 µg/m³ for the county with the highest concentration. The highest PM_{2.5} concentrations were found in Mecklenberg county, where Charlotte (the largest urban center in NC) is located, and the surrounding counties. The lowest PM_{2.5} concentrations were found in counties on the eastern coast and western border of the state.

We observed high variability between county-averaged PM_{2.5} concentrations and both lung cancer incidence and mortality rates across the 100 counties in North Carolina. R² values were 0.07 for the association between PM_{2.5} concentration and lung cancer incidence rates and 0.05 for the association between PM_{2.5} concentration and lung cancer mortality rates.

Despite the low R² values, an overall trend was observed, with counties that had higher levels of PM_{2.5} also having higher lung cancer incidence and mortality rates (Figure 2), although there are exceptions, such as Mecklenberg county. The unadjusted slope for the linear trend between PM_{2.5} concentrations and lung cancer incidence was 1.26 (95% CI 0.31, 2.21, p-value 0.01) per 1 µg/m³ PM_{2.5}. For lung cancer mortality, the slope of the relationship with PM_{2.5} concentration was 0.73 (95% CI 0.09, 1.36, p-value 0.03) per 1 µg/m³ PM_{2.5}. No statistically significant trends were observed for breast or prostate cancer incidence and mortality rates [per 1 µg/m³ PM_{2.5}: breast cancer incidence 0.43 (95% CI -1.25, 2.12, p-value 0.61); breast cancer mortality -0.14 (95% CI -0.61, 0.33, p-value 0.57); prostate cancer incidence 1.80 (95% CI -0.64, 4.25, p-value 0.15); prostate cancer mortality 0.21 (95% CI -0.51, 0.93, p-value 0.57)].

Figure 2. Lung Cancer Incidence and Mortality Rates *versus* PM_{2.5} levels for 100 counties in North Carolina.*



* Unadjusted linear models. Slopes: Incidence 1.26 per 1 µg/m³ PM_{2.5} (p-value 0.01) and Mortality 0.73 per 1 µg/m³ PM_{2.5} (p-values 0.03)

When adjusting for neighborhood SES and prevalence of cigarette smoking, the associations between PM_{2.5} concentration and lung cancer incidence and mortality rates increased slightly. The adjusted slopes were 1.35 (95% CI 0.36, 2.35, p-value 0.01) per 1 µg/m³ PM_{2.5} for lung cancer incidence and 0.96 (95% CI 0.34, 1.59, p-value < 0.01) per 1 µg/m³ PM_{2.5} for lung cancer mortality. The R² value, while still low, increased from 0.05 to 0.18 for lung cancer mortality. The R² value for lung cancer incidence increased slightly from 0.07 to 0.09.

4. Discussion

The associations between PM_{2.5}-concentration and lung cancer incidence and mortality rates provide limited evidence that PM_{2.5} exposure potentially contributes to lung cancer incidence and are consistent with previous studies that have reported an association between PM_{2.5} exposure and lung cancer mortality. A similar ecologic study performed using data from 15 countries in Europe reported a correlation between PM_{2.5} and lung cancer mortality among men but not women [8]. Recent work on the American Cancer Society cohort has demonstrated a positive association between PM_{2.5} and lung cancer mortality [2,3,6]. In addition, the Six Cities Study, which included follow-up from 1974–1998, reported a relative risk for lung cancer mortality of 1.27 (95% CI 0.96, 1.69) per 10 µg/m³ increase of PM_{2.5} [4]. However, other large studies (e.g., NLCS) have not detected an association between PM_{2.5} and lung cancer mortality [1], and some studies have found associations among only men or women [5,7]. The only previous study assessing the association between PM_{2.5} exposure and lung cancer incidence found no evidence of an association [1] while the studies of PM₁₀ and lung cancer incidence have reported mixed results [9,10]. However, the results presented above support an association with lung cancer incidence.

The low R² values represent the multifaceted factors that contribute to lung cancer incidence and mortality; just like many exposures, PM_{2.5} is not likely to be the sole etiologic agent responsible for increased lung cancer rates or deaths. The high variability demonstrates that tobacco smoking and other factors are contributing to lung cancer incidence and mortality rates. In addition, the smaller than expected change in R² values after inclusion of variables for SES and smoking may indicate that there is still variability and confounding present in the association due to these factors.

This study is an important contribution to the limited literature available on the association between PM_{2.5} concentration and lung cancer incidence; our results suggest that further study of PM_{2.5} and lung cancer may be warranted. A strength of the study is the ability to include areas in North Carolina that are often excluded due to lack of monitoring data. This was possible because the PM_{2.5} air data was based on both monitoring and model data. In addition, this analysis included both lung cancer incidence and mortality, whereas many studies focus solely on lung cancer mortality, as rates of lung cancer incidence and mortality are often similar. However, in North Carolina the rates for the years included in this study are slightly different (72.9 per 100,000 *versus* 61.3 per 100,000), which indicates that there is some difference between incidence and mortality. The results of this study show higher lung cancer incidence rates compared with mortality rates in North Carolina and also demonstrated a steeper slope for PM_{2.5} and lung cancer incidence rates than for mortality rates. This study also provides a validation of the association observed between PM_{2.5} and lung cancer by assessing the association between PM_{2.5} concentration and breast and prostate cancers, two cancers so far unrelated

to air pollution, and demonstrating no association in this ecologic analysis. This study is however limited by its ecologic nature. Assessment was performed at the county-level and the time periods utilized do not account for the latency period associated with lung cancer. However, due to the nature of PM_{2.5} as a regional pollutant, we expect that the counties that had higher concentrations of PM_{2.5} 20 or 30 years ago will be the same as those with higher PM_{2.5} concentrations during the period of our study. In other words, there is no reason for us to anticipate that the approximate rank order of the counties (by PM_{2.5} concentration) would have changed during the latency period of lung cancer, even though we recognize that, overall, concentrations of PM_{2.5} have decreased during this period. Because of the regional nature of PM_{2.5}, we have assumed that this decrease was uniform across the counties. Similar assumptions may be made for county-level smoking rates. If these assumptions are incorrect, we would expect that it would be more difficult to identify an association between PM_{2.5} and lung cancer due to the addition of exposure measurement error; the fact that we observed a small, but statistically significant effect for PM_{2.5} and lung cancer, but not for breast or prostate cancer, leads us to believe that these assumptions hold. Another limitation is the lack of data on specific components of PM_{2.5}, which could vary from county to county. PM_{2.5} concentrations were used in the analyses but specific components of PM_{2.5} might be more influential in lung cancer incidence and mortality. Nevertheless, data on PM_{2.5} components were not available. In addition, smoking rates were not available for each individual county and many of the counties' rates were grouped together, resulting in no variance of smoking rates among those groups of counties. If the cigarette smoking rates did vary between those counties, this was not adjusted for in the above analyses and the true smoking prevalence may have been inadequately captured by the variable that was utilized. Finally, other factors besides smoking and SES (such as radon and asbestos exposure) may have played a role in lung cancer incidence and mortality rates and confounded the association. We were unable to account for these additional factors in this analysis.

In sum, few studies have explored the potential relationship between PM_{2.5} exposure and lung cancer incidence. Using an ecologic study design, we examined the county-level associations between modeled PM_{2.5} concentrations and lung cancer incidence and mortality in North Carolina. Although variability is high, which partly reflects the fact that there are other etiologic agents that influence lung cancer incidence and mortality besides PM_{2.5}, there is a positive trend observed between PM_{2.5} concentration and lung cancer incidence and mortality rates. This provides evidence to suggest that PM_{2.5} concentrations are associated with lung cancer incidence and mortality rates. Future research at the individual-level, as opposed to an ecologic approach, will be important in understanding the role PM has on both lung cancer incidence and mortality as compared to and in interactions with tobacco smoking and other etiologic agents.

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Disclaimer

The views expressed in this article are those of the authors and do not necessarily reflect the views or policies of the U.S. EPA.

References

1. Beelen, R.; Hoek, G.; van den Brandt, P.A.; Goldbohm, R.A.; Fischer, P.; Schouten, L.J.; Armstrong, B.; Brunekreef, B. Long-term exposure to traffic-related air pollution and lung cancer risk. *Epidemiology* **2008**, *19*, 702-710.
2. Jerrett, M.; Burnett, R.T.; Ma, R.; Pope, C.A., III.; Krewski, D.; Newbold, K.B.; Thurston, G.; Shi, Y.; Finkelstein, N.; Calle, E.E.; *et al.* Spatial analysis of air pollution and mortality in Los Angeles. *Epidemiology* **2005**, *16*, 727-736.
3. Krewski, D.; Jerrett, M.; Burnett, R.T.; Ma, R.; Hughes, E.; Shi, Y.; Turner, M.C.; Pope, C.A., III.; Thurston, G.; Calle, E.E.; *et al.* Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. *Res. Rep. Health Eff. Inst.* **2009**, *140*, 5-114; discussion 115-136.
4. Laden, F.; Schwartz, J.; Speizer, F.E.; Dockery, D.W. Reduction in fine particulate air pollution and mortality: Extended follow-up of the Harvard Six Cities study. *Am. J. Respir. Crit. Care Med.* **2006**, *173*, 667-672.
5. Naess, O.; Nafstad, P.; Aamodt, G.; Claussen, B.; Rosland, P. Relation between concentration of air pollution and cause-specific mortality: Four-year exposures to nitrogen dioxide and particulate matter pollutants in 470 neighborhoods in Oslo, Norway. *Am. J. Epidemiol.* **2007**, *165*, 435-443.
6. Pope, C.A., III; Burnett, R.T.; Thun, M.J.; Calle, E.E.; Krewski, D.; Ito, K.; Thurston, G.D. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *JAMA* **2002**, *287*, 1132-1141.
7. McDonnell, W.F.; Nishino-Ishikawa, N.; Petersen, F.F.; Chen, L.H.; Abbey, D.E. Relationships of mortality with the fine and coarse fractions of long-term ambient PM10 concentrations in nonsmokers. *J. Expo. Anal. Environ. Epidemiol.* **2000**, *10*, 427-436.
8. Nawrot, T.S.; Nackaerts, K.; Hoet, P.H.; Nemery, B. Lung cancer mortality and fine particulate air pollution in Europe. *Int. J. Cancer* **2007**, *120*, 1825-1826.
9. Beeson, W.L.; Abbey, D.E.; Knutsen, S.F. Long-term concentrations of ambient air pollutants and incident lung cancer in California adults: Results from the AHSMOG study. Adventist health study on smog. *Environ. Health Perspect.* **1998**, *106*, 813-822.
10. Vineis, P.; Hoek, G.; Krzyzanowski, M.; Vigna-Taglianti, F.; Veglia, F.; Airoidi, L.; Autrup, H.; Dunning, A.; Garte, S.; Hainaut, P.; *et al.* Air pollution and risk of lung cancer in a prospective study in Europe. *Int. J. Cancer* **2006**, *119*, 169-174.
11. McMillan, N.J.; Holland, D.M.; Morara, M.; Feng, J. Combining numerical model output and particulate data using Bayesian space-time modeling. *Environmetrics* **2010**, *21*, 48-65.