Particulate Matter Emissions from Building Destruction in Armed Conflict Regions

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1. Introduction

Negative health effects from particulate matter (PM) inhalation are well-documented, specifically for $PM_{2.5}$, PM less than 2.5 micrometers (µm) in diameter. There has been an abundance of evidence linking $PM_{2.5}$ exposure with cardiovascular and respiratory disease[1]. Commonly examined sources of $PM_{2.5}$ emissions include cars and factories, yet a less-discussed source is building collapse. There are only a handful of studies, but one in particular is extensive with many parallels. Pinto et al. (2005) look at the immediate aftermath of the September 11 attacks[2]. Yet the presence of ground-level monitoring devices enable an accuracy that is practically nonexistent in most places that experience frequent armed conflict. While $PM_{2.5}$ can dissipate quickly depending on distance and wind conditions, short exposure durations of even a few hours can lead to deleterious health effects[3]. This risk is compounded if building collapses occur frequently; thus the goal here is to motivate how to obtain $PM_{2.5}$ figures in the absence of direct readings.

2. Methods

Two models of different complexities are selected for illustrative purposes. The first is a back-of-the-envelope inverse proportion calculation. This calculation is pulled from Stevens et al. (1984)[4] and cited in Pinto et al. (2005) as part of their analysis:

$$PM_{2.5}(\mu g/m^3) = \frac{k}{\text{Visibility (m)}} \qquad (1)$$

Here, k is a constant of proportionality with units $\mu g/m^2$. The general intuition is that the more $PM_{2.5}$ there is floating around, the less distance someone can see into the distance.

The second model relies on satellite remote sensing data but builds upon the first model's same intuition. Aerosol optical depth (AOD) is a measure of how much aerosol, suspended solid and liquid particles, is present in the atmosphere. The "depth" in AOD can be thought of as coming from how satellites obtain measurements of aerosols. The degree of penetration of electromagnetic radiation will indicate how much aerosol there is; the farther the penetration, the less aerosols there are. Additionally, by using radiation of different wavelengths, the composition of atmospheric aerosols can be teased out as particles will absorb and scatter wavelengths differently. While a simple inverse proportion can also be used by replacing visibility with AOD, a more involved model is pulled from Just et al. (2015)[5]. It consists of two parts:

$$\mathrm{PM_{ij}} = (\alpha + \mathrm{u_j}) + (\beta_1 + \mathrm{v_j})\mathrm{AOD_{ij}} + \beta_2\mathrm{Temperature_{ij}} + \beta_3\mathrm{RelativeHumidity_{ij}} + \beta_4\mathrm{MeanAMPBL_j} + \beta_5\sqrt{\mathrm{Precipitation_j}} + \beta_6\mathrm{RoadwayDensity_i} + \varepsilon_{ij} \qquad (2)$$

$$\sqrt{\mathrm{PredPM_{ij}}} = \alpha + \beta_1\sqrt{\mathrm{MPM_j}} + \mathrm{s(X_i, Y_i)_{k(j)}} + \varepsilon_{ij} \qquad (3)$$

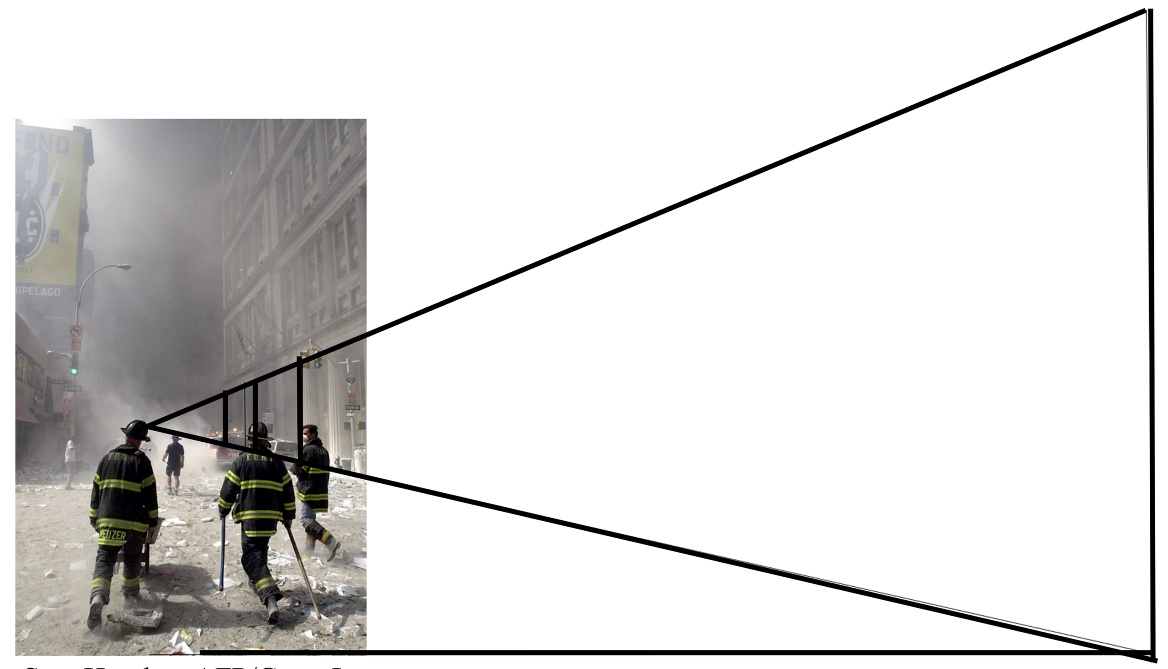
The specifics can be left to the paper itself, but the general idea is simple. First, coefficients are fit using using AOD, weather conditions, and potential contributors to $PM_{2.5}$, in this case, how many cars are on the road. MeanAMPBL is the average planetary boundary layer (PBL) in the morning. PBL affects how quickly $PM_{2.5}$ is dispersed, and because of satellite reliance on visible and infrared light wavelengths, AOD is often only measured in daytime. The second part predicts $PM_{2.5}$ levels for which AOD measurements are not available using the mean $PM_{2.5}$ levels of surrounding grids. The fitting process, however, needs $PM_{2.5}$ levels which must be obtained without using ground monitors for the purposes here.

3. Results

To demonstrate the first model, consider *Figure 1*, a scene from September 11, and the superimposed black lines. Pulling out a ruler and considering how quickly objects shrink in the distance, visibility can be ballparked to be around 20 m. Setting $k = 5{,}000\ \mu g/m^2$, the value for Mexico City, a place with noticeable pollution concerns[6], the obtained $PM_{2.5}$ concentration is $250\ \mu g/m^3$.

The spatial data for the second model is still a work in progress, but nevertheless, a comparison of sensitivity can still be performed in broad strokes. With the first model, the sensitivity of $PM_{2.5}$ estimates depend on visibility. For small distances, a small change implicates a large change in $PM_{2.5}$ and vice versa. This relationship may be true, but would drastically increase measurement error problems. Though arguably at that point, $PM_{2.5}$ concentrations are high enough such that the exact level becomes less important. The sensitivity for the second model is not as immediately clear, but presumably it would be relatively more stable. A small change in any of the covariate measures would likely be diluted by the other covariates, and because the spots with missing AOD measurements are predicted using surrounding $PM_{2.5}$ levels, any change in one of the surrounding areas will similarly be diluted by the other surrounding areas.

Figure 1. Estimating visibility using a ruler and exponential growth



Stan Honda—AFP/Getty Images

Assuming a standard story height of 4.3 m and an SUV length of 5 m, visibility is estimated at 20 m.

4. Conclusion

A meta-analysis of Chinese studies found that on average, for every increase of $PM_{2.5}$ levels by $100\ \mu g/m^3$ increased daily mortality rates of residents by 12.06%[7]. Plugging in the results from the first model thus predicts an increase of about 30%. Even with the large sensitivity, immediate exposure poses significant risks. *Figure 2* shows some of the destruction from the Syrian civil war, suggesting intense short-term exposure to residents and first responders is made even worse by prolonged conflict. Though Pinto et al. (2005) find that staying indoors eliminates pretty much all $PM_{2.5}$ exposure, *Figure 2* shows that staying indoors unlikely to be an option in regions with large amounts of armed conflict.

Figure 2. Syria's third largest city in 2014

Ghassan Najjar—Reuters

A stark illustration of the issue's relevance.

On-the-ground measurements may be difficult in the face of the scale of destruction, but it would offer insight into the longer term consequences of armed conflict, thereby influencing policy. There are also implications for individuals, for example, better education and healthcare concerning $PM_{2.5}$ exposure. People perhaps already have a sense of the dangers given the use of cloth as makeshift, but their effectiveness is likely bounded by the effectiveness of more commercial surgical masks. Last but not least, perhaps just as important is a better understanding of the chemical composition of PM exposure. $PM_{2.5}$, after all, refers to particles of a physical size, and some substances can be more toxic than others.

5. Works Cited

[1] Kim, Ki-Hyun, et al. "A Review on the Human Health Impact of Airborne Particulate Matter." Environment International, vol. 74, Jan. 2015, pp. 136–43. DOI.org (Crossref), doi:10.1016/j.envint.2014.10.005.

[2] Pinto, Joseph, et al. "Evaluation of Potential Human Exposures to Airborne Particulate Matter Following the Collapse of the World Trade Center Towers." *Urban Aerosols and Their Impacts*, vol. 919, 2005, pp. 190–237.

[3] Brook, Robert D., et al. "Particulate Matter Air Pollution and Cardiovascular Disease: An Update to the Scientific Statement From the American Heart Association." *Circulation*, vol. 121, no. 21, June 2010, pp. 2331–78. *Crossref*, doi:10.1161/CIR.0b013e3181dbece1.

[4] Stevens, Robert K., et al. "Source Apportionment Methods Applied to the Determination of the Origin of Ambient Aerosols That Affect Visibility in Forested Areas." *Atmospheric Environment (1967)*, vol. 18, no. 2, Jan. 1984, pp. 261–72. *ScienceDirect*, doi:10.1016/0004-6981(84)90099-4.

[5] Just, Allan C., et al. "Using High-Resolution Satellite Aerosol Optical Depth to Estimate Daily PM2.5 Geographical Distribution in Mexico City." *Environmental Science & Technology*, vol. 49, no. 14, July 2015, pp. 8576–84. *PubMed Central*, doi:10.1021/acs.est.5b00859.

[6] Chow, J.C., Watson, J.G., Lowenthal, D.H. et al. Environ Monit Assess (2002) 79: 29. https://doi-org.libproxy.lib.unc.edu/10.1023/A:1020047307117

[7] Qian, Xiao Lin, et al. "Meta-Analysis of Association Between Air Fine Particulate Matter and Daily Mortality." *Journal of Environment and Health*, Apr. 2005, http://en.cnki.com.cn/Article_en/CJFDTOTAL-HJYJ200504002.htm.