Applying SenMAP to Assess Air Quality, Equity, and Health in Milwaukee

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What is SenMAP?

SenMAP, or Satellite-enabled InMAP, is a tool currently under development that combines the Intervention Model for Air Pollution (InMAP) with corrections from satellite-derived data. Utilizing scaling strategies developed by Gallagher et al. (in review), SenMAP improves upon the accuracy of InMAP while retaining the quick nature of the model. With these corrections for the biases of InMAP, SenMAP is suitable for intra-urban analyses. The following results use both emissions inputs adapted from the EPA's National Emissions Inventory (NEI) as well as satellite-derived data (Donkelarr et al., 2021; U.S. EPA, 2016).

InMAP
+
Satellite-derived Data
=
SenMAP

The Intervention Model for Air Pollution (InMAP) is a linear, reduced-form model that estimates ambient concentrations of fine particulate matter ($PM_{2.5}$) across the contiguous United States (Tessum et al., 2017). Combining the results of a chemical transportation model, simplified chemistry, and annual emissions, InMAP predicts annual average concentrations of five species of $PM_{2.5}$: primary particulate matter, secondary organic aerosol, particulate sulfate, particulate nitrate, and particulate ammonium. Building on the accuracy of InMAP, SenMAP is scaled with a near surface satellite-derived data product from Washington University North American Regional Estimates that provides annual averages for particulate sulfate, nitrate, and ammonium (Donkelarr et al., 2021). The data product extrapolates near surface concentrations from aerosol optical depth and integrates ground-based monitor data. For scaling, the satellite-derived data is attributed to the grid of SenMAP.

SenMAP utilizes a variable grid, meaning grid cells vary in size determined by population density. This provides finer resolution in urban areas and coarser resolution in rural areas, allowing for a quick run-time while making it feasible to assess $PM_{2.5}$ at the neighborhood scale. Spatial resolution has a significant impact on the evaluation of environmental justice issues (Paolella et al., 2018). As a result, InMAP has been used to quantify racial-ethnic disparities in exposure to $PM_{2.5}$ (Tessum et al., 2019, 2021). In collaboration with community partners, our team is developing SenMAP with equity applications in mind.

$PM_{2.5}$ Concentrations at the Neighborhood Scale

Fine Particulate Matter in Milwaukee

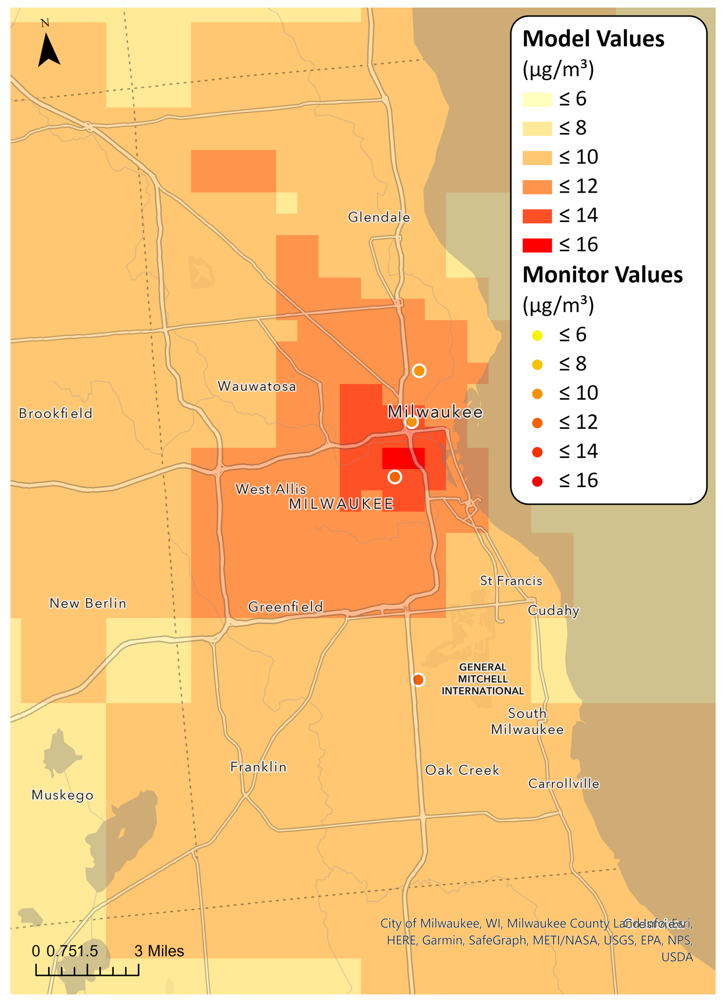

Figure 1. A map of average annual $PM_{2.5}$ at the neighborhood scale across Milwaukee county in µg/m³ with corresponding annual average measurement values from EPA monitors.

SenMAP can be used to estimate $PM_{2.5}$ concentrations at the neighborhood scale anywhere within the contiguous United States. On the left, estimated concentrations for the year 2014 are compared with annual averages from the EPA's ground-based monitors which are represented by circles on the map. Within Milwaukee county, the minimum estimated value is 6.72 µg/m³. The maximum value is 15.48 µg/m³, occurring south of the city center. The population-weighted average for this area is 10.17 µg/m³.

Equity Analysis

Air pollution is a leading environmental health risk that disproportionately impacts people of color in the United States (Bullard, 2016; Miranda et al., 2011; Mohai et al., 2019). Here, SenMAP can be used to assess absolute and relative inequity in exposure to fine particulate matter. Inequity is calculated using population-weighted average concentrations. Disparities in concentrations within Milwaukee are presented below.

Demographic Group	Absolute Inequity (µg/m³)	Relative Inequity (%)
Asian	-0.17	-1.67
Black	0.23	2.26
Indigenous	0.31	3.05
Latino	1.11	10.91
White	-0.39	-3.83

Figure 3. A table containing absolute inequity measured in µg/m³ and relative inequity in percent for each demographic group in Milwaukee.

How can SenMAP be used?

Mortality Impacts

Using a Cox proportional hazards regression, we calculated mortality impacts from exposure to fine particulate matter. For this analysis, we used a hazard ratio of 6.2% increase in all cause mortality associated with a 10 µg/m³ increase in exposure (Hoek et al., 2013). This analysis also used an estimated all cause mortality rate of 891.016 per 100,000 (CDC). An estimated **534.56 premature deaths** can be attributed to fine particulate matter annually, translating to a cost of **5.19 billion dollars**.

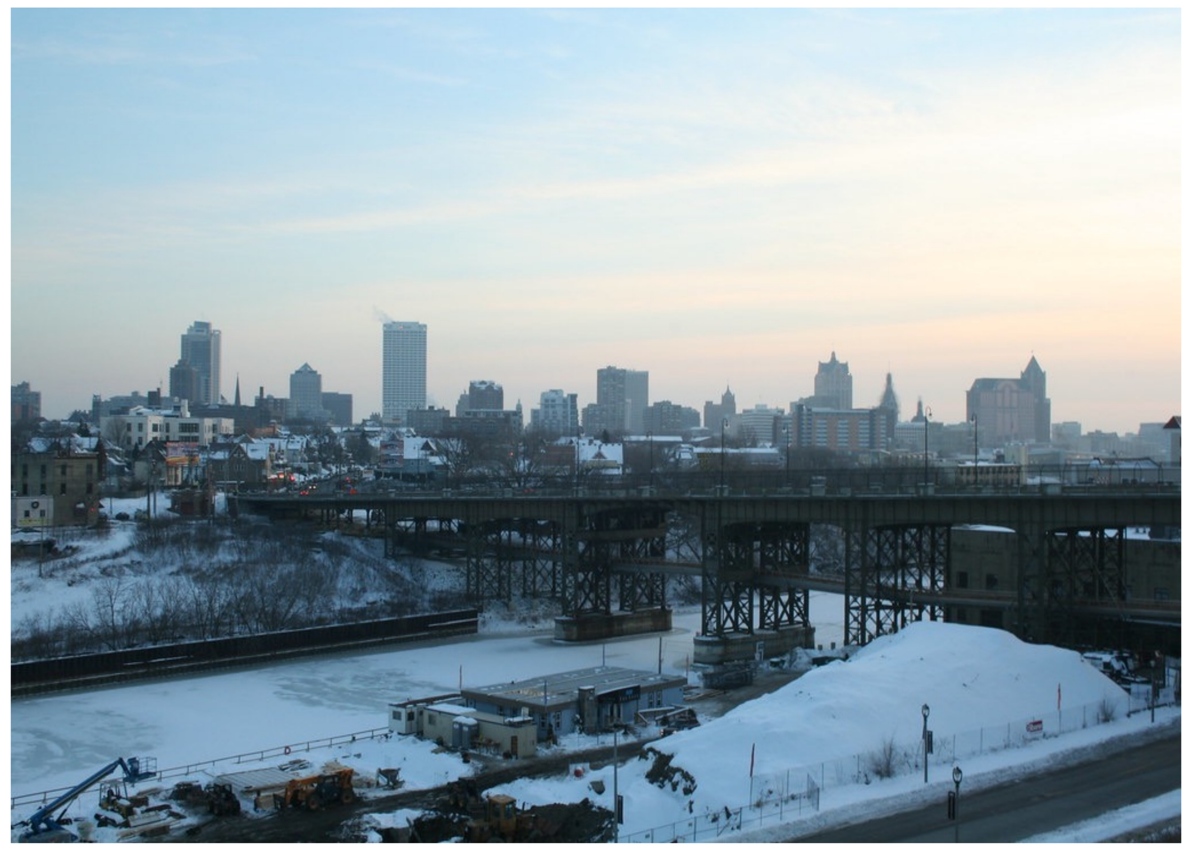

Figure 2. A photograph of the Milwaukee skyline in winter.

Source Contribution

This source contribution reflects the proportional impact of each sector of emissions on $PM_{2.5}$ concentrations in Milwaukee county. This analysis was generated using emissions inputs adapted from the 2014 NEI. As a result, this source contribution omits the impacts of wildfires. In 2014, the largest sources contributing to $PM_{2.5}$ in Milwaukee were non-point sources, on-road sources, and electricity generation.

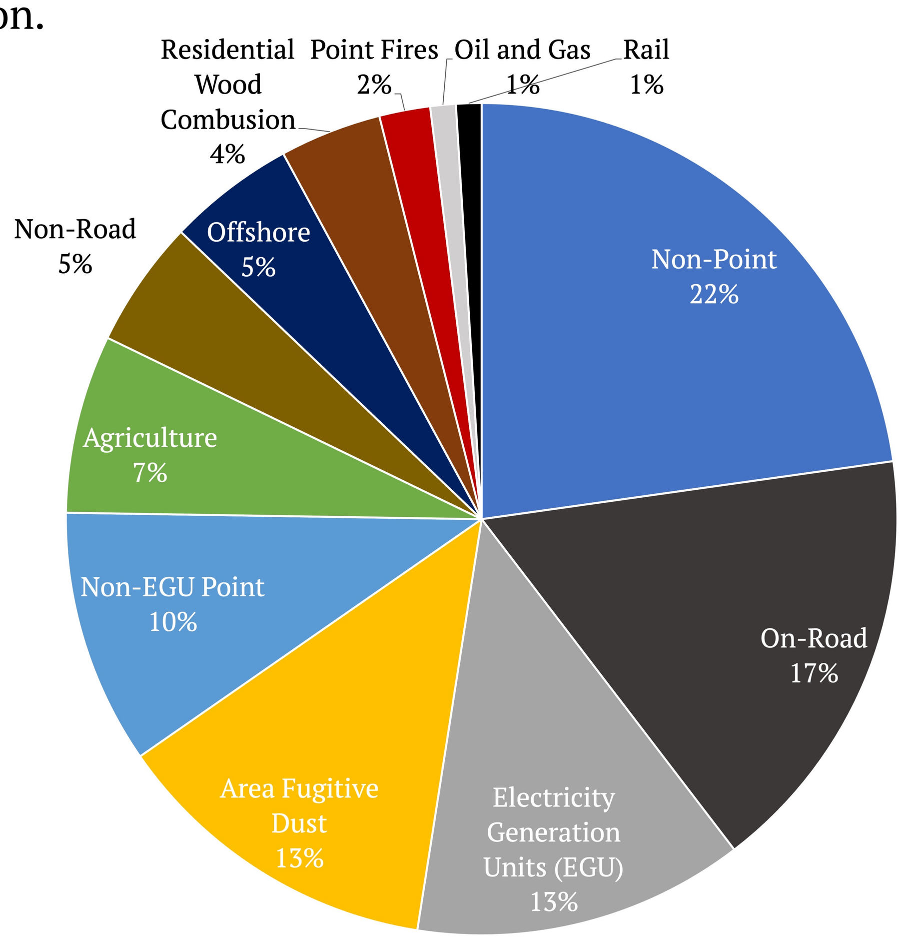

Figure 4. A pie chart showing source contribution of $PM_{2.5}$ in Milwaukee county.

Conclusions

- The SenMAP model is designed to integrate the rapid abilities of InMAP with the accuracy of satellite-derived data.
- Moreover, SenMAP supports the analysis of air quality, equity, and human health impacts at the intra-urban scale.
- SenMAP can be used to provide spatial coverage of $PM_{2.5}$ concentration estimates at the annual level over any area within the contiguous United States with resolutions as fine as 1 km X 1 km.
- Utilizing the neighborhood scale concentration data, SenMAP users can calculate population-weighted averages, absolute and relative inequity for each demographic group to assess equity in air pollution exposure.
- The high-resolution concentration data can be used to calculate mortality impacts for an individual city or over a larger area.
- In addition to source contribution analysis, SenMAP can also be used to analyze the distribution of species of $PM_{2.5}$ over an area.

Next Steps

- The SenMAP tool will be hosted on a GIS-enabled web interface that serves a wide range of users.
- The team at University of Illinois Urbana – Champaign is currently processing updated emissions input files.
- In collaboration with community organizations, we are engaging with the information needs of our partners. We are using SenMAP to gauge the air pollution impacts of "what-if" policy scenarios including the adoption of electric vehicles and other emission reductions.

References

Bullard, R. (2016). *Global environmental politics: from person to planet*. (P. K. Wapner, Ed.). London: Routledge.

Centers for Disease Control and Prevention (CDC) WONDER. (1997

Gallagher C.L., Holloway, T., Tessum, C.W., Jackson, C.M., & Heck, C. (in review) Combining satellite-derived PM2.5 data and a reduced-form air quality model to support air quality analysis in U.S. cities.

Hoek, G., Krishnan, R. M., Beelen, R., Peters, A., Ostro, B., Brunekreef, B., & Kaufman, J. D. (2013). Long-term air pollution exposure and cardio- respiratory mortality: a review. *Environmental Health*, *12*(1), 43. https://doi.org/10.1186/1476-069X-12-43

Miranda, M. L., Edwards, S. E., Keating, M. H., & Paul, C. J. (2011). Making the Environmental Justice Grade: The Relative Burden of Air Pollution Exposure in the United States. *International Journal of Environmental Research and Public Health*, *8*(6), 1755–1771. https://doi.org/10.3390/ijerph8061755

Mohai, P., Pellow, D., & Roberts, J. T. (2009). Environmental Justice. *Annual Review of Environment and Resources*, *34*(1), 405–430. https://doi.org/10.1146/annurev-environ-082508-094348

Paolella, D. A., Tessum, C. W., Adams, P. J., Apte, J. S., Chambliss, S., Hill, J., et al. (2018). Effect of Model Spatial Resolution on Estimates of Fine Particulate Matter Exposure and Exposure Disparities in the United States. *Environmental Science & Technology Letters*, *5*(7), 436–441. https://doi.org/10.1021/acs.estlett.8b00279

Tessum, C. W., Hill, J. D., & Marshall, J. D. (2017). InMAP: A model for air pollution interventions. *PLOS ONE*, *12*(4), e0176131. https://doi.org/10.1371/journal.pone.0176131

Tessum, C. W., Apte, J. S., Goodkind, A. L., Muller, N. Z., Mullins, K. A., Paolella, D. A., et al. (2019). Inequity in consumption of goods and services adds to racial–ethnic disparities in air pollution exposure. *Proceedings of the National Academy of Sciences*, *116*(13), 6001–6006. https://doi.org/10.1073/pnas.1818859116

Tessum, C. W., Paolella, D. A., Chambliss, S. E., Apte, J. S., Hill, J. D., & Marshall, J. D. (2021). $PM_{2.5}$ polluters disproportionately and systemically affect people of color in the United States. *Science Advances*, *7*(18), eabf4491. https://doi.org/10.1126/sciadv.abf4491

Van Donkelaar, A., Hammer, M. S., Bindle, L., Brauer, M., Brook, J. R., Garay, M. J., et al. (2021). Monthly Global Estimates of Fine Particulate Matter and Their Uncertainty. *Environmental Science & Technology*, *55*(22), 15287–15300. https://doi.org/10.1021/acs.est.1c05309