Using Geographic Information Systems and Questionnaire Data to Predict Indoor and Outdoor Concentrations of Traffic-Related Air Pollution

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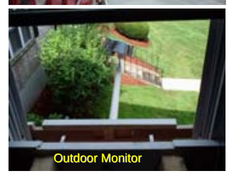
INTRODUCTION

- Asthma prevalence is elevated in low-SES urban settings, but few studies have evaluated outdoor exposure gradients within these urban areas, and indoor exposure patterns are rarely considered.
- Numerous studies have found associations between GIS-based measures of residential proximity to traffic and respiratory outcomes, but such studies have often been in non-residential settings and measures may not be strongly correlated with the causal agents.
- Exposure misclassification is exacerbated by the presence of indoor sources of key traffic-related air pollutants (i.e., nitrogen dioxide, fine particulate matter) and by differential ventilation/time activity patterns.
- This study is part of the Asthma Coalition on Community, Environment, and Social Stress (ACCESS), a prospective birth cohort study assessing the contributions of environmental, social, and genetic factors to asthma etiology in urban Boston. Our objective is to characterize traffic-related air pollution exposures, for ultimate epidemiological applications.

SAMPLING METHODS

- Homes selected based on initial traffic density classification, representation of target neighborhoods
  - Cohort homes supplemented with non-cohort participants for geographic representativeness
- Sampling in heating and cooling seasons, indoors and outdoors for:
  - Fine particulate matter ($PM_{2.5}$): Harvard PEM, size-selective inertial impactor attached to a Medo linear-piston vacuum pump (4 LPM)
    - Elemental carbon (EC): Reflectance analysis on particle filters
    - Elemental analysis on particle filters using x-ray fluorescence spectroscopy (XRF)
  - Nitrogen dioxide (NO_2): Yanagisawa passive filter badges
- Traffic counts measured on highest-density road within 100 m of home (Jamar Trax I Plus)
- Temperature/humidity measured with HOBOs
- Questionnaires administered to participants linked to indoor sources, ventilation, indoor activities, etc.



Indoor and outdoor concentrations collected simultaneously using integrated 3 – 4 day measurements

STATISTICAL APPROACH

Outdoors

- Use central site monitor to account for temporal variability
- Develop GIS covariates representing different dimensions of traffic at different radii
- Use correlation analysis to select among variables
- Incorporate important modifying factors (i.e., wind speed and direction, presence of obstruction between home and roadway) as effect modifiers for traffic terms

Indoors

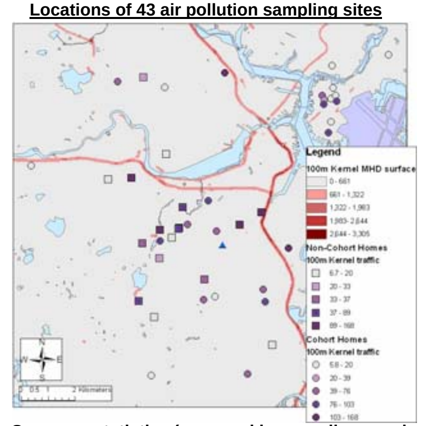
- Use outdoor measurement for ambient contribution
- Develop proxy for effective penetration efficiency using indoor-outdoor ratio of sulfur
- Use questionnaire information to capture indoor sources/activity patterns, restricted to variables with logical causal connection to pollutant of interest
- Use mass-balance model concepts to develop appropriate functional form

CANDIDATE VARIABLES

GIS – based traffic indicators	
Cumulative Density Scores (unweighted/kernel-weighted at 50, 100, 200, 300, 500m buffer)	
Distance – based measures (distance to nearest major road, highway, truck route)	
Summary measures (Total roadway length contained w/in 50, 100, 200, 300, 500m buffers)	
Characteristics of nearest major road (Average daily traffic, % Diesel traffic)	
Modifiers of Traffic	
Monitor placement (Obstructed from nearest road or nearest major road)	
Meteorology (Average daytime wind speed, % of hours with low (< 2 m/s) wind speed)	
Weekday/Weekend Effect (% of sample collected on the weekend)	
Indoor Sources	**Candidate Pollutants**
Cleaning Activities	$PM_{2.5}$, Ca, Fe, K, Si, Na, Cl, Zn
Humidifier Use	$PM_{2.5}$, Ca, K, Si, Cl
Candle Use	$PM_{2.5}$, EC
Cooking Time	$PM_{2.5}$, EC, Ca, Fe, K, Si, Na, Cl, Zn
Gas stove usage	NO_2
Occupant density	$PM_{2.5}$, Ca, Fe, K, Si, Na, Cl, Zn

RESULTS

Locations of 43 air pollution sampling sites



Summary statistics (averaged by sampling session)

Pollutant	Outdoor Concentrations N	Outdoor Mean (SD)	Outdoor Range	Indoor Concentrations N	Indoor Mean (SD)	Indoor Range
NO_2 (ppb)	52	17.2 (5.67)	5.21 – 33.3	54	19.6 (11.0)	5.67 – 61.1
$PM_{2.5}$ ($\mu g/m^3$)	60	14.2 (5.43)	6.75 – 31.3	64	20.3 (12.5)	6.77 – 74.9
EC ($m^{-1} \times 10^{-5}$)	58	0.63 (0.49)	0.08 – 3.8	62	0.57 (0.35)	0.12 – 2.2
Ca (ng/m^3)	58	29.4 (17.2)	9.12 – 113	62	48.0 (84.8)	12.8 – 676
Fe (ng/m^3)	58	66.5 (26.4)	15.4 – 162	62	46.1 (20.0)	3.50 – 101
K (ng/m^3)	58	57.5 (56.7)	19.1 – 446	62	78.6 (8.22)	15.2 – 477
Si (ng/m^3)	58	55.9 (71.9)	4.81 – 467	62	83.4 (200)	5.53 - 1480
Na (ng/m^3)	58	144 (160)	29.2 – 1260	62	185 (320)	2.27 - 2520
Cl (ng/m^3)	58	15.2 (41.4)	0.194 – 3050	62	87.2 (3680)	0.528 – 2920
Zn (ng/m^3)	58	14.7 (19.3)	5.23 – 1520	62	14.7 (18.0)	3.40 – 1050
S (ng/m^3)	58	1540 (1450)	413 – 11300	62	1120 (699)	310 – 3910
V (ng/m^3)	58	4.79 (4.00)	1.08 – 22.5	62	3.54 (2.66)	0.392 – 15.5

Coefficients of determination (R^2)

Pollutant	Outdoor vs. Ambient	Indoor vs. Outdoor
NO_2	0.21	0.07
$PM_{2.5}$	0.65	0.23
EC	0.08	0.42
Ca	N/A	0.33
Fe	N/A	0.25
K	N/A	0.52
Si	N/A	0.03
Na	N/A	0.43
Cl	N/A	0.12
Zn	N/A	0.28
S	N/A	0.78
V	N/A	0.77

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OUTDOOR MODELS

Dependent variable	R^2	Independent variables	Parameter estimate	p-value
ln($PM_{2.5}$)	0.76	Intercept	0.21	0.32
		ln(central site $PM_{2.5}$)	0.78	< 0.0001
		Roadway length, 100m buffer	1.5E-4	0.02
		Smoking/grilling near outdoor monitor	0.16	0.01
		Block group population density	9.2E-6	0.01
ln(EC)	0.44	Intercept	-0.61	0.004
		ln(central site EC)	0.48	0.002
		Roadway length, 200m buffer	8.1E-3	0.08
		(Roadway length, 200m buffer)* (% of hours with wind < 2 m/s)	4.6E-4	0.03
		Cooling season	-0.48	0.0004
NO_2	0.56	Intercept	-12.5	0.009
		Central site NO_2	1.1	< 0.0001
		Roadway length, 50m buffer	0.014	0.002
		(Roadway length, 50m buffer)* (Obstructed from nearest major road)	-0.0094	0.005
		Cooling season	4.9	0.001
		Population density	4.0E-4	0.001

SELECTED INDOOR-OUTDOOR MODELS

Dependent Variable	R^2	Independent Variables	Parameter Estimate	p-value
$PM_{2.5}$	0.36	Outdoor Concentration	0.86	0.0002
		Cooking more than 1 h/day	5.9	0.04
		Occupant Density	3.8	0.09
EC	0.49	Outdoor Concentration	0.72	<0.0001
NO_2	0.16	Outdoor Concentration	0.53	0.02
		Gas stove usage more than 1 h/day	5.7	0.07
S	0.78	Outdoor Concentration	0.95	<0.0001
Ca	0.45	Outdoor Concentration	0.49	<0.0001
		Humidifier Use	18	0.0009
Na	0.46	Outdoor Concentration	0.44	<0.0001
		Occupant Density	31	0.14
Zn	0.36	Outdoor Concentration	0.82	<0.0001
		Cooking more than 1 h/day	6.0	0.02

SUMMARY OF CONCLUSIONS

- Outdoor $PM_{2.5}$ displayed more temporal than spatial heterogeneity, with significant contributions from indoor sources
- Outdoor EC displayed significant spatial heterogeneity, explained in part by proximity to traffic, with no significant indoor sources
- Outdoor NO_2 displayed significant spatial heterogeneity, explained in part by proximity to traffic, with an influence of indoor gas stove usage
- Indoor-outdoor relationships were strongest for combustion pollutants without indoor sources (S, V), weakest for crustal elements
- Next steps: structural equation modeling to better characterize source contributions, approaches for extrapolation to full cohort