Overview of Air pollution in Ghana: the past, present and future

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Outline

- Broader context
- Early work
- Present work
- Where next?

My motivation – in the beginning









What is the air?

Chemical 'pea' soup

Gases

Pentane
Ethylene
Water Vapour
Toluene
Methane
Nitrogen Oxide
Methanol
1,3-Butadiene
Formaldehyde
Propylene
Nitrous Oxide
Carbon Dioxide
Isobutylene
Benzene
Acetylene
Nitrogen Dioxide
Acetaldehyde

Inorganic Species

Elemental Carbon

Organic Species

Metals

Particles

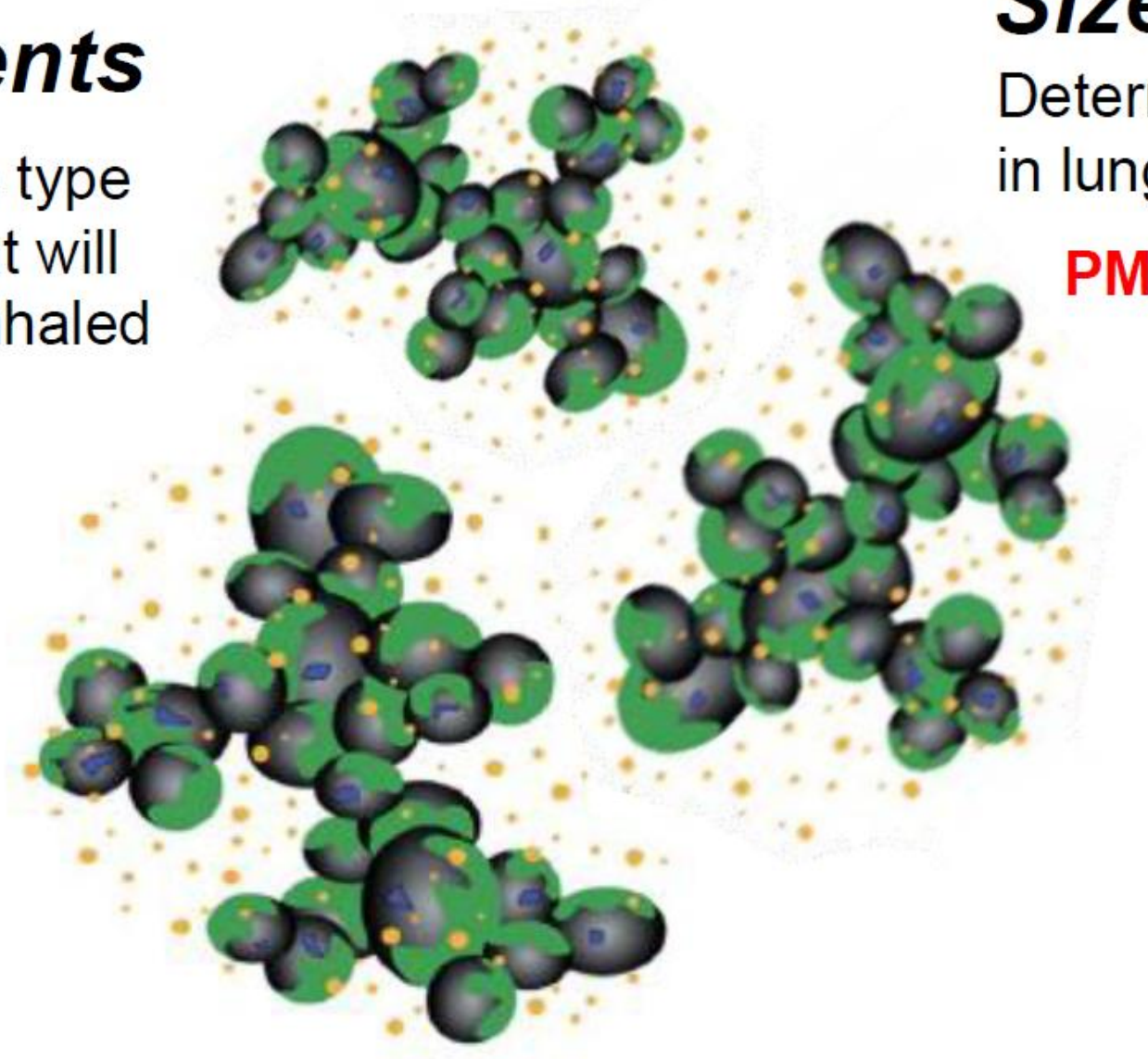
Sources of Air Pollutants

When thinking/talking about Air Pollution

Components

Determines the type of reactions that will happen once inhaled

Gases



Size

Determines deposition region in lung (or other organs)

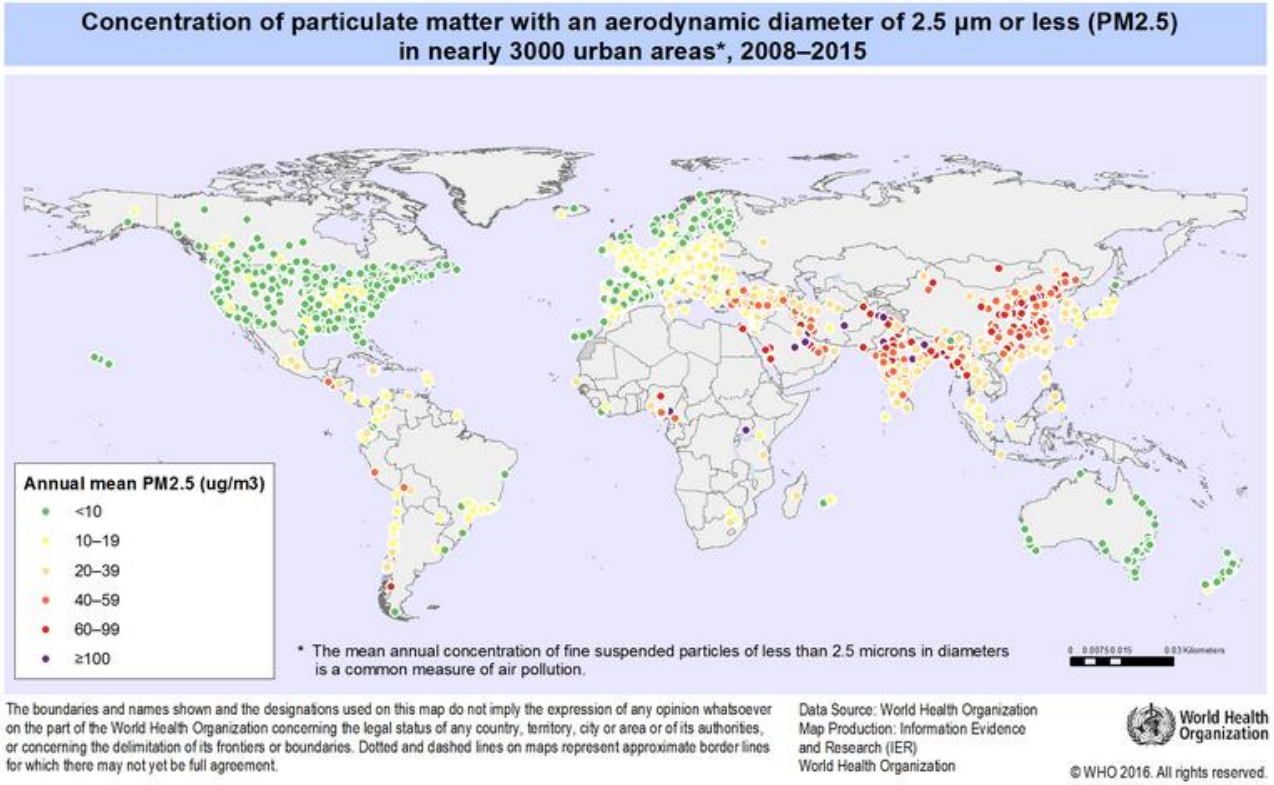
$PM_{2.5}$ vs. Ultrafine PM

Concentration

Determines the magnitude of the biological response

Number vs. Mass Concentration

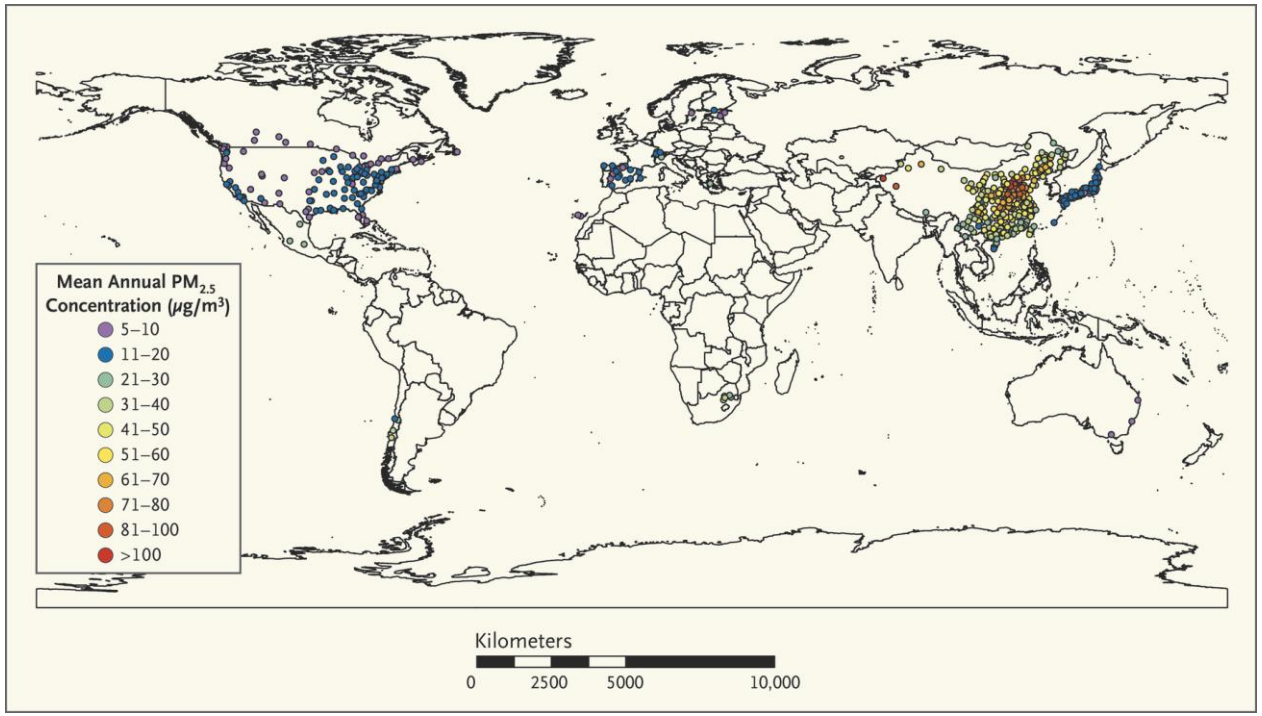
Global inequalities in pollution monitoring and health data



- Limited monitoring data in SSA

- Sparse epidemiological studies in SSA

Locations of 652 urban areas in 24 countries or regions with $PM_{2.5}$ data covering the period from 1986 through 2015



WHO, 2016; Liu et al. NEJM (2019)

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Characterizing air pollution in two low-income neighborhoods in Accra, Ghana

Raphael E. Arku[a], Jose Vallarino[b], Kathie L. Dionisio[b,c], Robert Willis[d], Hyunok Choi[b,c], J. Gaines Wilson[c], Christina Hemphill[b], Samuel Agyei-Mensah[a,e], John D. Spengler[b], Majid Ezzati[b,c,*]

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Environ. Res. Lett. 8 (2013) 044025 (9pp)
doi:10.1088/1748-9326/8/4/0440

Chemical composition and sources of particle pollution in affluent and poor neighborhoods of Accra, Ghana

Zheng Zhou[1,2], Kathie L Dionisio[1,2], Thiago G Verissimo[3], Americo S Kerr[3], Brent Coull[2,4], Raphael E Arku[2], Petros Koutrakis[2], John D Spengler[2], Allison F Hughes[5], Jose Vallarino[2], Samuel Agyei-Mensah[6] and Majid Ezzati[7]

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Sustainability Science, Sustainability Science

Household and community poverty, biomass use, and air pollution in Accra, Ghana

Zheng Zhou,[a,b] Kathie L. Dionisio,[a,b] Raphael E. Arku,[b] Audrey Quaye,[c] Allison F. Hughes,[d] Jose Vallarino,[b] John D. Spengler,[b] Allan Hill,[a] Samuel Agyei-Mensah,[c,e] and Majid Ezzati[f,1]

Within-Neighborhood Patterns and
Monitoring and Geographic Informa
in Accra, Ghana

ion in Accra
hoods: Spatial,
nomic, and Temporal

DIONISIO,[†]
E. ARKU,[§,∥]
F. HUGHES,[⊥]

Introduction

Although more than 60% of sub-Saharan Africa's (SSA) population is currently rural, Africa's urban population is growing faster than that in any other world region (1). Despite this trend, there is limited data on air pollution in SSA cities, especially for particulate matter (PM) which is considered the best indicator of the health effects of pollutant mixtures. For example, a comprehensive review found that in 2000 annual PM data were available for only 3 of 212 cities with population ≥100,000 in SSA (2).

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Chemical Characterization and Source Apportionment of Household Fine Particulate Matter in Rural, Peri-urban, and Urban West Africa

Zheng Zhou,[†,‡] Kathie L. Dionisio,[†,‡] Thiago G. Verissimo,[§] Americo S. Kerr,[§] Brent Coull,[‡,∥] Stephen Howie,[⊥] Raphael E. Arku,[‡] Petros Koutrakis,[‡] John D. Spengler,[‡] Kimberly Fornace,[⊥,#] Allison F. Hughes,[▽] Jose Vallarino,[‡] Samuel Agyei-Mensah,[◇] and Majid Ezzati[&,*]

patterns of particulate matter sources and pollution in four
a, Ghana

ael E. Arku [b,1], Kathie L. Dionisio [b,c,1], Christopher Paciorek [d,e], Ari B. Friedman [f], g Zhou [b,c], Allison F. Hughes [h], Jose Vallarino [b], Samuel Agyei-Mensah [i],

ALTHY CITIES

Early work in four neighborhoods in Accra, Ghana

Ambient

Personal

Occupational

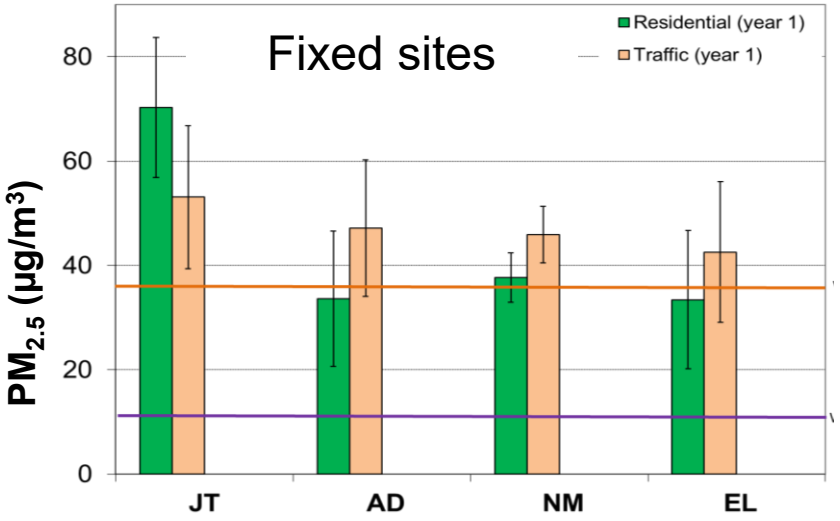
Household

Mobile

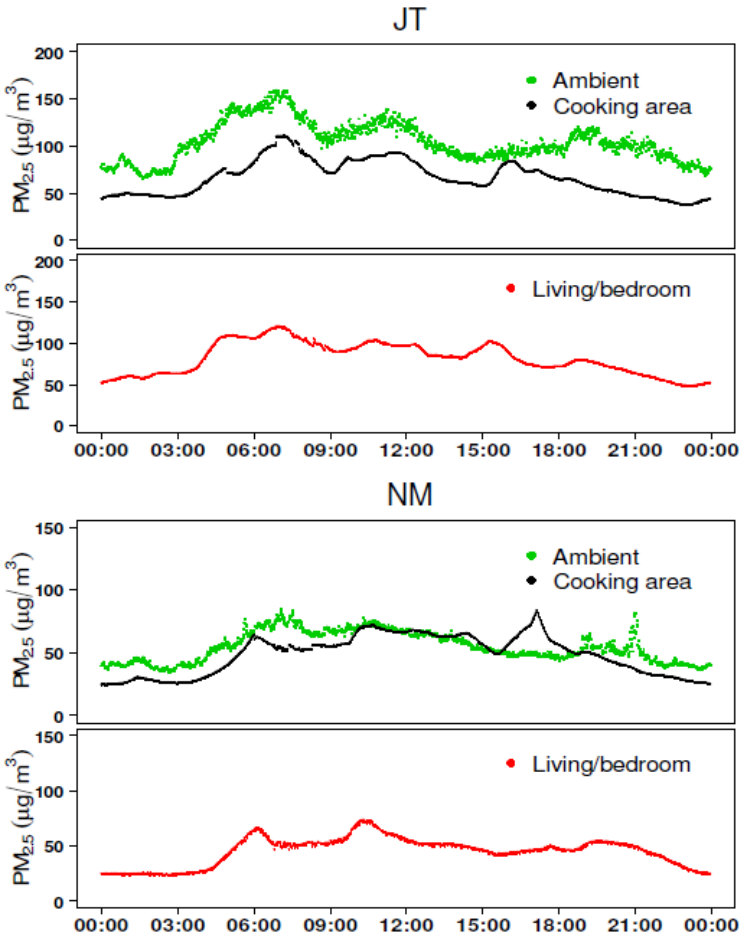
Occupational

s and

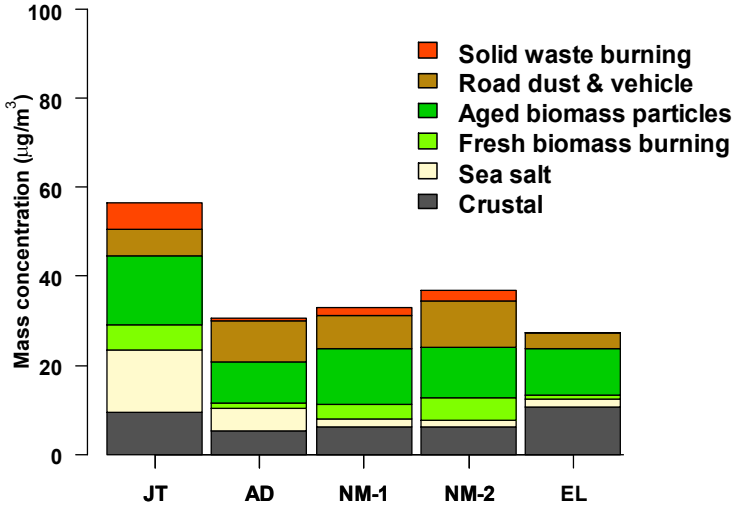
Significant contribution from biomass use and traffic



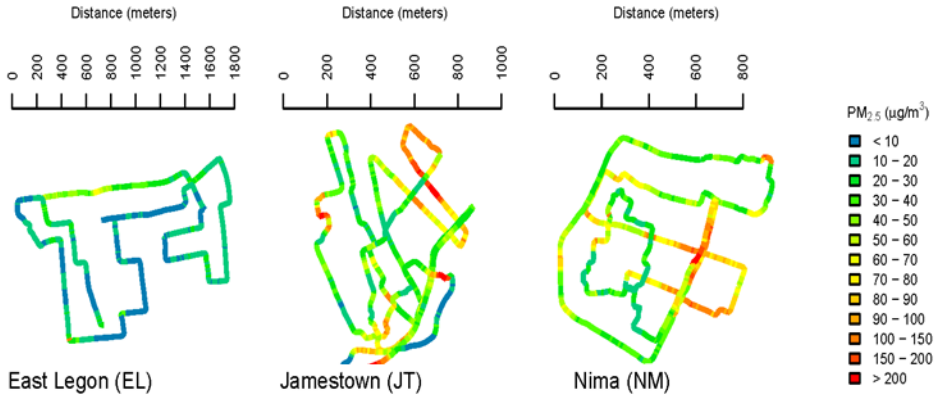
Household



Source contributions



Mobile monitoring

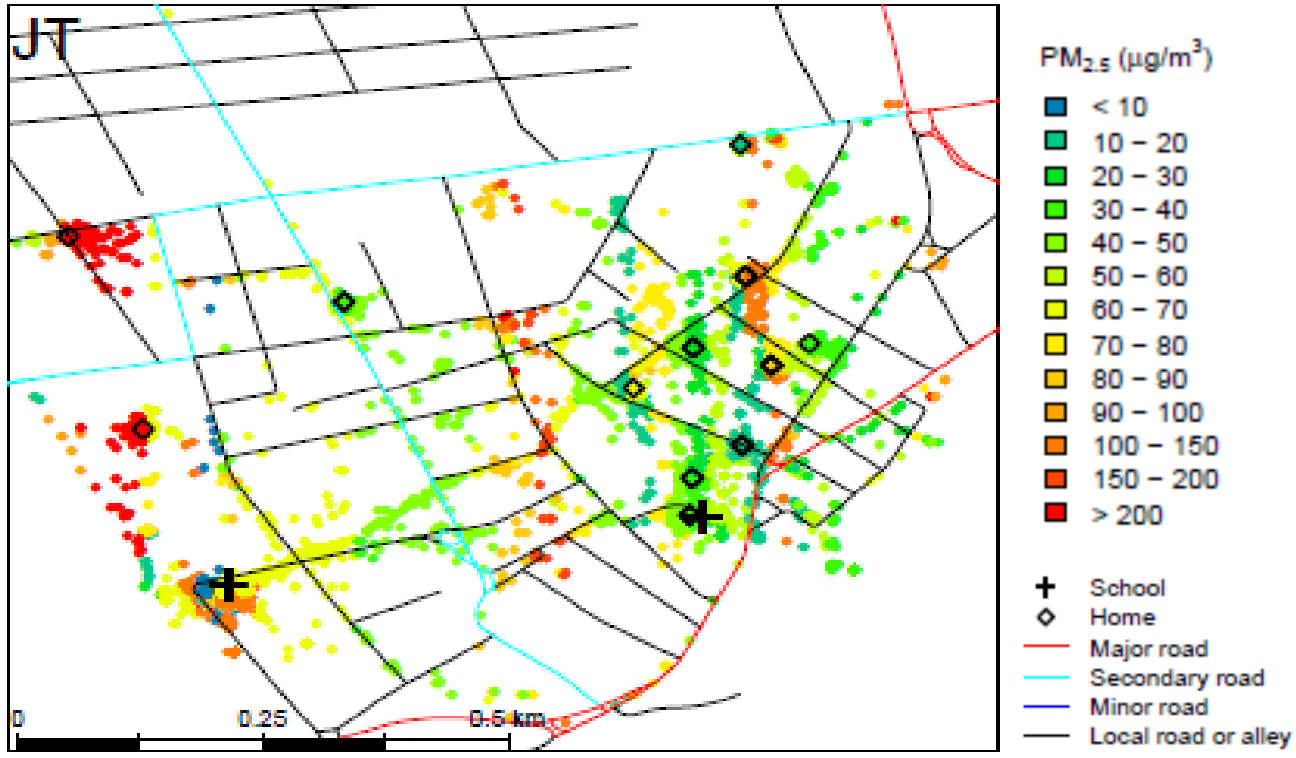


Nitrogen dioxide (NO_2) concentrations from 30 sites were almost universally low, with virtually no variation across sites

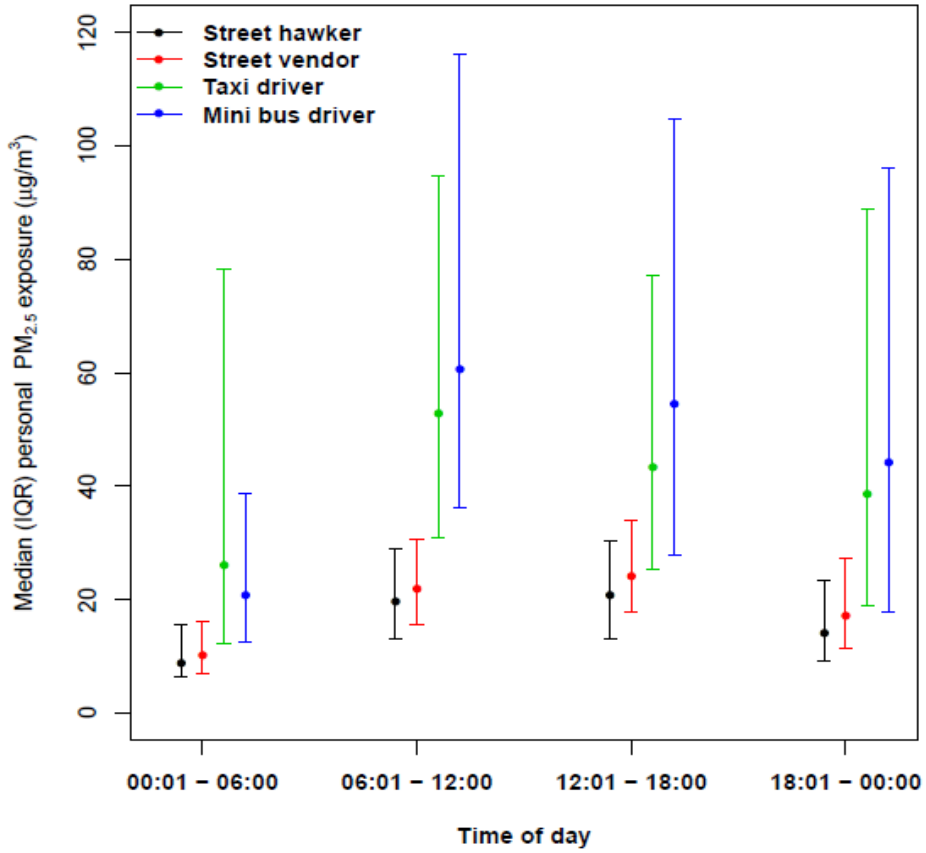
Dionisio et al 2010a, 2010b, Zhou et al 2011, 2013

Personal exposure of schoolchildren and outdoor workers

Personal exposures of schoolchildren



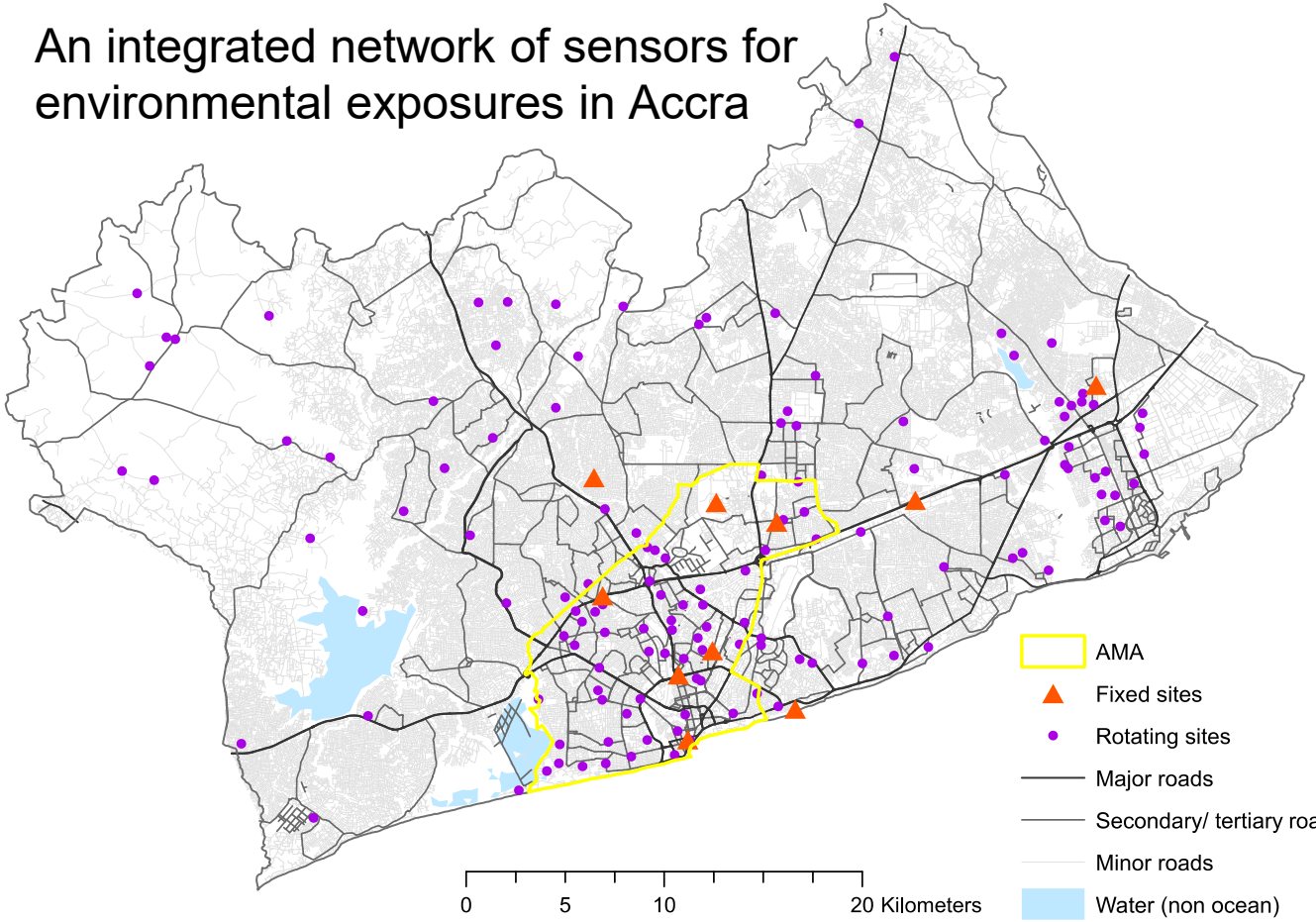
Exposure patterns of traffic related workers



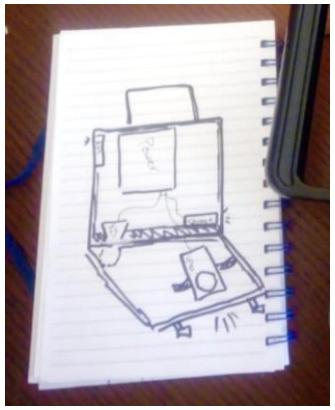
Arku et al 2015

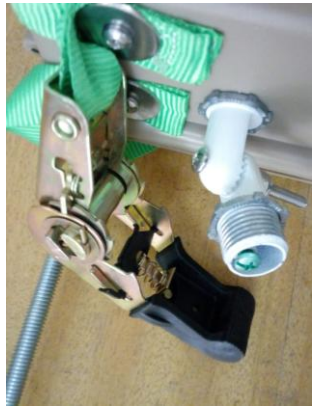
Present work – Develop consistent and transferable protocol to generate rich environmental data in SSA cities

An integrated network of sensors for environmental exposures in Accra



Locations of fixed (5+ years) and rotating (1 week) monitoring sites





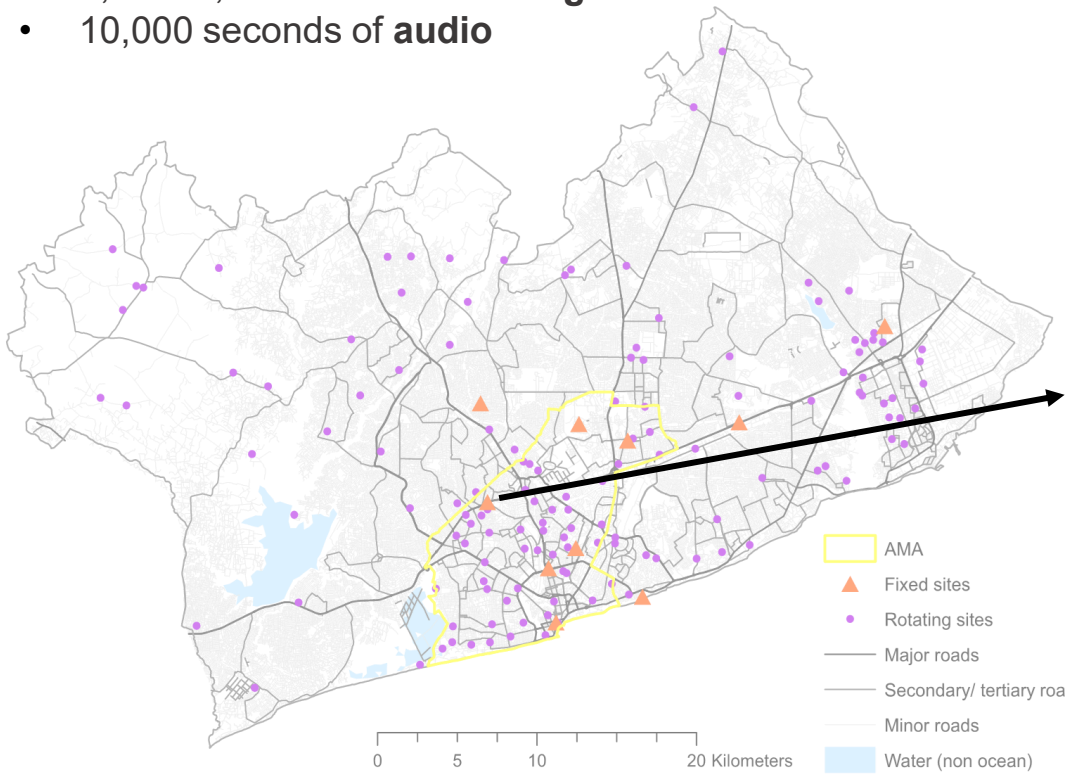
- Field validated
- Robust to elements
- Cost effective
- Power
- Positioning and mounting
- Small, discreet, and lightweight
- Permissions

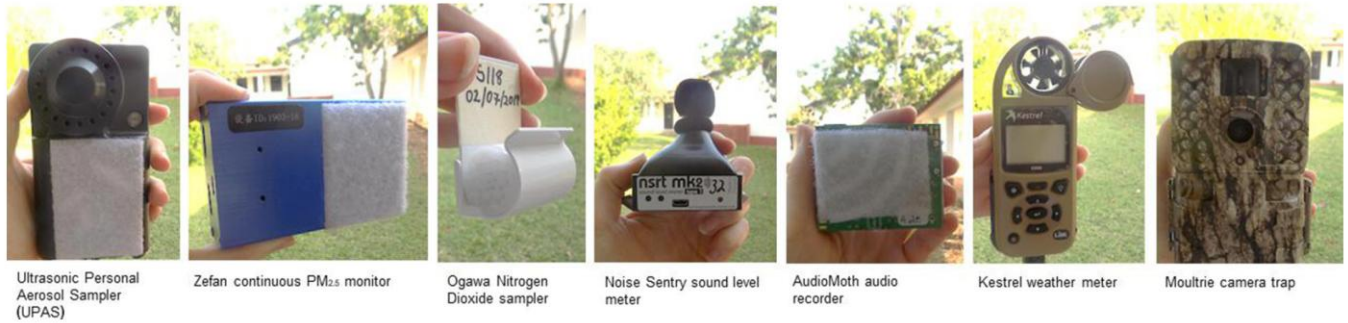
Clark et al 2020

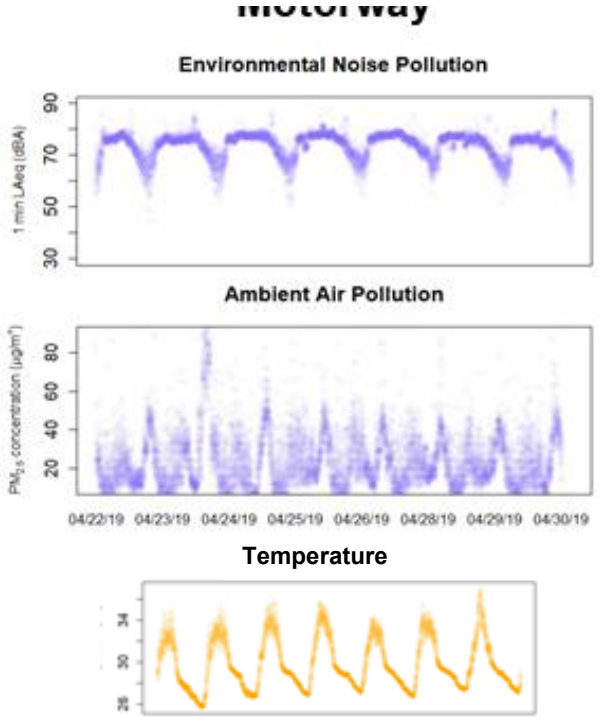
Rich data from the Accra environmental measurement campaign

Per site per week

- Real-time (10,000 mins) and weekly integrated **$PM_{2.5}$ and NO_2 air pollution**
- 10,000 mins of real-time **noise levels**
- 10,000 mins of **weather** data
- 2,000–4,000 **street view images**
- 10,000 seconds of **audio**



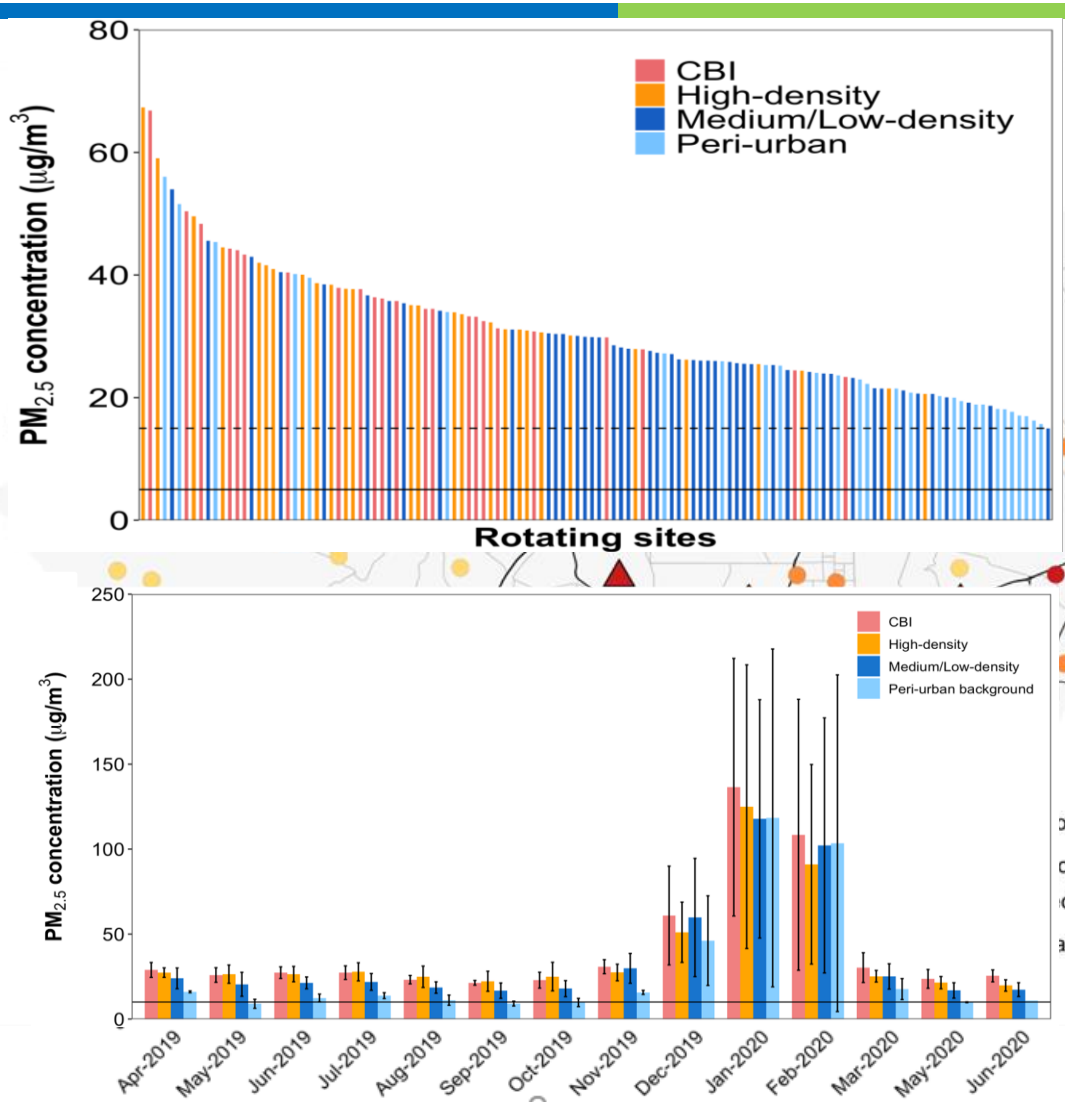


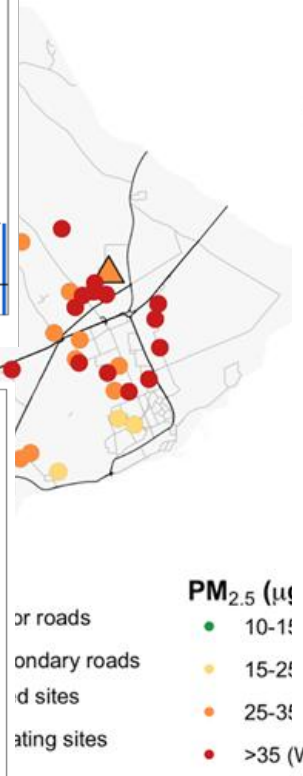


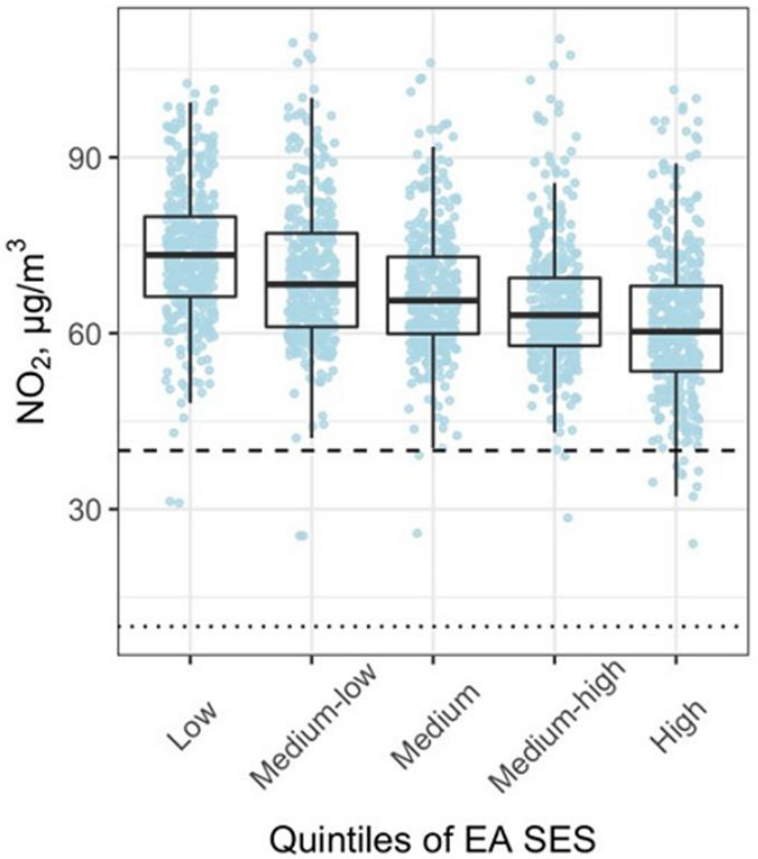
$PM_{2.5}$ air pollution particles on a filter

Clark et al 2020

Marked spatial, temporal, and socioeconomic disparities







Previous WHO annual AQG (40 µg/m^3)

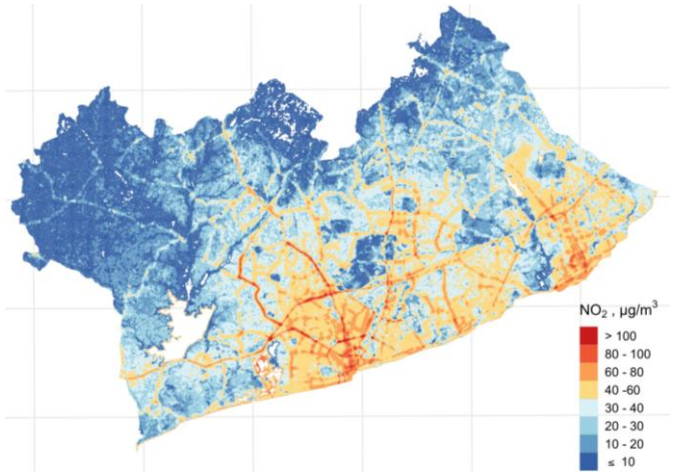
2021 WHO annual AQG (10 µg/m^3)

Horizontal lines represent WHO annual $PM_{2.5}$ guidelines

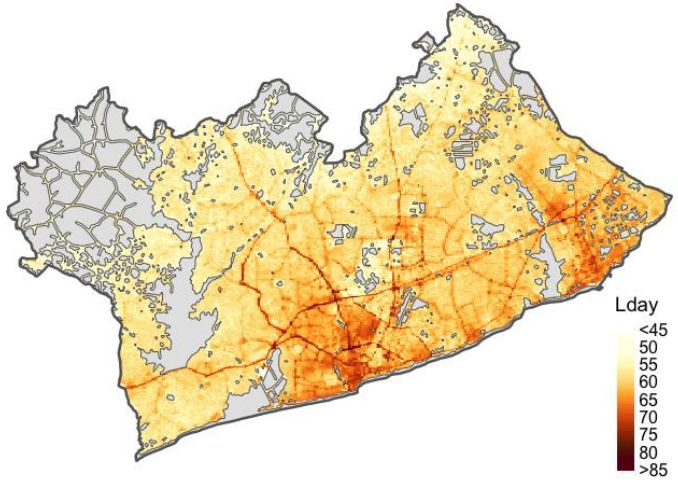
Alli et al 2021; Wang et al 2021

Measurement to city-wide models for Accra

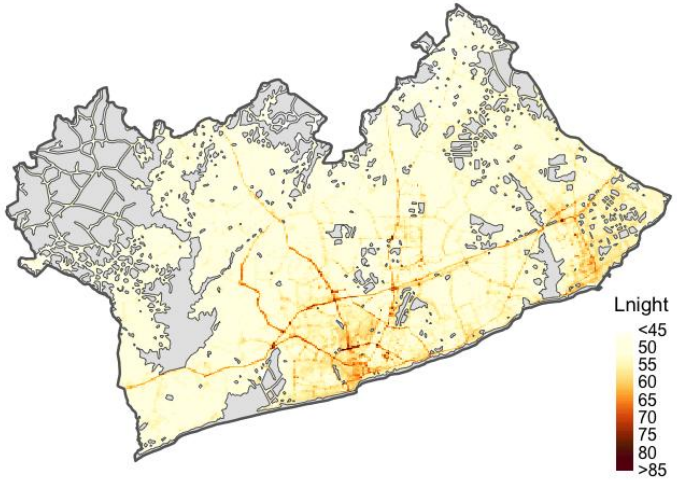
Air pollution (NO_2)



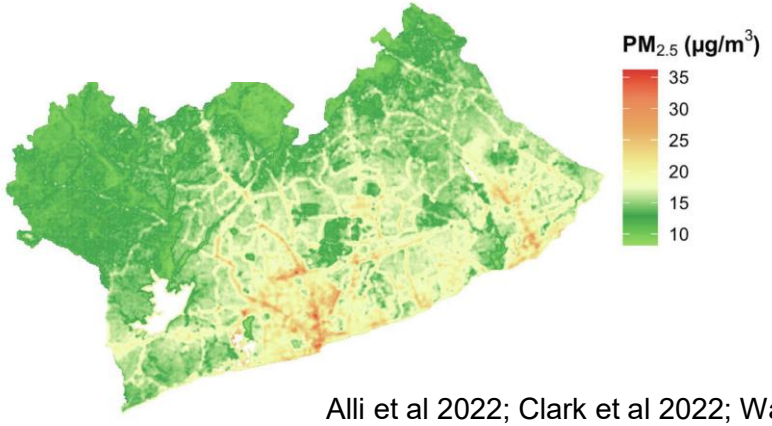
Day-time noise



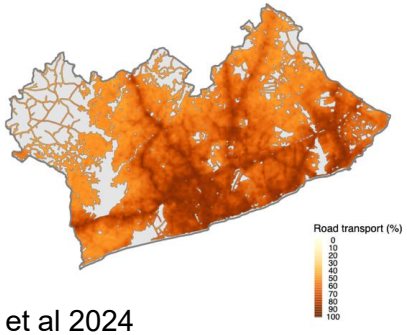
Night-time noise



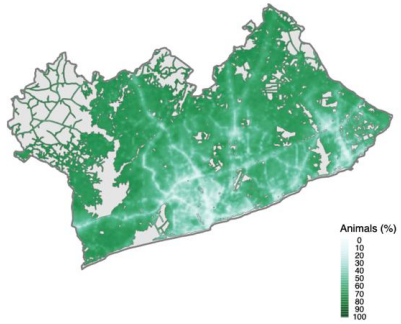
Air pollution ($PM_{2.5}$)



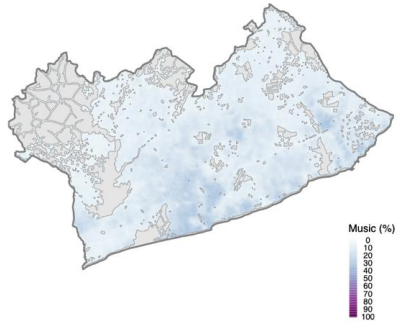
Road-transport



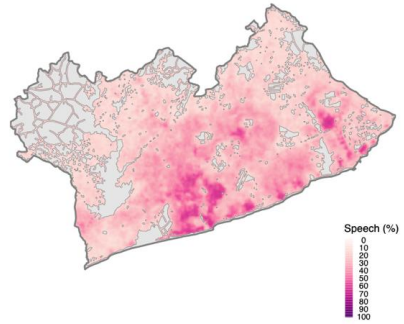
Animals (e.g., birds)



Music



Human speech



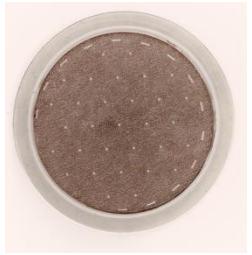
Alli et al 2022; Clark et al 2022; Wang et al 2024

Is ambient fine particle pollution plateauing in cities in SSA?

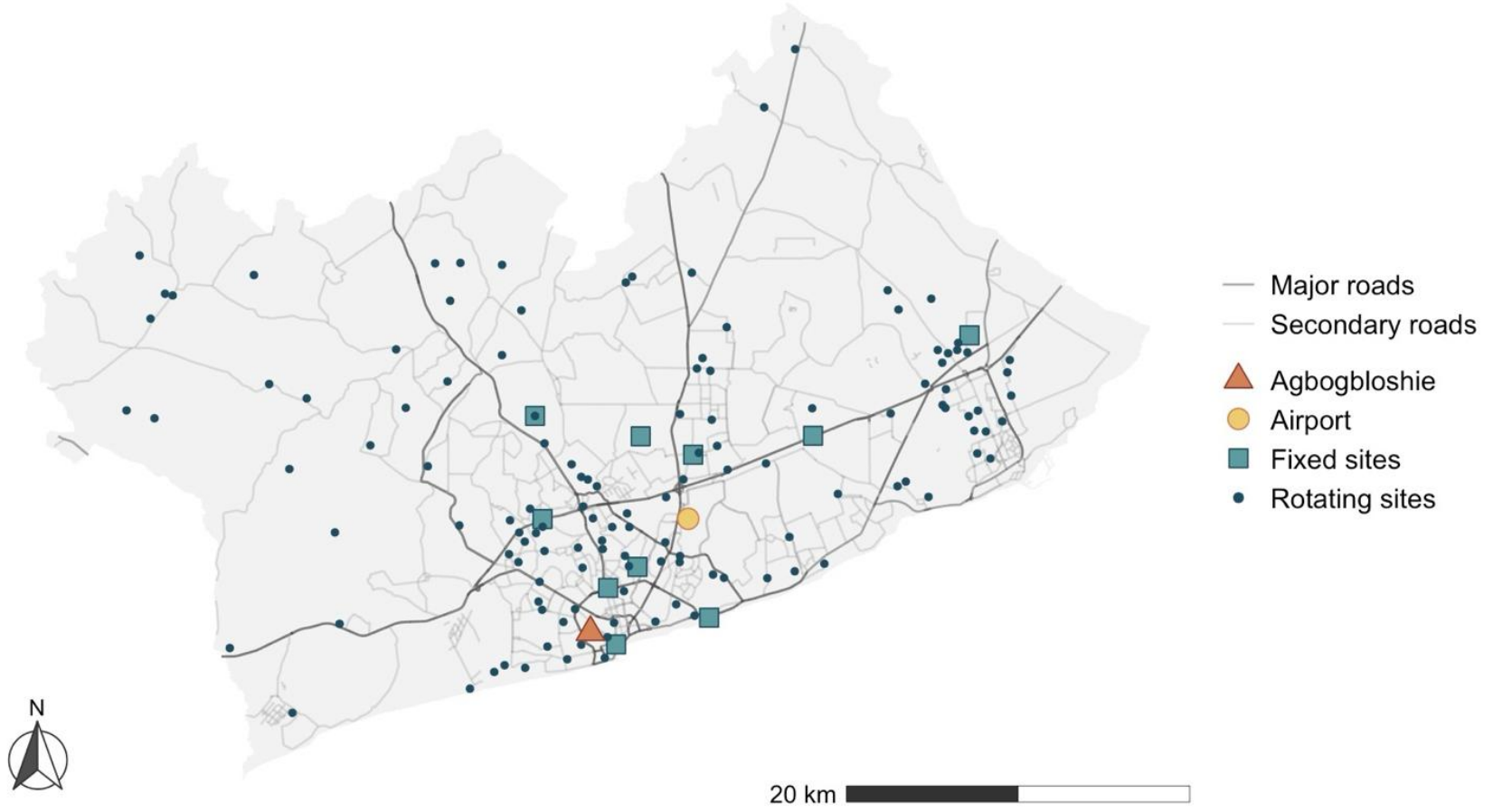
Present work – City-wide campaign 2019-2024

- Integrated (filter-based) $PM_{2.5}$ measurement

- 146 sites
  - 10 “fixed” sites (sampled continuously for ~5 years
  - 136 ‘rotating sites (sampled 7 days) only in April 2019 – June 2020



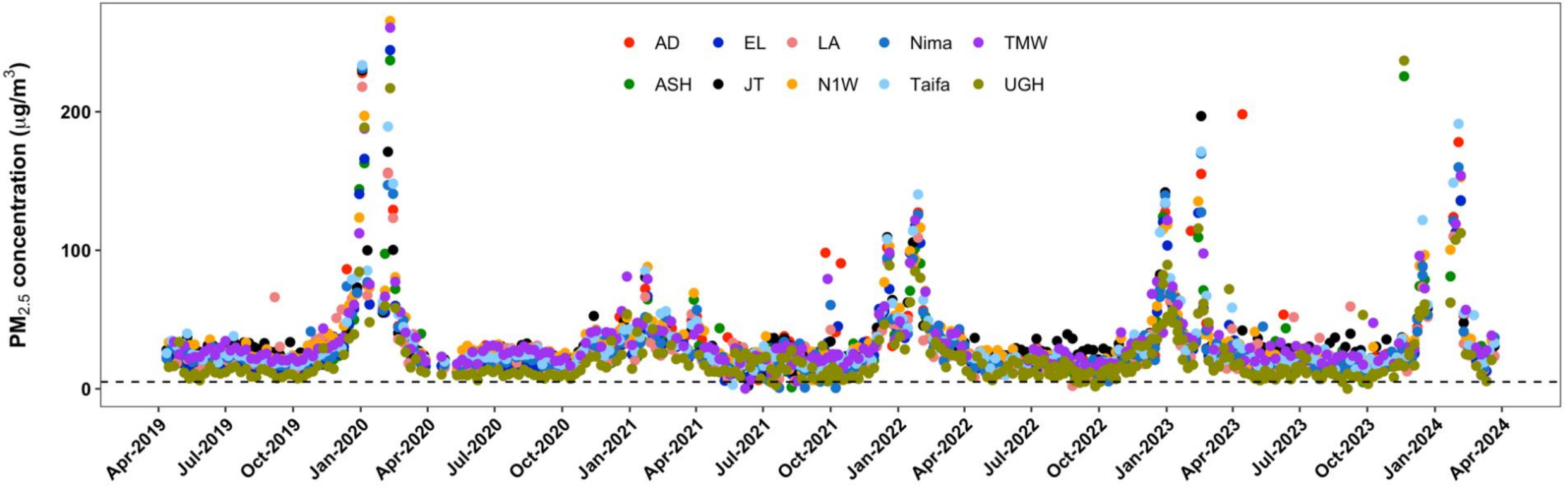
$PM_{2.5}$ concentrations collected on filters



Map of the GAMA depicting year-long (fixed) and week-long (rotating) monitoring locations

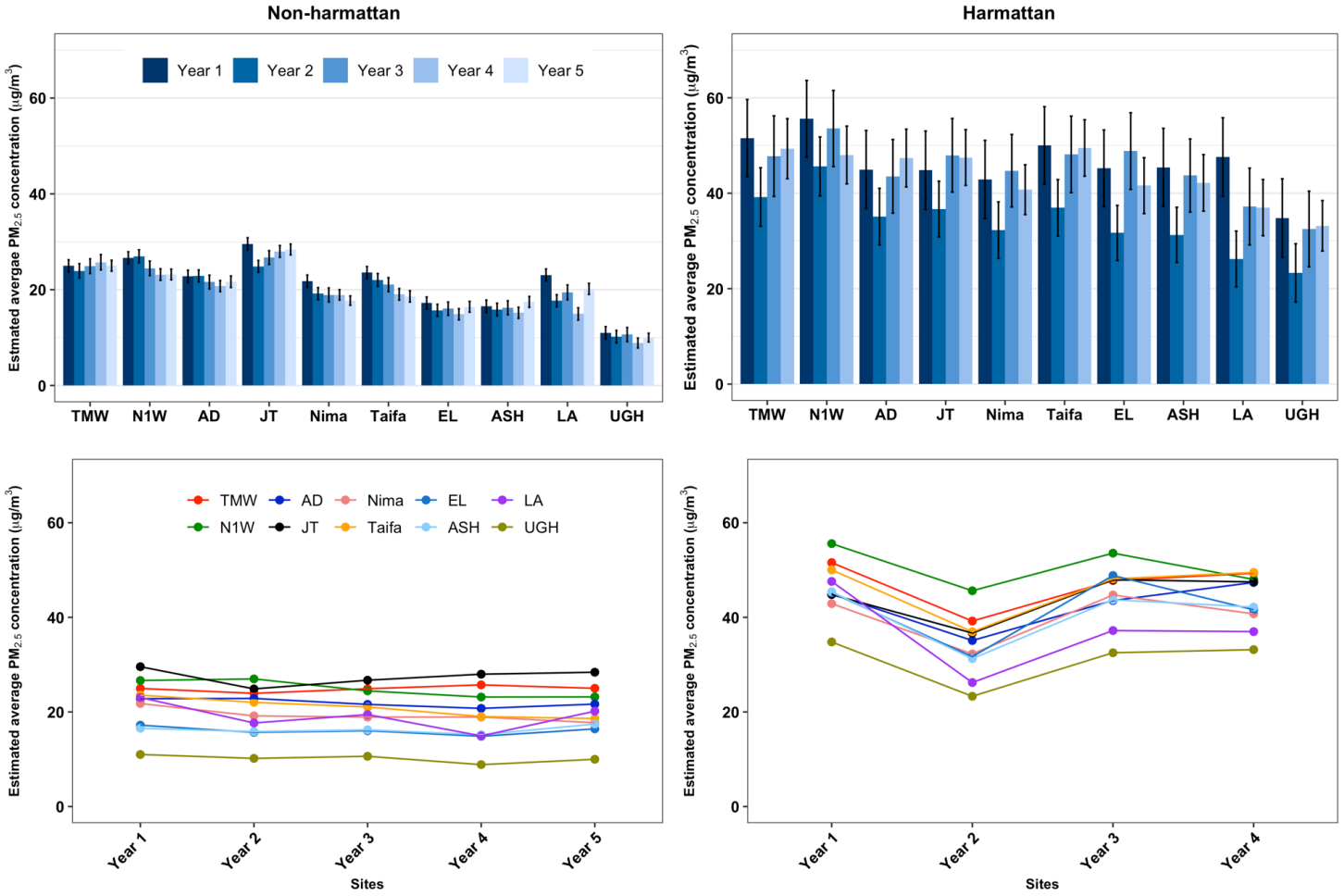
Clark et al 2020

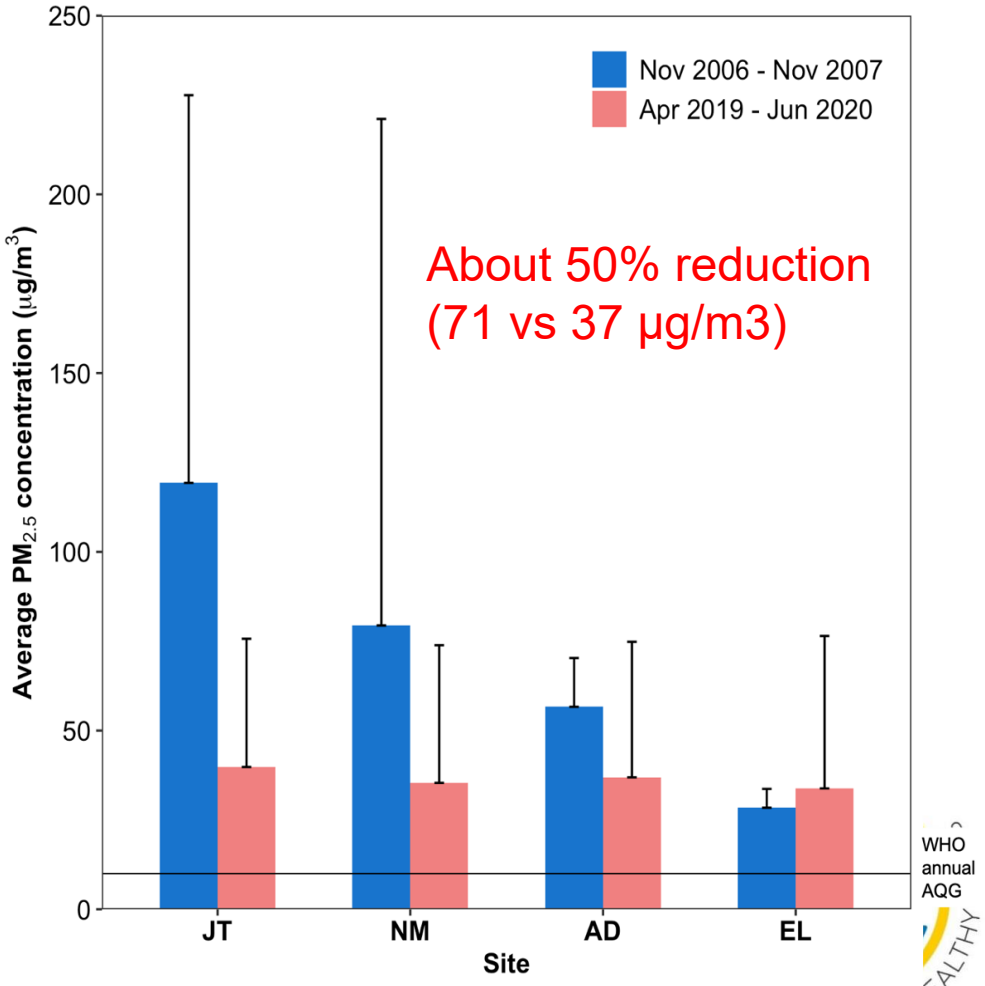
Is ambient fine particle pollution plateauing in cities in SSA?



PATHWAYS TO EQUITABLE HEALTHY CITIES

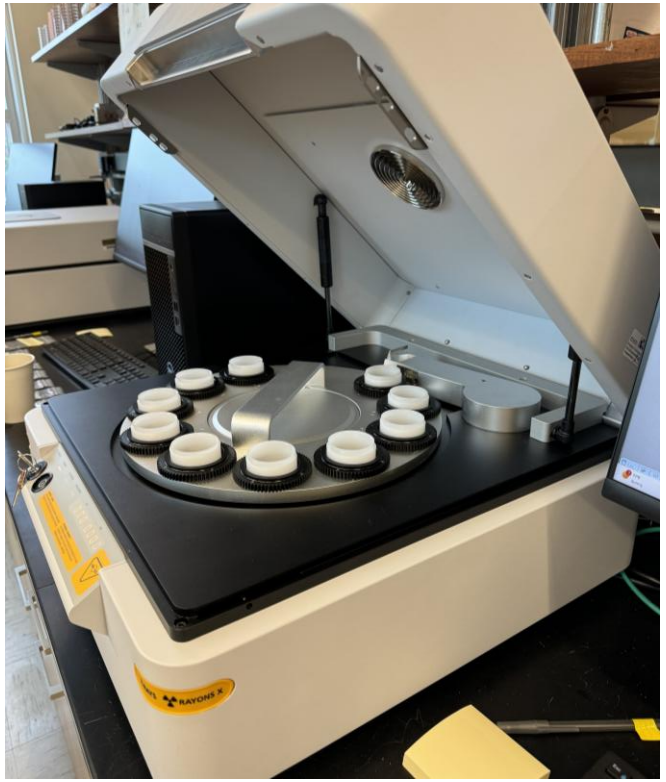
Is ambient fine particle pollution plateauing in cities in SSA?





Are the dominant air pollution sources in SSA cites shifting in the changing urban environment?

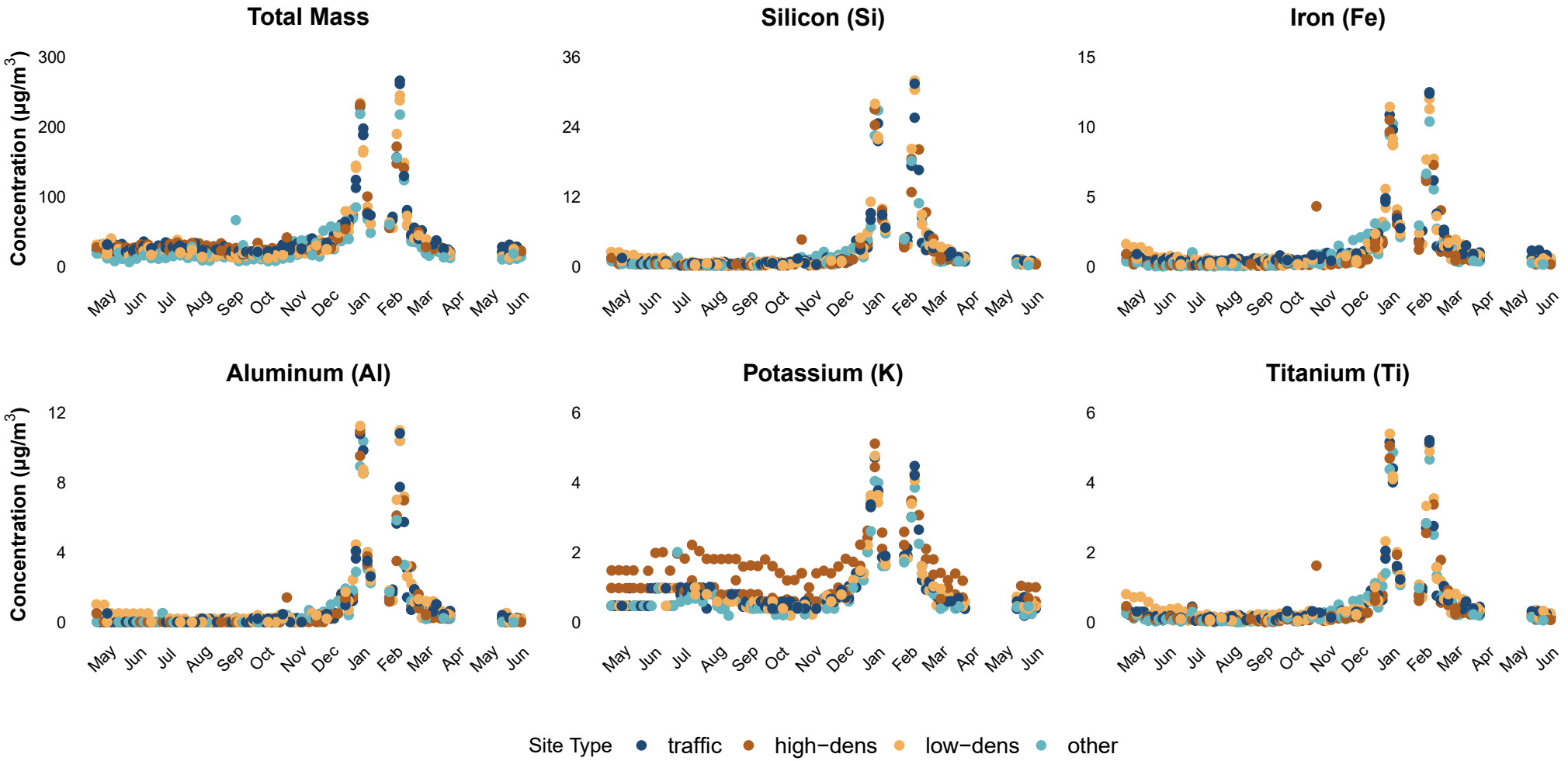
Elements contributing the largest proportion of total $PM_{2.5}$ mass



- Elemental concentrations of 603 filters quantified
- Epsilon 4 ED-XRF instrument
- 45 elements were analyzed

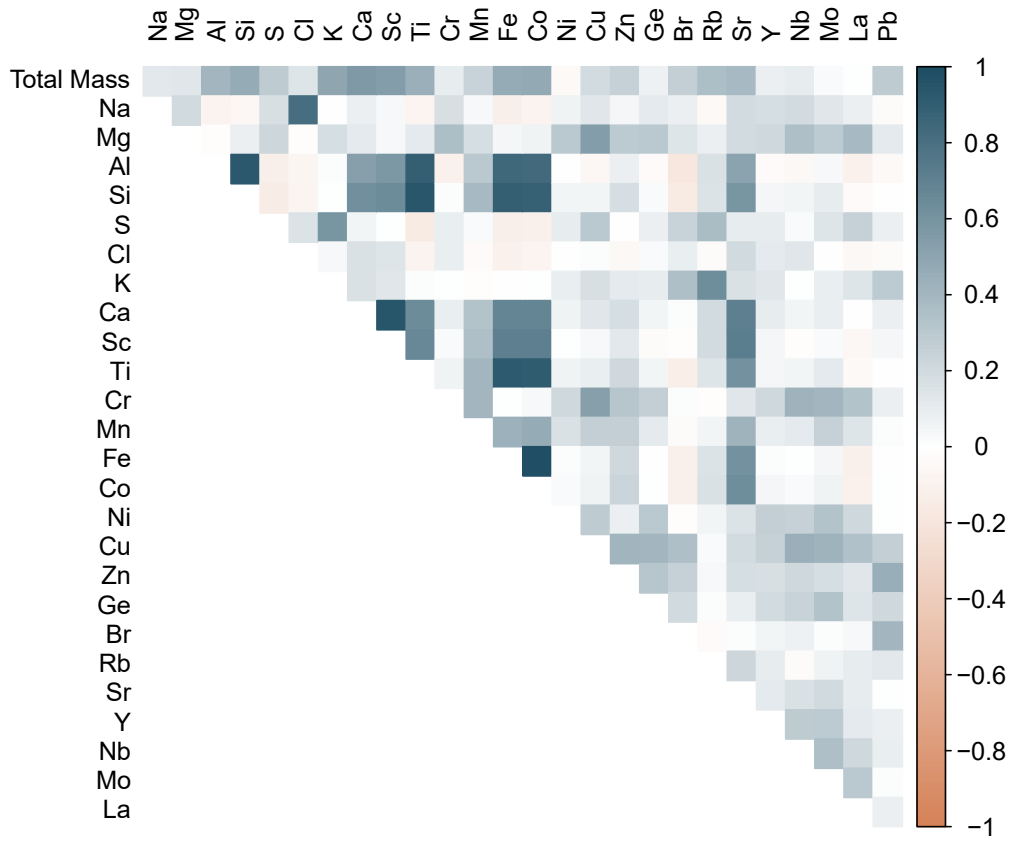
Element	Commercial (n = 18)	Traffic (n = 103)	High-density (n = 92)	Low-density (n = 135)	Ocean (n = 35)	Peri urban Background (n = 48)
Mass[a]	21 ± 4	25 ± 5	24 ± 7	19 ± 6	21 ± 9	13 ± 15
Al	137 ± 164 (0.66%)[b]	143 ± 233 (0.56%)	108 ± 218 (0.45%)	**172 ± 263 (0.92%)**	73 ± 134 (0.32%)	**163 ± 243 (0.95%)**
Si	542 ± 348 (2.6%)	**759 ± 505 (3.0%)**	588 ± 597 (2.4%)	**712 ± 621 (3.8%)**	524 ± 408 (2.5%)	**707 ± 644 (4.9%)**
S	1168 ± 420 (5.6%)	1425 ± 586 (5.6%)	1421 ± 631 (5.9%)	1333 ± 514 (7.1%)	1559 ± 821 (7.7%)	1160 ± 460 (9.4%)
Na	204 ± 294 (1.0%)	227 ± 142 (0.89%)	219 ± 122 (0.91%)	205 ± 102 (1.1%)	**1004 ± 728 (4.8%)**	186 ± 92 (1.6%)
Cl	**669 ± 754 (3.2%)**	325 ± 669 (1.3%)	492 ± 505 (2.0%)	274 ± 441 (1.5%)	**2755 ± 1621 (13.2%)**	170 ± 236 (1.5%)
Mg	563 ± 647 (2.7%)	1114 ± 1657 (4.4%)	1117± 1669 (4.7%)	**1105 ± 1490 (5.4%)**	1133 ± 1848 (5.7%)	**867 ± 1393 (7.4%)**
K	522 ± 204 (2.5%)	620 ± 247 (2.4%)	**1090 ± 450 (4.5%)**	594 ± 209 (3.2%)	576 ± 319 (2.9%)	497 ± 182 (3.9%)
Fe	401 ± 281 (1.9%)	**535 ± 264 (2.1%)**	347 ± 518 (1.4%)	**411 ± 355 (2.2%)**	214 ± 242 (1.02%)	301 ± 292 (2.09%)
Ca	358 ± 224 (1.7%)	427 ± 179 (1.7%)	420 ± 528 (1.7%)	343 ± 246 (1.8%)	503± 534 (2.2%)	214 ± 171 (1.6%)
Ti	134 ± 84 (0.65%)	**184 ± 122 (0.72%)**	154 ± 192 (0.64%)	**182 ± 166 (0.97%)**	105 ± 94 (0.52%)	**154 ± 140 (1.06%)**
Zn	**61 ± 69 (0.29%)**	**33 ± 22 (0.13%)**	**33 ± 22 (0.14%)**	27 ± 31 (0.15%)	24 ± 26 (0.12%)	15 ± 12 (0.12%)
Br	**20 ± 26 (0.10%)**	20 ± 17 (0.08%)	**26 ± 16 (0.11%)**	11 ± 5 (0.06%)	19 ± 9 (0.10%)	7 ± 5 (0.05%)
Sc	18 ± 15 (0.09%)	21 ± 11 (0.08%)	22 ± 40 (0.09%)	17 ± 17 (0.09%)	28 ± 38 (0.12%)	9 ± 9 (0.06%)
Cu	11 ± 6 (0.05%)	**28 ± 26 (0.11%)**	20 ± 20 (0.08%)	16 ± 17 (0.09%)	20 ± 22 (0.10%)	13 ± 11 (0.12%)
Pb	**14 ± 16 (0.07%)**	9 ± 7 (0.03%)	12 ± 6 (0.05%)	16 ± 15 (0.04%)	6± 4 (0.03%)	4 ± 2 (0.03%)
Cr	11 ± 6 (0.05%)	17 ± 21 (0.07%)	14 ± 10 (0.06%)	4 ± 15 (0.08%)	16 ± 13 (0.10%)	11 ± 10 (0.08%)
Co	10 ± 7 (0.05%)	**13 ± 7 (0.05%)**	9 ± 13 (0.04%)	10 ± 9 (0.05%)	6 ± 6 (0.03%)	8 ± 7 (0.05%)

Seasonal variation in total $PM_{2.5}$ mass and selected elements

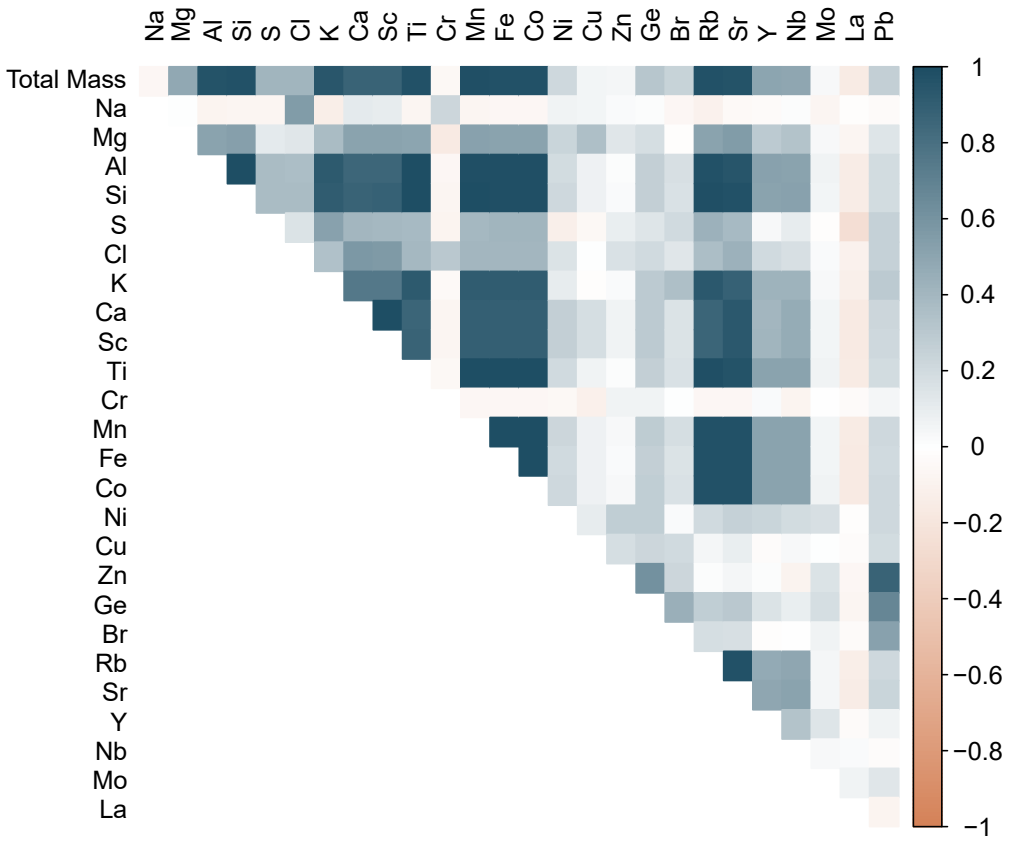


Relationship between total $PM_{2.5}$ mass and its elements

Non-Harmattan



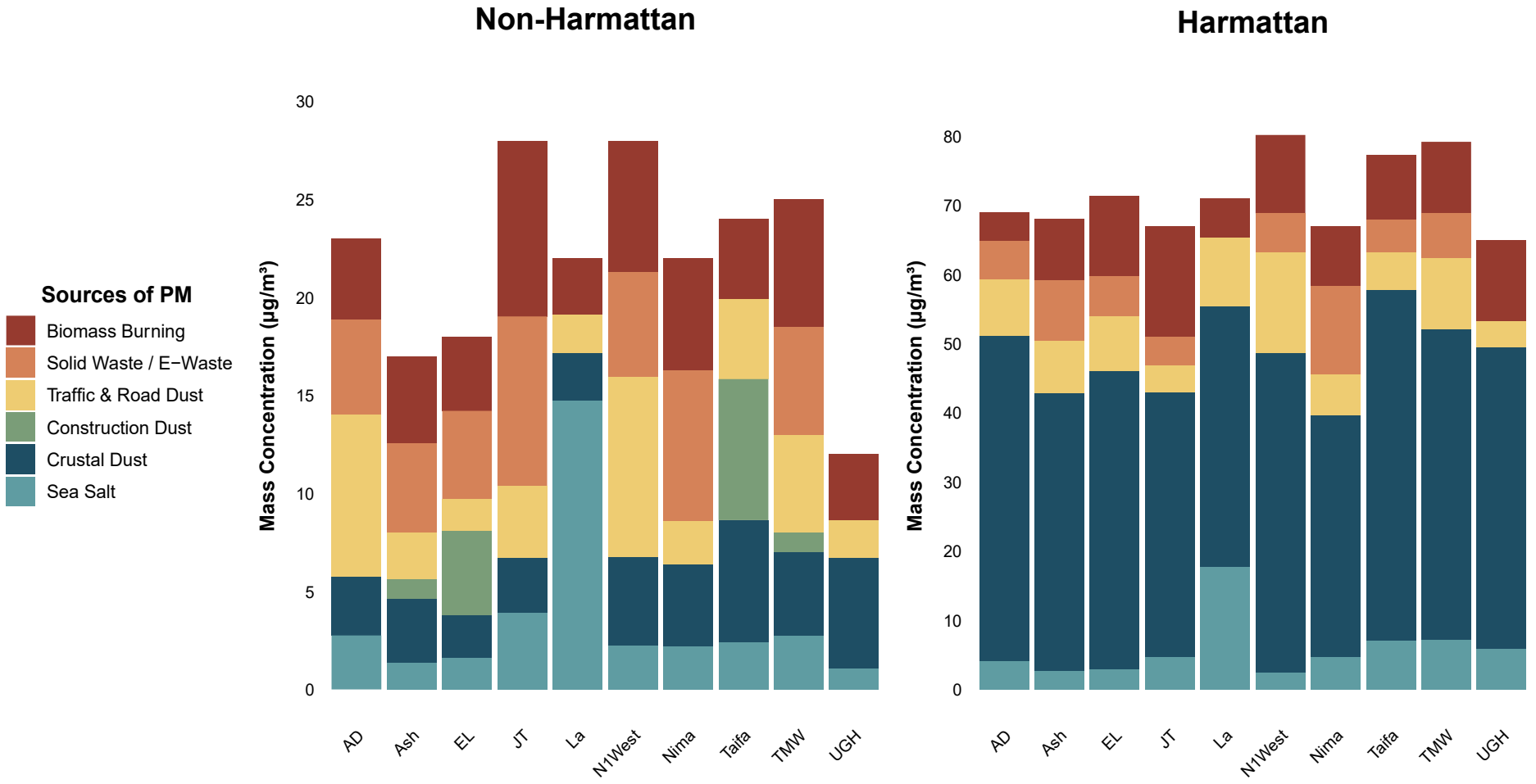
Harmattan



TO EQUITABLE HEALTHY CITIES

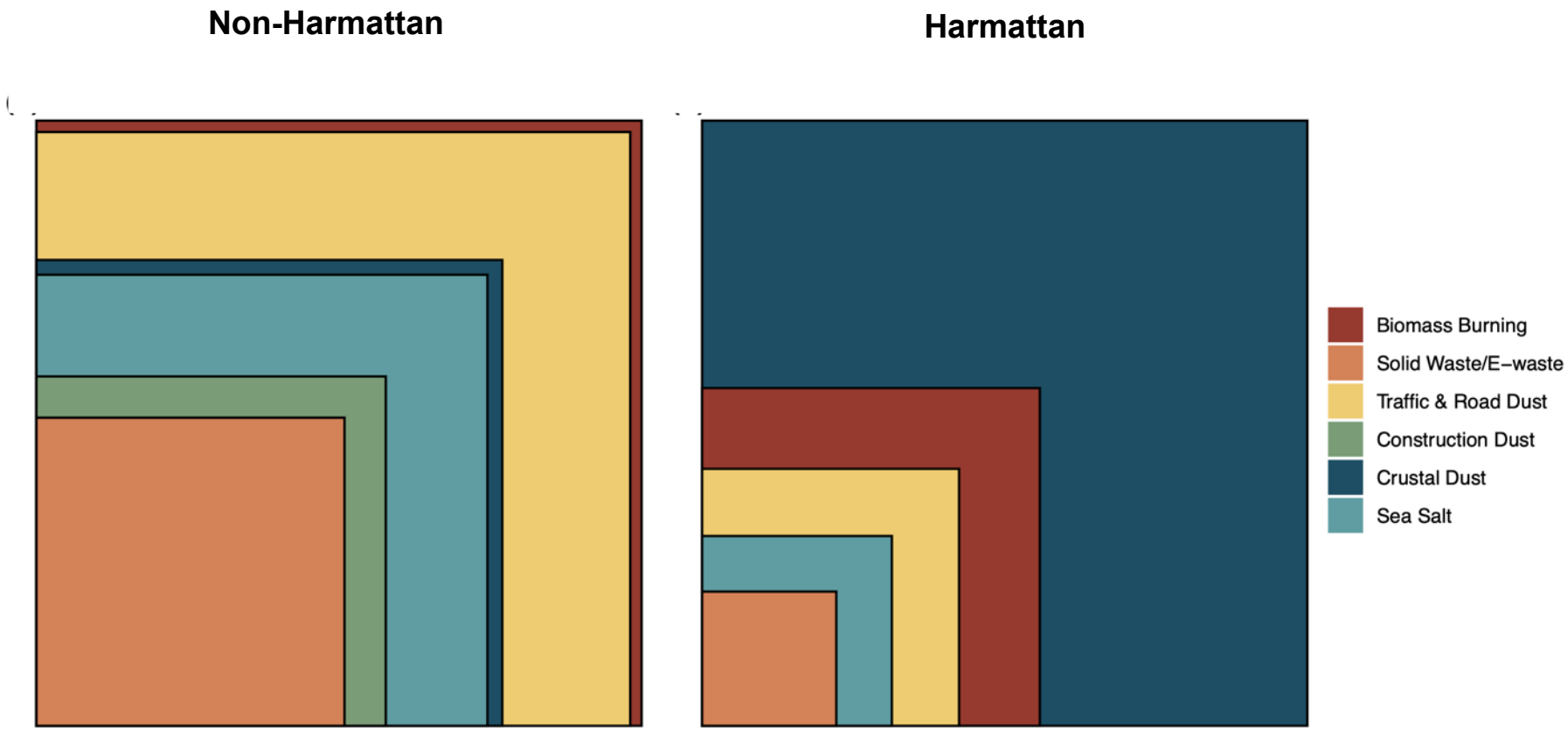
Source contributions to $PM_{2.5}$ pollution – fixed sites

- US EPA Positive Matrix Factorization (PMF)
- 4-6 potential sources in non-Harmattan
  - Biomass burning: 11-32%
  - Traffic emissions and road dust (9-36%)
  - Solid and electronic waste burning: 0-35%
  - Construction dust (0-30%)
  - Crustal dust (11-47%)
  - Sea salt (8-67%)
- Across rotating, metal processing at CBI areas contributing 9.7%
- In Harmattan, crustal dust dominated all sites, contributing 52–68%



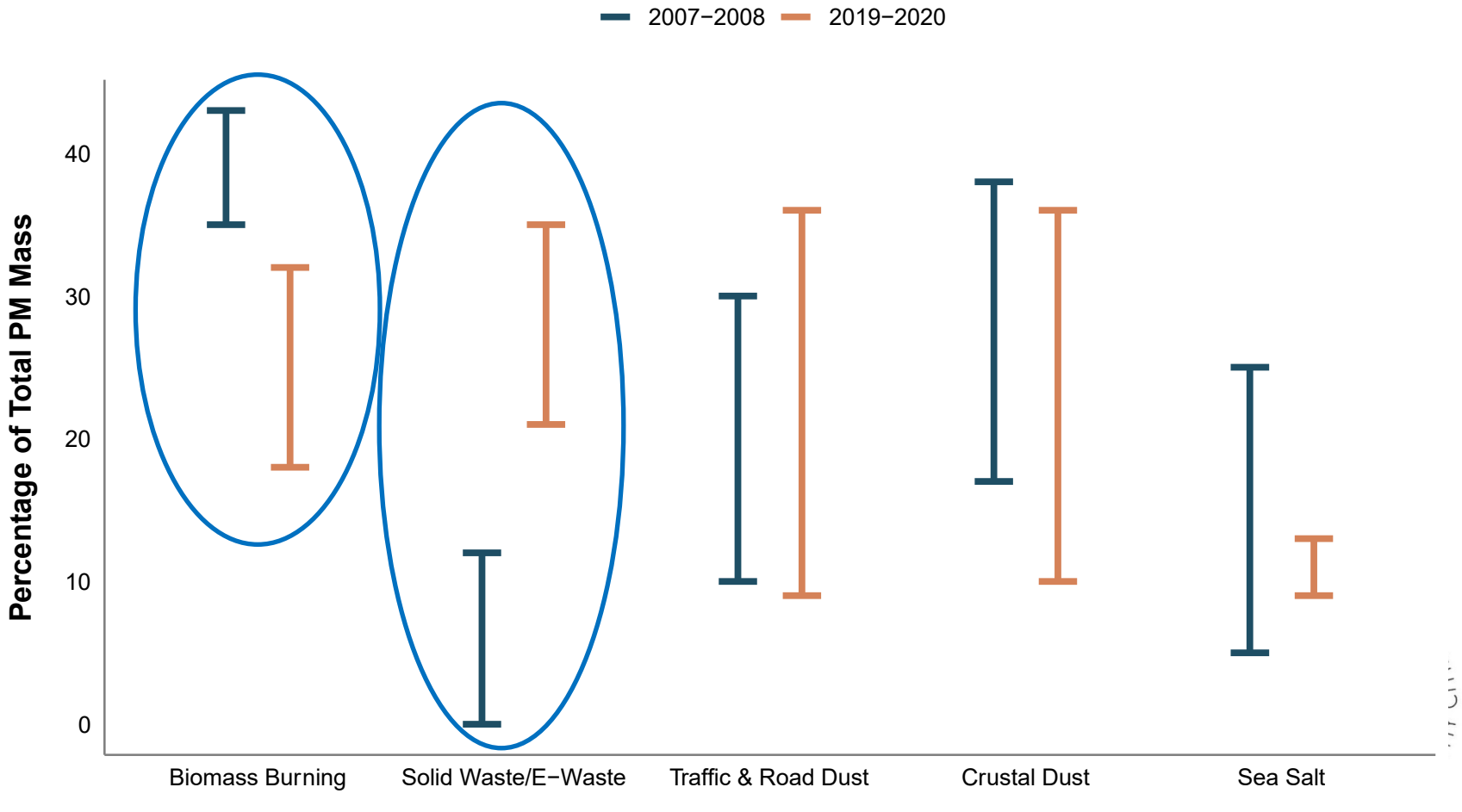
Source contributions to $PM_{2.5}$ pollution – Combined data

- Non-Harmattan
  - Biomass burning: 27%
  - Traffic emissions and road dust: 26%
  - Crustal dust: 16%
  - Sea salt: 15%
  - Construction dust: 9%
  - Solid and electronic waste burning: 7%
- In Harmattan, crustal dust dominated: 61%

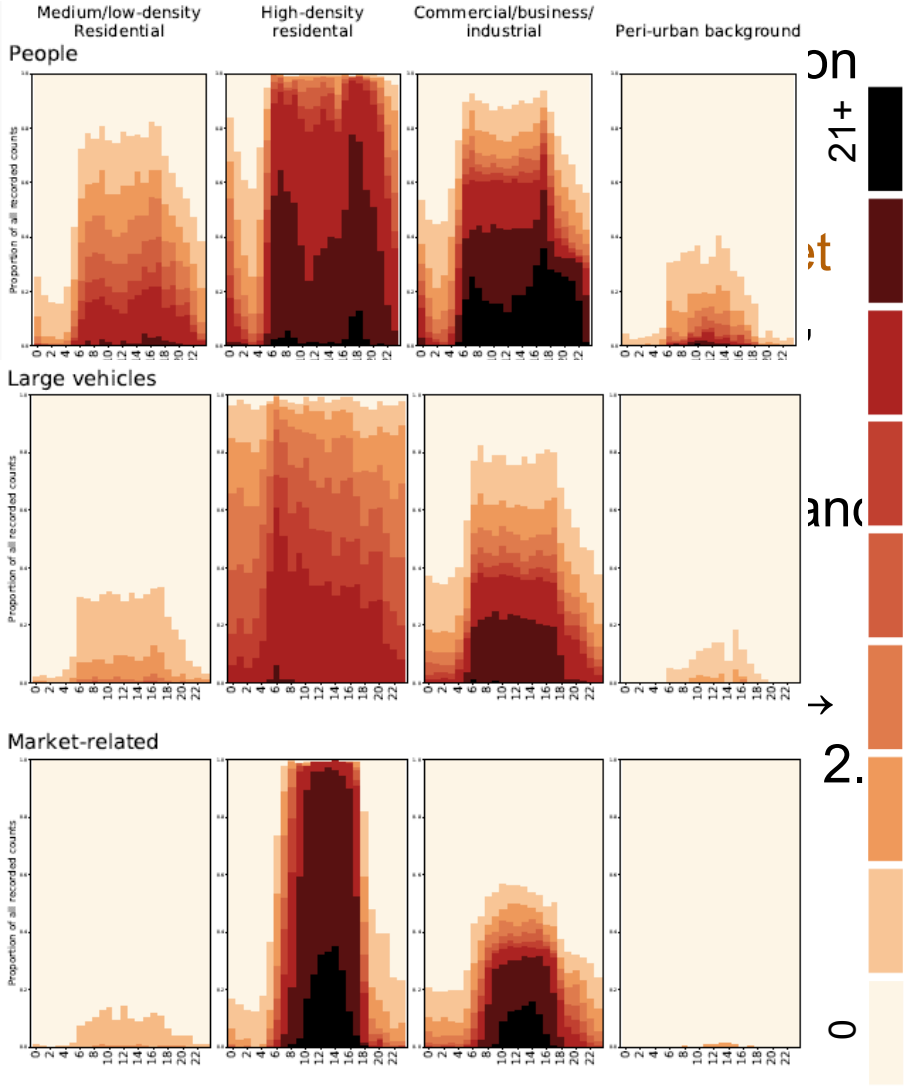


Comparison of source contributions between 2007-2008 and current 2019-2020

- Four sites: AD, EL, JT and Nima
- A general decreased in $PM_{2.5}$ mass concentrations by 35-60%
- Proportion attributed to traffic and road dust and crustal dust remained unchanged
- Biomass burning remains a significant source, but its contribution has decreased to 18-32%
- Electronic waste burning increased significantly, now contributing 21-35%



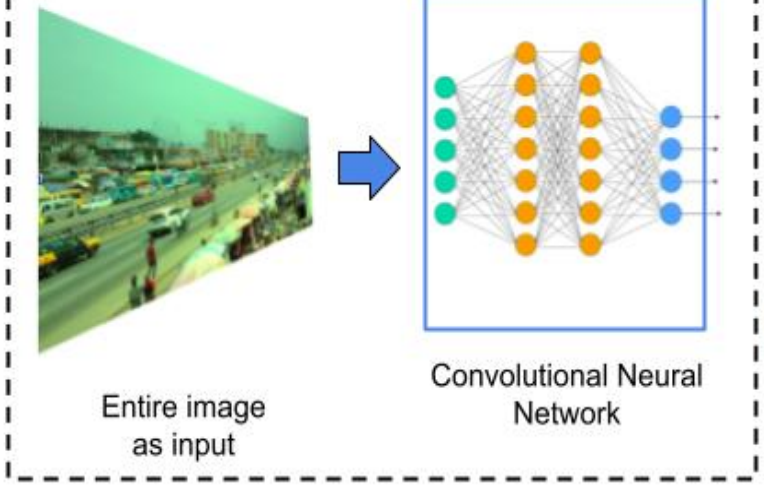
Characterizing the dynamics of urban environment and activities in Accra



Nathvani et al 2022

Predict air and noise pollution from images

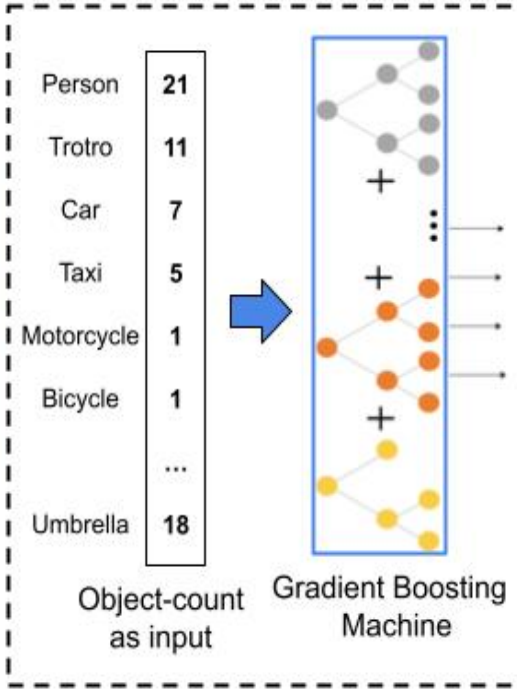
Approach 1: Outcome driven



Pollution classes

Sound ranges (dBA)	PM2.5 ranges ($\mu g/m^3$)
<=39	0-5
40-44	6-10
45-49	11-15
50-54	16-20
55-59	21-25
60-64	26-30
65-69	31-40
70-74	41-50
75-79	51-100
80=<	101-150
	150+

Approach 2: Feature driven



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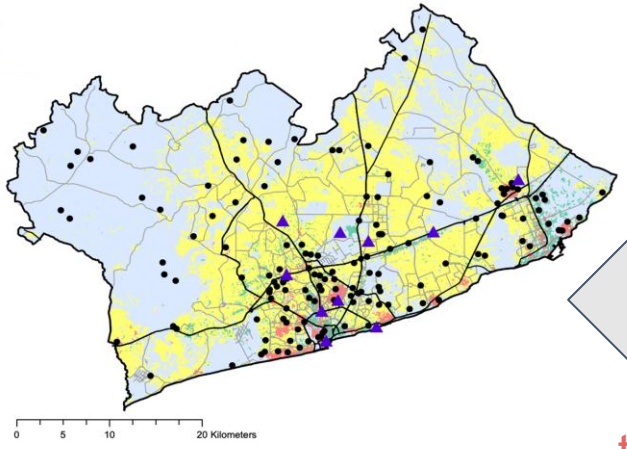
	150+

PATHWAYS TO EQUITABLE HEALTHY CITIES

Nathvani et al 2023

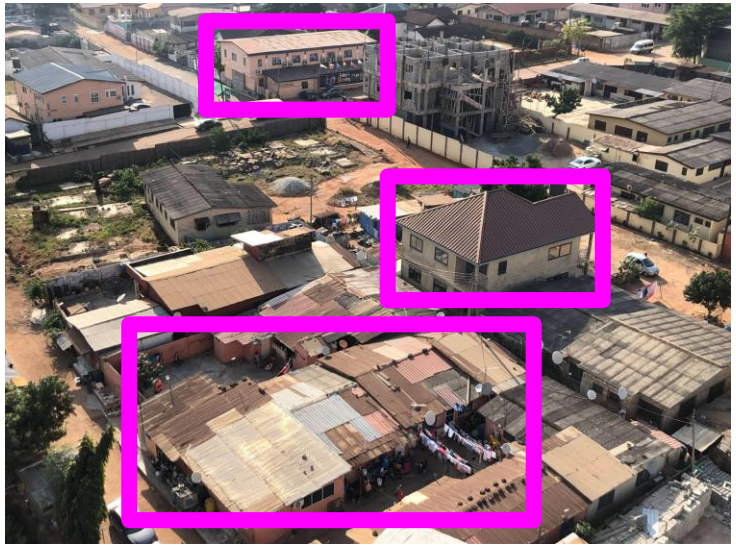
Outdoor and indoor heat exposures

~120 homes and neigh



Imp
tempe

Effects of housing design on indoor temperature



In case of a reply, the number and the date of this letter should be quoted.

My Ref. No. GHS/DGS/

Your Ref. No

Ghana Health Servic
Private Mail Ba
Ministries Post Office
Accra. Ghan

GPS ADDRESS: GA-143-460
TEL.: +233 302 662 01
FAX: +233 302 666 80

25TH February, 2024

For Immediate Release

TO ALL MEDIA HOUSES

PRESS RELEASE

RE: HEALTH IMPLICATIONS FOR CURRENT WEATHER CONDITIONS

February has been characterized by very harsh weather conditions of dryness and dust with a high Air Quality Index as reported by the Environmental Protection Agency. The Ghana Meteorological Agency is also reporting of very hot conditions for the coming months of March and April. These adverse weather conditions predispose individuals to several ill health conditions including respiratory illness and meningitis.

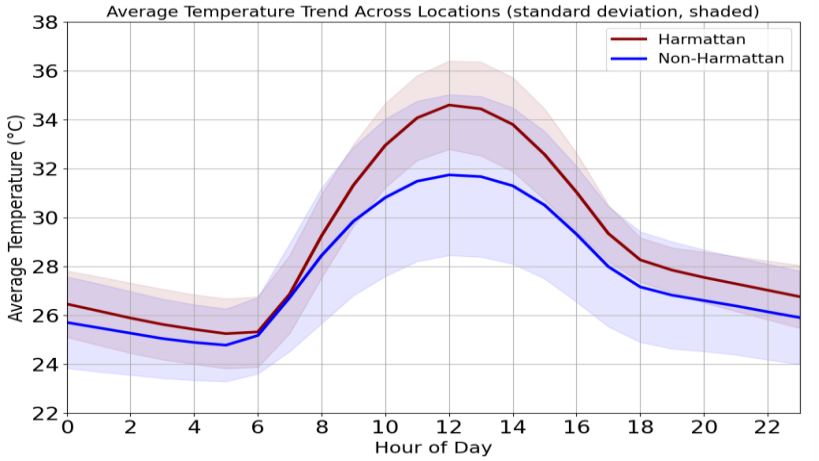
The Ghana Health Service (GHS) appreciates that, persons with Asthma and other chronic respiratory conditions may suffer acute attack or may experience worsening of their conditions. The increased dryness of the air may predispose persons and individuals to dehydration, especially among children and the elderly. In the northern part of the country in particular, the dry and hot weather conditions can lead to increased risk of meningitis as evident with the reported cases of meningitis though there are no outbreaks in the country.

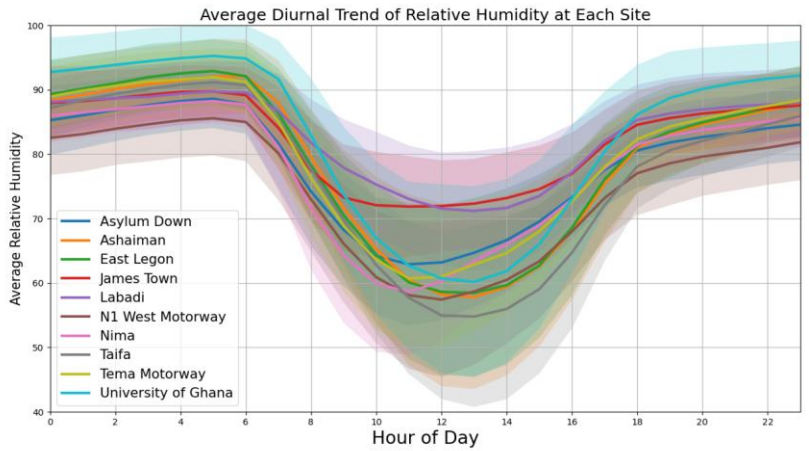
The GHS is therefore recommending the following to minimize the effect of the harsh weather conditions:

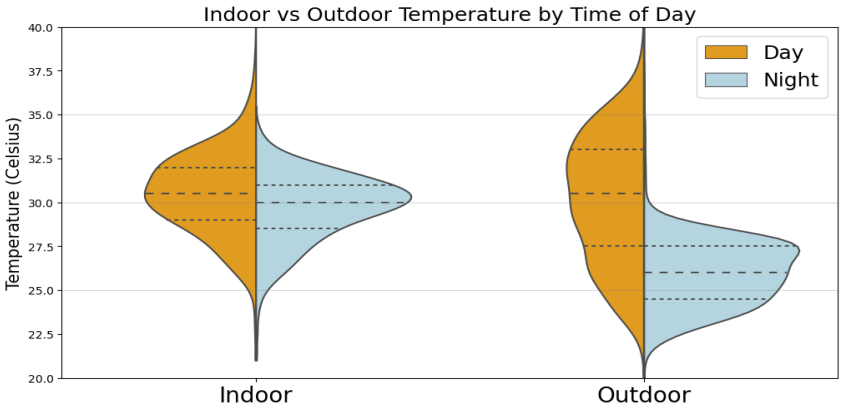
- **Limit outdoor activities especially for children and the elderly.**
- **Wear face-masks to reduce exposure to the dust.**
- **Stay hydrated by drinking a lot of water throughout the day.**
- **People living with chronic respiratory conditions like asthma should continue to take their prescribed medications.**

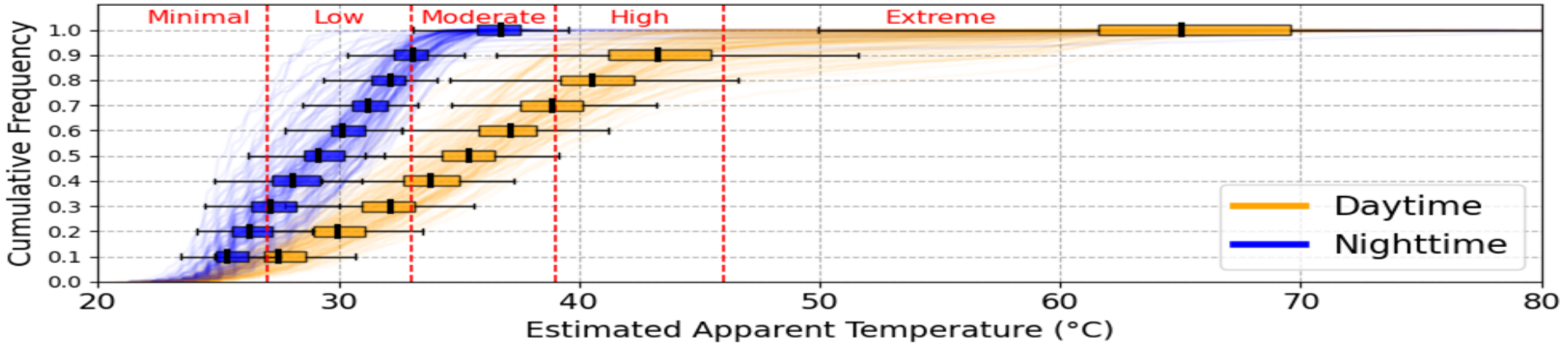
We urge the public to observe these recommendations during this period of harsh weather conditions and report to the nearest health facility when they have difficulty in breathing. It must be noted that, treatment is available for all these conditions including Meningitis and therefore persons with fever and neck stiffness should report immediately to the nearest health facility.

Outdoor/indoor temperature and humidity





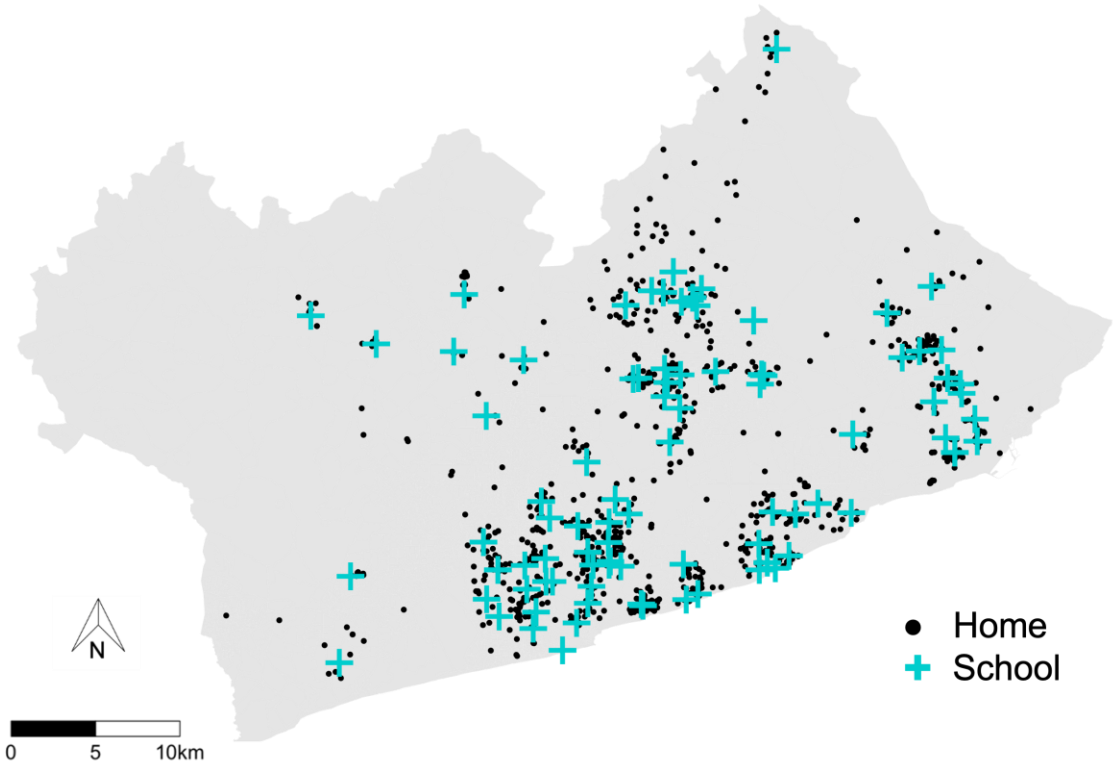




What about health?

- Child health and development in complex urban environments
  - Accra birth cohort (ABC)
  - Schools

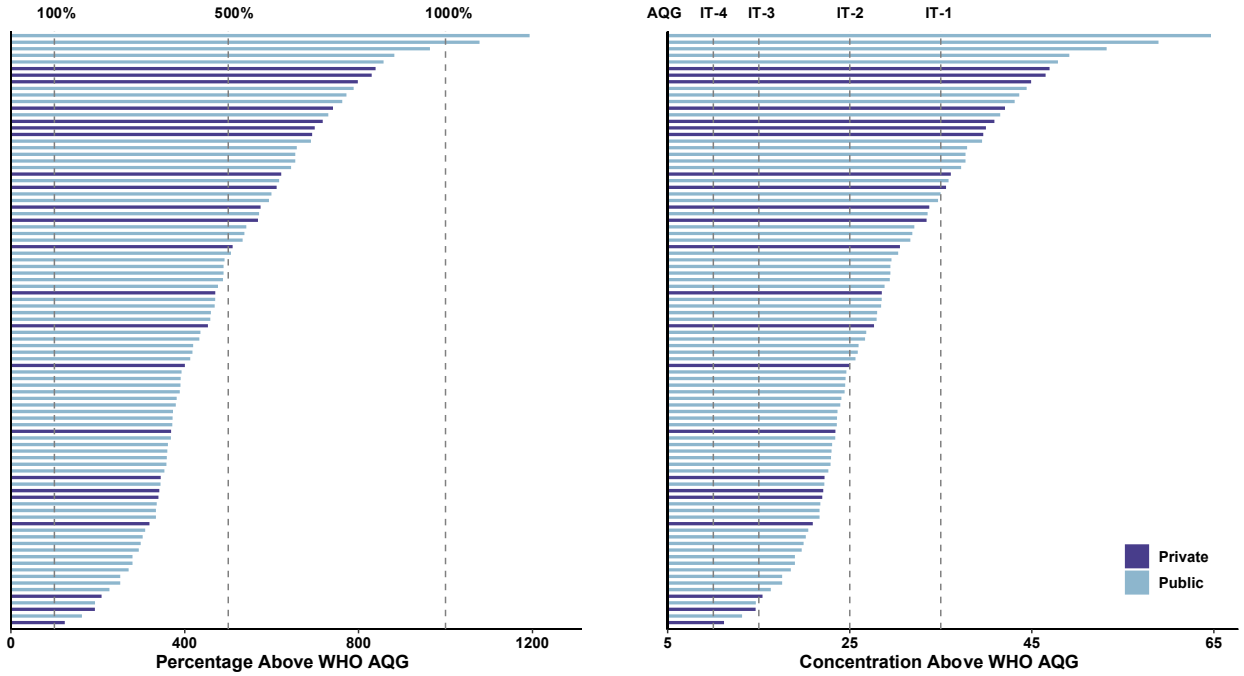
Child health and development in complex urban environments - schools

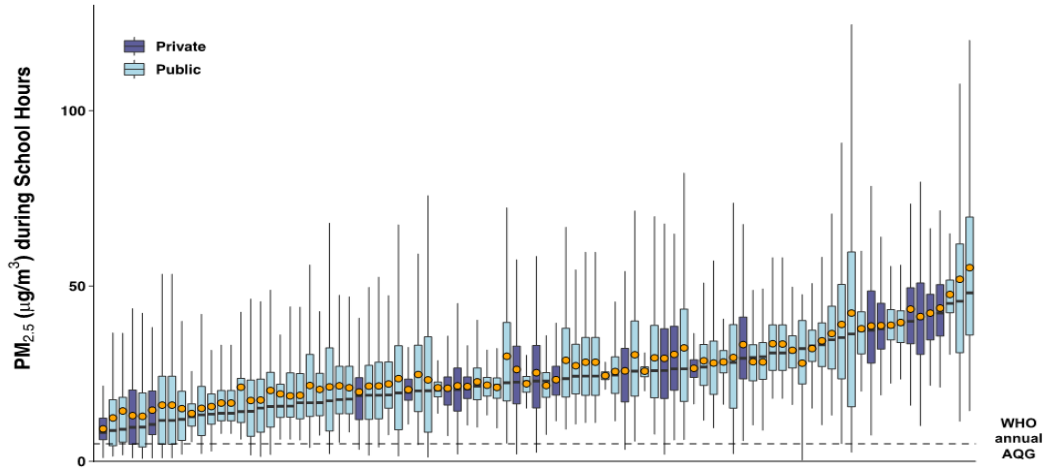


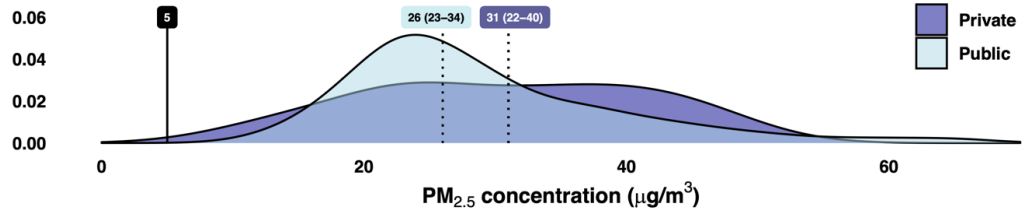
Environmental noise

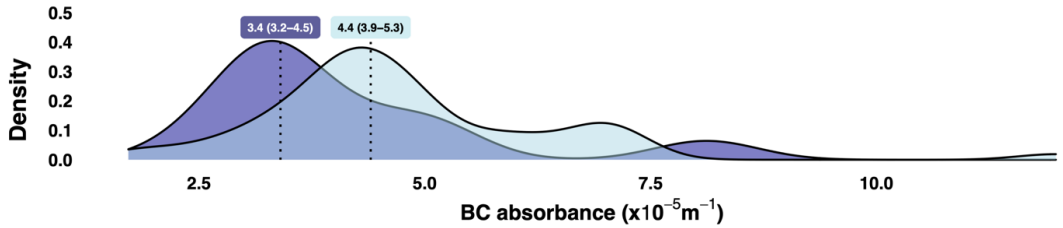
- We conducted weeklong measurements of ambient $PM_{2.5}$, measured both gravimetrically and continuously), and black carbon (BC, measured gravimetrically in the yards of 90 public (74%) and private (26%) schools.

Schoolchildren learning in dirty air and noisy environments









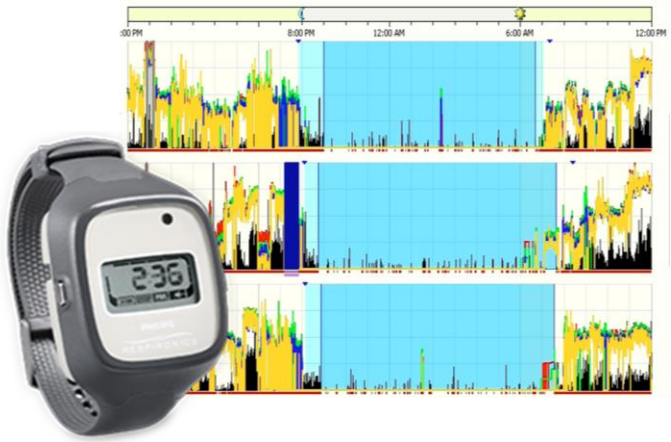
- $PM_{2.5}$ concentrations were 2-13 times higher than the WHO guideline, ranging from 11 µg/m^3 at a private school to 65 µg/m^3 at a public school
- BC and noise levels were higher in public schools, and in schools located in the most urbanized AMA and TMA when compared to other districts in the GAMA
- Within the AMA, all three pollutants were inversely associated with SES of the school neighborhood

Child health and development in complex urban environments - schools

Cognitive and behavioral assessment

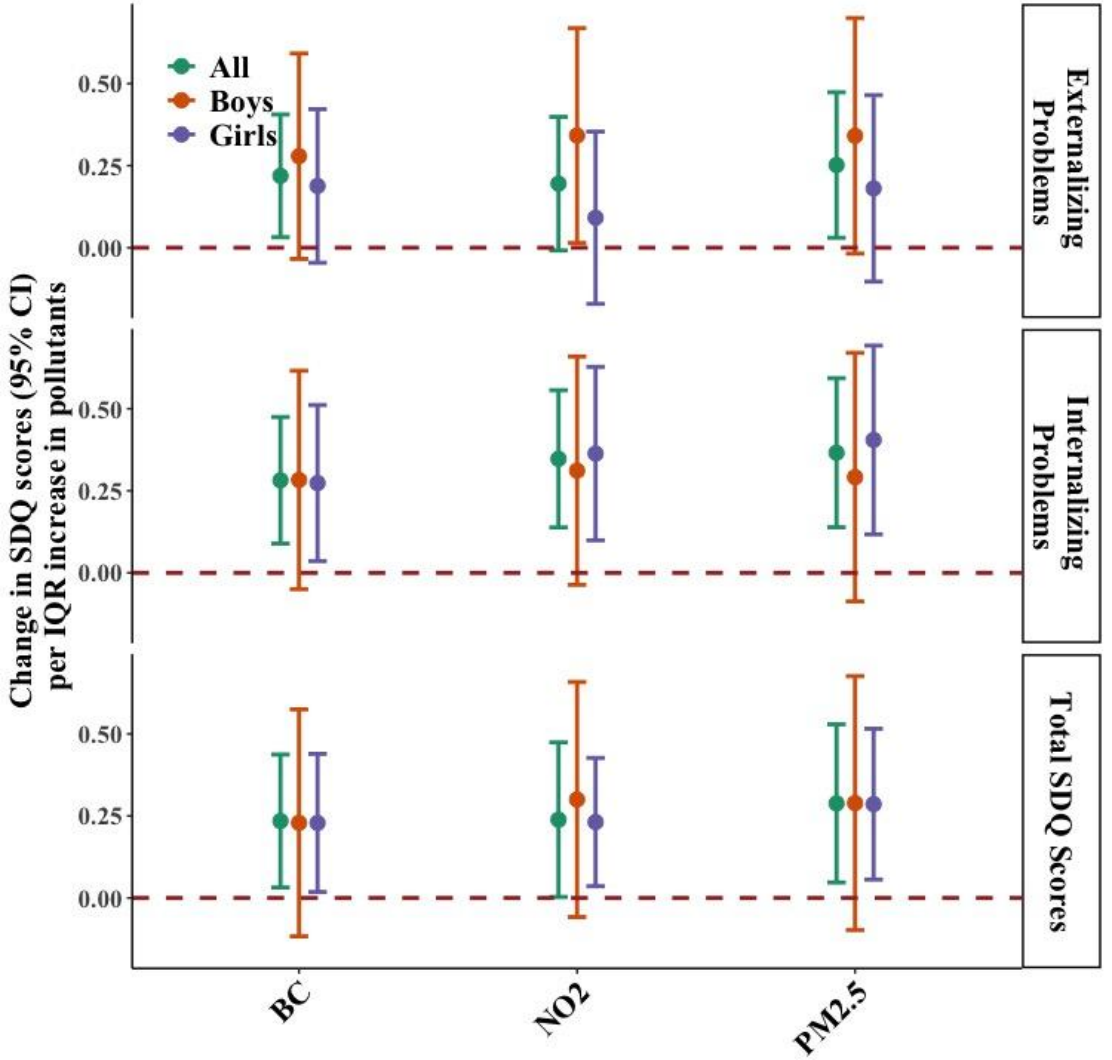
Spirometry

Sleep



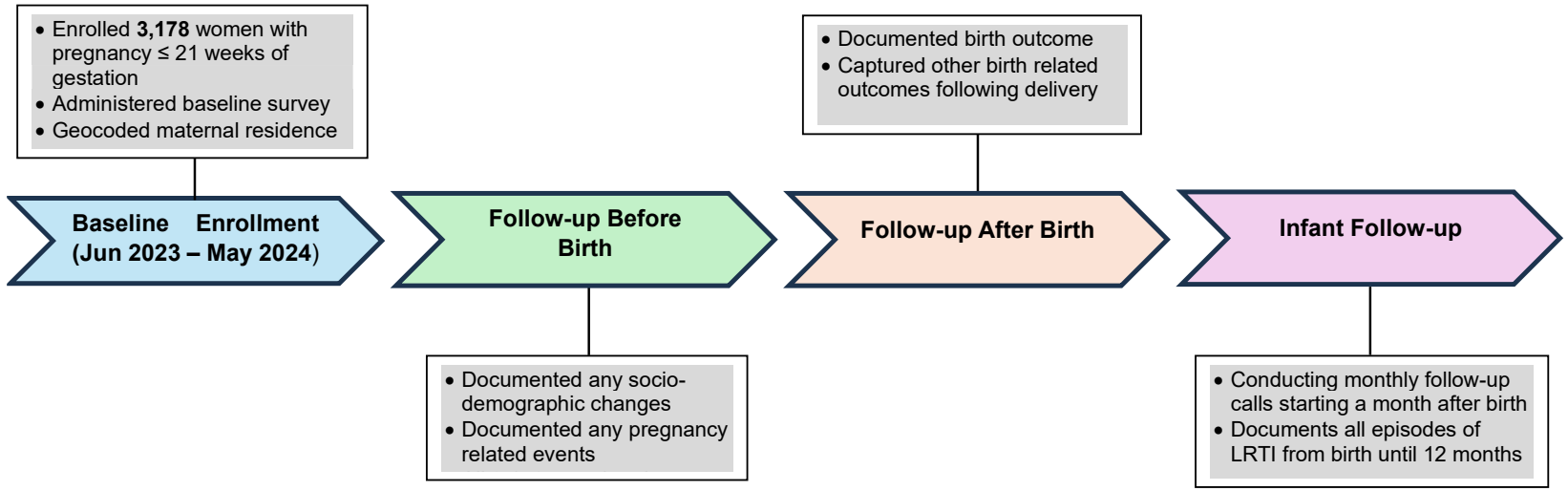
Blood pressure

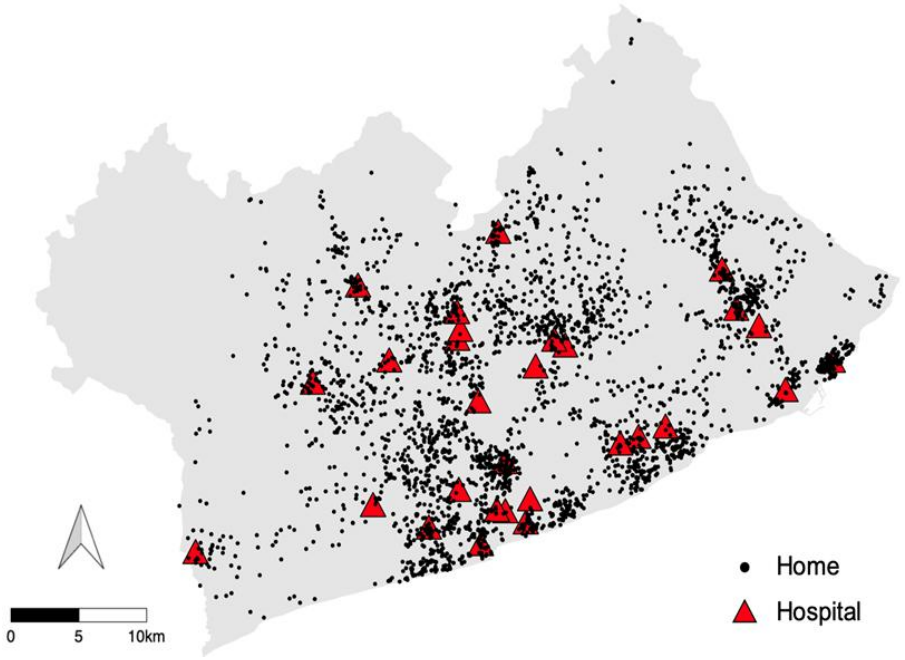
Child health and development in complex urban environments - schools



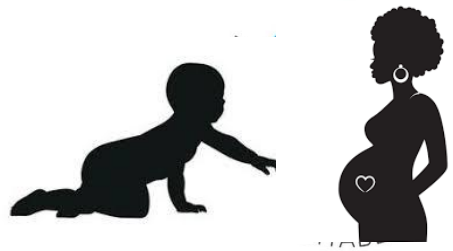
Study design and recruitment

- Initiated in 2022; recruited **3,178** pregnant women from 30 health facilities





Map of GAMA, health facilities (red), and homes of enrolled participants



Accra Birth Cohort (ABC) study

- Immediate goals
  - Characterize gestational and early life exposures to
    - Multiple ambient air pollutants
    - Chemical constituents
    - Noise
    - Heat
  - Evaluate their individual and cumulative impacts o
    - Adverse birth outcomes
    - Respiratory infections in infancy
    - Sleep health
    - Adverse childhood neurodevelopment

$PM_{2.5}$ and NO_2 exposure and preterm birth