Jonathan Gingrich- jon.gingric@utexas.edu

Investigations of Spatial and Temporal Variations of $PM_{2.5}$ in an Urban city using a Network of Low-cost Sensors

Jonathan D. Gingrich[1], Mark J. Campmier[1], Advaitha Byereddy[1], Shayan Charolia[1], Heather Howton[1], Brian Mai[1], Meenakshi Kushwaha[2], Elbin Savio[2], Adithi Updaya[2], Pratyush Agrawal[2], Sreekanth Vakacherla[3], Julian D. Marshall[4], Joshua S. Apte[1]

(1) The University of Texas at Austin, Austin TX, USA (2) ILK Consultancy Ltd., Bangalore, India (3) Centre for Science, Technology, and Policy, Bangalore, India (4) University of Washington, Seattle WA, USA

Introduction and Methods

In many locations around the world, the spatial density of monitoring networks is low, especially in many developing world cities. Lower-cost (<$500) air quality monitors could increase this spatial density and contributing to a better understanding of spatial and temporal variation of ambient particulate matter.

We set up a network of low-cost sensors throughout Bangalore, India. 60 PurpleAir II (PA) sensors were collocated with a Beta Attenuation Monitor (BAM 1022, MetOne Inc.) for a period of 440 hours. Hourly averaged PA-PA comparisons resulted in an average R^2 of 0.99 and a normalized root mean squared error (NRMSE) of 5.1%. PA-BAM comparisons resulted in an average R^2 of 0.65 with an NRMSE of 3.4%.

After collocation, 40 of the best performing sensors were placed in the field and categorized into six broad categories (Figure 1). Sensors collected over 7500 hours of two minute data from August 2019 to June 2020. Each PA sensor has two sensors within it to test for agreement. The data were cleaned by comparing the A and the B sensor resulting in the removal of 11 sensors from the dataset. The median uptime of the 31 remaining sensors was 86%. The two-minute data was averaged up to hourly data, and calibrated using a Deming regression model developed from the two long term sensors collocated with the BAM.

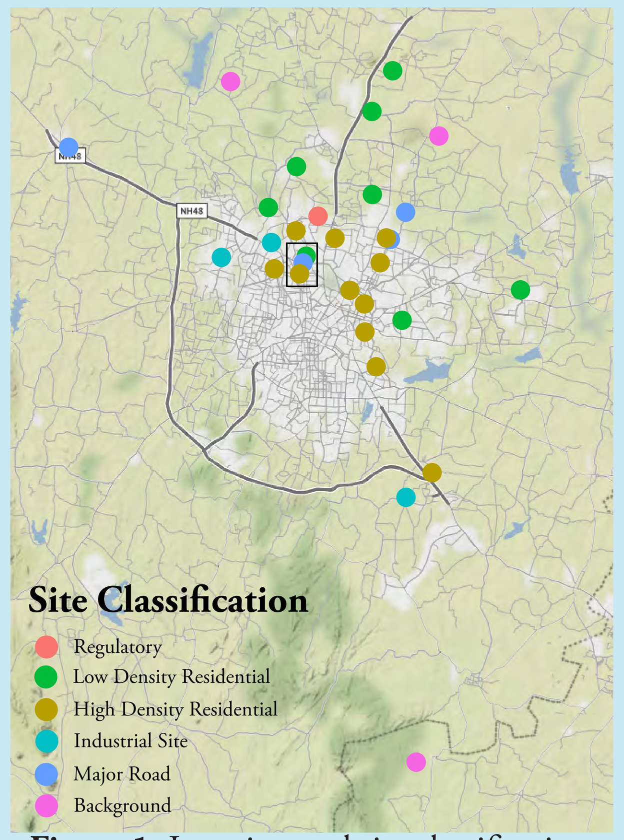

Figure 1. Location and site classification of sensors place throughout Bangalore, India and the surrounding area. A total of 31 sensors reported sufficient data for inclusion in the analysis. Each site received a basic site classification of one of six broad site classifications. The black box in the north central portion of the city highlights the Indian Institute of Science Bangalore, where Figure 3 occurs. The far south sensor is cut off in future plots for clarity.

Annually Averaged Spatial Characteristics

- Median concentrations ranged from 25 to 36 µg/m³
- Concentrations in the urban core generally ranged from 27-33 µg/m³ and decreased moving outwards to the rural areas
- Far west sensor is directly off of a main highway (~20 m), which contributes to the high median concentration
- Along NH-48 transect (Figure 2a), concentrations change substantially
- Sensors closest to the city center have larger peaks than sensors on the outskirts of the city
- The ratio between the 95th percentile and the median ranges from 1.6 to 2.2, showing limited peak concentrations
- Most ratios between 95th percentile and the median center around 1.9, indicating little influence of large peaks on sensors
- The ratio between the interquartile range and the median is very similar to the 95th percentile:median ratio, relative to the other sensors. This indicates that most sensors showed the same pattern during the year of collection

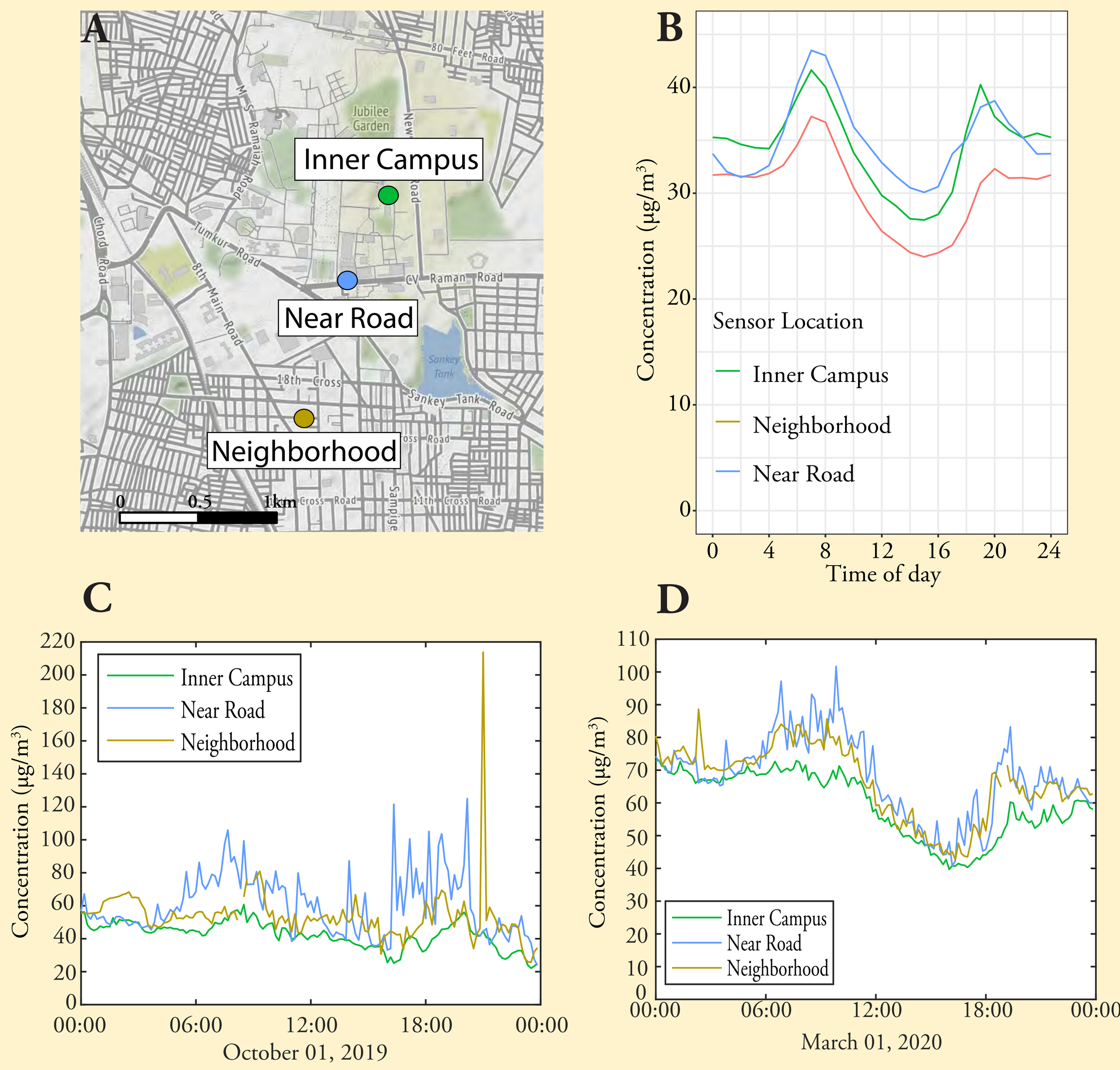

Figure 3. Case study of sensors on and near IISc campus. (A) Three sensors were placed on campus in three different site classifications (B) Annual diurnal averages of the three sensors (C) 10 minute average $PM_{2.5}$ concentrations for October 1, 2019 (D) 10 minute average $PM_{2.5}$ concentrations for March 1, 2020

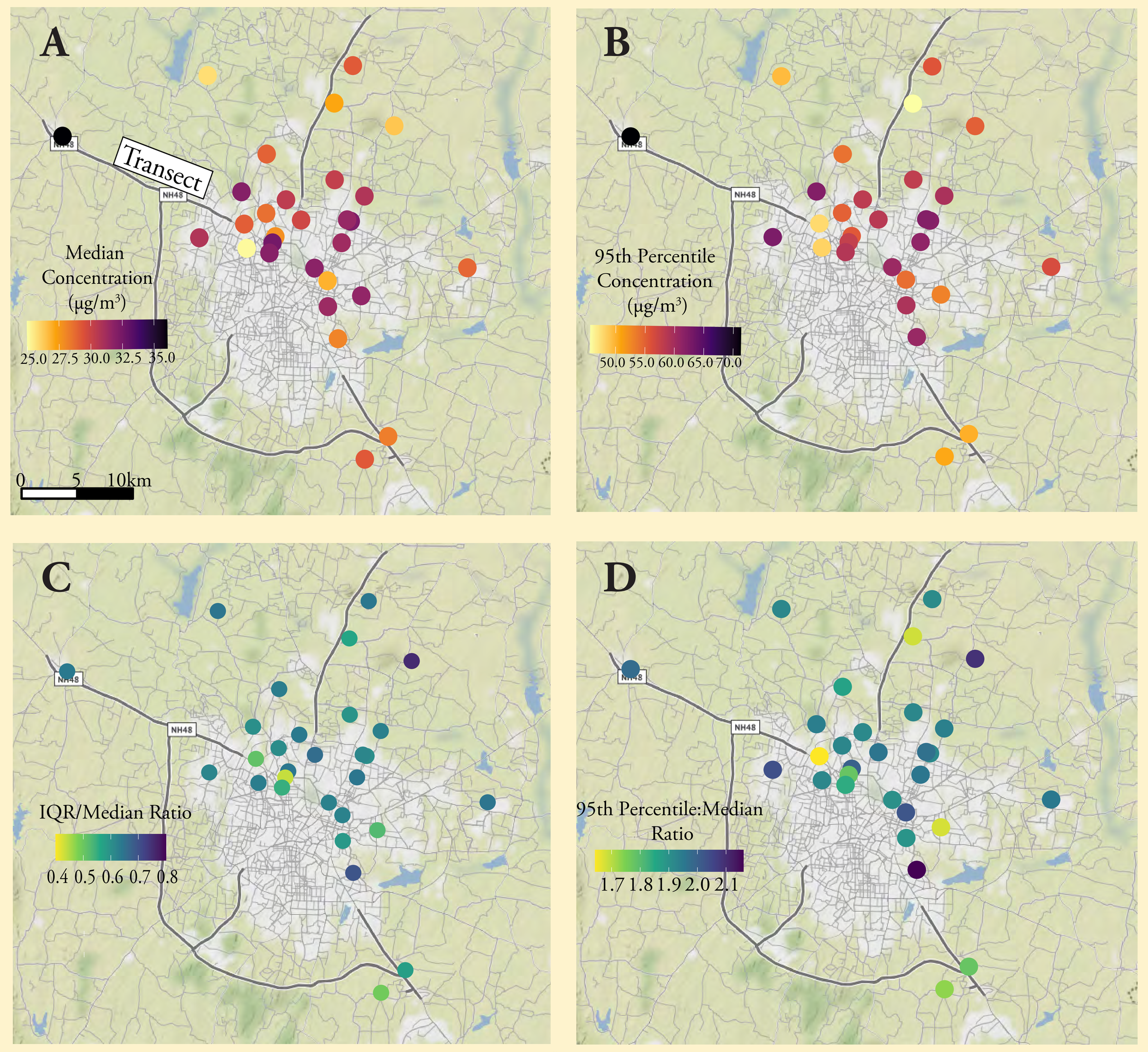

Figure 2. Maps of spatial distribution of sensors. (A) Hourly median concentration of each sensor from August 18, 2019 to June 30, 2020 (B) Hourly 95th percentile of each sensor during the collection time period (C) Ratio between the interquartile range and the median (D) Ratio between the 95th percentile and median concentrations of each sensor

- Three sensors were investigated in depth (Figure 3). These three sensors were located on or near the campus of the Indian Institute of Science (IISc Bangalore) located in the north central part of Bangalore (Figure 1 and 3a). One sensor was within the campus, one near the main road entering the campus, and one was located in the neighborhood in the south
- Median annual concentrations ranged between 27 and 30 µg/m³
- While annual concentrations were fairly similar, there were differences in diurnal trends (Figure 3b). A morning peak was seen by all three sensors, though it was most pronounced in the near road sensor. An evening peak was seen in both the neighborhood and the high traffic site. The Inner Campus sensor followed similar peaks but at reduced concentrations, demonstrating some green space shielding effects
- 10 minute averaged timeseries in the autumn and spring seasons (3c and 3d) show peaks changing rapidly in mornings and evenings for the near road and neighborhood monitors, similar peaks are not as pronounced in the inner campus sensor

Site Class Comparison

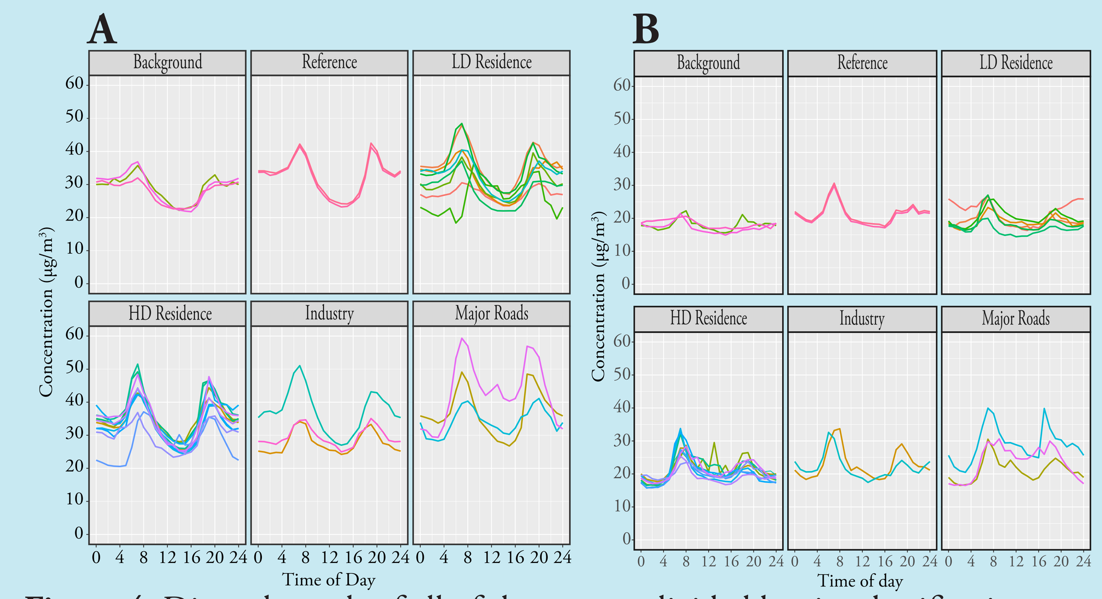

Figure 4. Diurnal trends of all of the sensors divided by site classifications (A) Autumn diurnal trends (B) Monsoon diurnal trends

- Autumn and winter seasons record higher concentrations while summer and monsoon seasons recorded the lowest concentrations
- Autumn trends show far more variability, both within site class, and between different site classes, than monsoon trends
- Near road sensors have the largest concentrations and range in concentrations; Industry, LD and HD residences all show similar results to one another
- $PM_{2.5}$ concentrations vary by 10-25 µg/m³ in autumn and 5-20 µg/m³ in monsoon over the period of a day

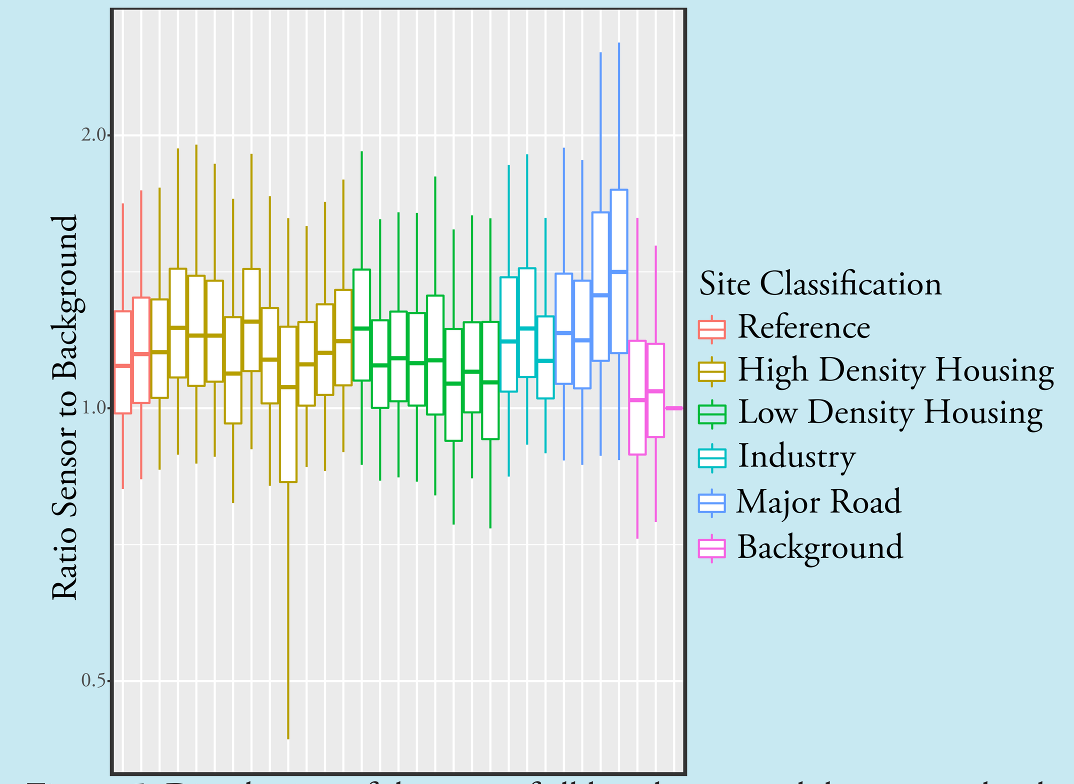

Figure 5. Distribution of the ratio of all hourly averaged data, normalized to a background sensor and grouped by site classification

- Range of difference between the median of the background and other sites is 5-50% — greater than the NRMSE — showing that low cost sensors can determine differences between background sites and other locations. In addition, local influences still increase $PM_{2.5}$ above the background concentration
- Sensors placed near major roads consistently had the highest median relative concentrations
- Both high and low density sites saw similar median concentrations, indicating that rough estimates of housing density do not lead to substatial differences in $PM_{2.5}$ concentration

Acknowledgements

The authors would like to thank CSTEP for hosting the sensors at the collocation site in Bangalore, to Jai Asundi CSTEP and David Eaton (University of Texas at Austin) for their assistance.
Thank you to the Presidents Award for Global Learning for the funding for this project.

Conclusions

- Low-Cost Sensors can be used in a network to determine that urban areas have an epidemiologically signficant variance of $PM_{2.5}$ concentration
- Overall, most variance is $PM_{2.5}$ is temporal, not spatial. Most temporal variability is broadly similar among different sites, reflective of diurnal patterns in ambient air

Further Work

- Investigate the effects of meterology and it's contribution to seasonal concentration changes
- Determine contribution of local sources compared to regional sources
- Develop and test model based on site classification data

For questions, contact: jon.gingric@utexas.edu