College of Engineering
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Exploring the robustness of lower capital cost air sensors for understanding the impacts of location-specific agricultural practices on local air quality in Ghana

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Abstract

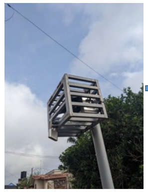
$PM_{2.5}$ is a carcinogen and a key contributor to air pollution related deaths globally. The utility of miniaturized air sensors for air quality campaign is providing useful information for estimating $PM_{2.5}$ to control air pollution in environments where this data will be more desirable. Till date, there is little to no information on the robustness of miniaturized air sensors for understanding air pollution at rural agricultural settings especially in emerging economies. This study examines the robustness of Clarity Node-S for understanding $PM_{2.5}$ pollution at two agricultural settings in rural Ghana.

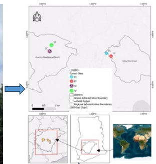
Desired Attribute	Clarity Node-S	Reason
Detect $PM_{2.5}$ during burning and other agricultural activities	?	Determine the impacts of slash and burn and other agricultural activities on $PM_{2.5}$ pollution
Detect $PM_{2.5}$ at rural settings	?	Examine the robustness of the nodes in reporting $PM_{2.5}$ data from complex and varying sources in rural settings
Detect spikes/ episodes of $PM_{2.5}$	?	Examine the robustness of the nodes in reporting $PM_{2.5}$ in natural events e.g., harmattan
Withstand harsh environmental conditions	?	Examine the performance of the nodes for long-term deployment
Suitability of GEOS-CF and MERRA-2 to estimate localized $PM_{2.5}$ pollution compared to miniaturized air sensor data	?	Whether modeled data can provide $PM_{2.5}$ estimates at a smaller scale

Research Objectives:

- Determine the robustness of miniaturized air sensors (Clarity Node-S) in reporting $PM_{2.5}$ at rural agricultural settings.
- Provide evidence of $PM_{2.5}$ estimates at rural agricultural settings using miniaturized air sensors (Clarity Node-S).

Field measurements





Co-location with Teledyne API PM Mass Monitor

Field Deployment

Rural agricultural setting

- Co-locate Clarity Node-S at a regional representative site for 4 weeks (University of Ghana, Accra).
- Used MLR to develop a transferrable calibration factor bearing in mind
  - Aerosol composition
  - Particle size
  - Particle distribution
  - Impacts of Temp and RH

Calibration results

Table 1: Multiple Linear Regression (MLR) Model and Statistical Metrics

Data type	Model	Average Time (hour)	R^2	MAE (μgm^{-3})
Clarity_raw	MLR	1	0.82	11.93
Clarity_calibrated	MLR	1	0.86	1.20

Table 2: Estimated co-efficient and corresponding error statistics

Co-efficient	Variable	Estimate	Estimate Std Error
a	Clarity_raw	0.48	0.01
b	Temperature	0.01	0.07
c	Relative Humidity	-0.09	0.02
d	Intercept	8.60	2.99

Transferrable estimated errors for calibration

Linear equation for calibration:

Eqn 1: $[Calibrated]_{PM2.5} = 0.48*[Clarity\_raw]_{PM2.5} + 0.01*Temp + (-0.09)*RH + 8.60$

Upshots

Comparing the raw $PM_{2.5}$ to the reference grade data from T640, we observed the nodes over-estimated $PM_{2.5}$ concentrations (Figure 1). By applying the calibration factor using the linear model, we observed an improvement in the raw data (for the raw data, $R^2 = 0.82$ and MAE = 11.93 μgm^{-3}, and for the calibrated data, $R^2 = 0.86$ and MAE = 1.20 μgm^{-3}).

Observed $PM_{2.5}$ daily variation compared to GEOS-CF and MERRA-2 modeled datasets to verify the suitability of the model in predicting $PM_{2.5}$ pollution on a local scale (Figure 2).

- The observed $PM_{2.5}$ in the agricultural settings was due to anthropogenic activities considering peak hours of the day (06:00 hrs, 18:00 hrs, and 22:00 hrs). The models over-estimated the observations, but peak hours were similar. GEOS-CF corresponds to morning peaks while MERRA-2, to the evenings.
- Comparing the observed $PM_{2.5}$ estimates to current WHO Air Quality Guidelines, we observed that the 24-hour limits were exceeded at all the sites except for SF (Figure 3).
- The MLR as shown in previous studies (Malings et al, 2019; Raheja et al., 2022) have shown to improve the raw $PM_{2.5}$ data.
- In environments with limited monitoring capabilities and logistical demands, miniaturized sensors can provide useful information for establishing baseline information on $PM_{2.5}$ levels as shown in Raheja et al., 2022 comparable to national or international standards (e.g., WHO Air Quality Guidelines).

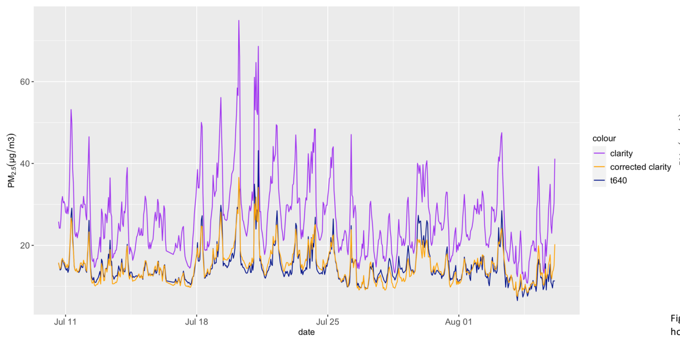


Figure 1: Time series plot for raw (purple), calibrated (orange), and reference grade $PM_{2.5}$ on hourly data.

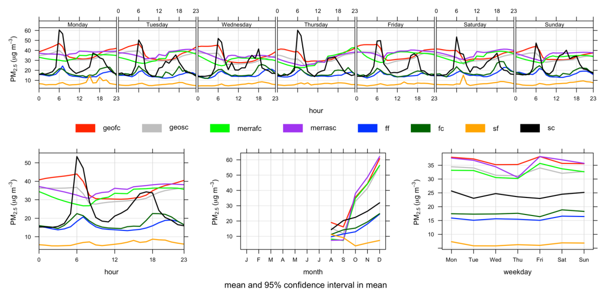


Figure 2: Diurnal trend plot for calibrated $PM_{2.5}$ values at the agricultural settings in the Ashanti Region using modelled (GEOS-CF and MERRA-2) and calibrated Clarity Node-S data where geofc represents GEOS-CF $PM_{2.5}$ values for Fumesua (red); geosc for GEOS-CF $PM_{2.5}$ for Sokwai (grey); merrafc for MERRA-2 $PM_{2.5}$ for Fumesua (green); merrasc for MERRA-2 $PM_{2.5}$ for Sokwai (purple); Fumesua Farm (ff – blue); Fumesua Community (fc – dark green); Sokwai Farm (sf – orange); and Sokwai Community (sc – black) from August 28 to December 19, 2022. Top panel represents day and hour; left bottom represents hour; middle bottom represents month; and right bottom represents weekday.

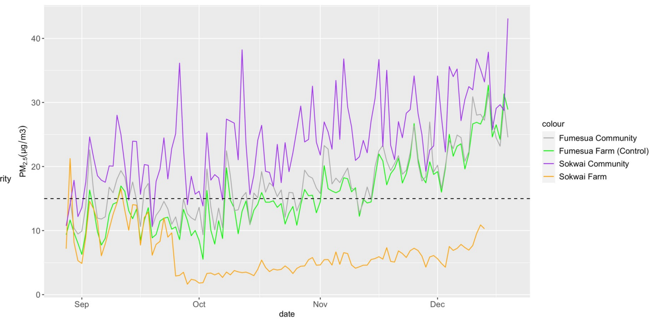


Figure 3: 24-hour time series plot for calibrated $PM_{2.5}$ values at the agricultural settings in the Ashanti Region with the black dash horizontal line showing WHO AQG threshold for $PM_{2.5}$ (15): at Fumesua Farm (ff - green); Fumesua Community (fc – grey); Sokwai Farm (sf – orange); and Sokwai Community (sc – purple) from August 28 to December 19, 2022

Conclusions

In homogenous environments with similar aerosol composition, correction factors are transferrable and useful for improving raw $PM_{2.5}$ data from air sensors to establish baseline levels of air pollution in rural agricultural settings.

Site-specific data is relevant for understanding $PM_{2.5}$ and models are useful for predicting regional air pollution.

Miniaturized air sensors if calibrated can provide useful information for tracking air pollution in environments previously not monitored due to logistical and human capacity demands.

Literature cited

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Disclaimer: Miniaturized air sensor used here refers the colloquial "low-cost" sensor

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