Summary

Essays on Mapping and Improving Urban Air Quality Monitoring in a Developing Country Setting: The Case of Ethiopia

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The expansion of urbanization and the advancement of industries have reduced air quality in various cities worldwide, particularly in low and middle-income countries. This deterioration significantly impacts both health and overall quality of life, contributing to an approximate annual loss of three to seven million lives.[1] While the levels of fine particulate matter (PM2.5) vary across different times and locations, the extensive monitoring of these levels presents a difficulty due to their intricate nature and associated expenses. This situation has sparked growing concerns among policymakers and the general public, particularly in developing countries.

Many countries in sub-Saharan Africa lack permanent PM2.5 measuring stations. Instead, they have increasingly relied on real-time air quality data broadcasted from measurement stations situated in US Embassies. A noteworthy alternative information source has emerged through these broadcasts. The AirNow program has facilitated regular air quality updates for some sub-Saharan

[1] https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

African countries.[2] Ethiopia stands among these nations. For instance, in the capital city of Addis Ababa, the limited monitoring infrastructure is evident: a single station, positioned within the US embassy's parkland. With its rapid urbanization and population growth Addis Ababa faces numerous challenges in maintaining acceptable air quality standards. The city's development, accompanied by increased vehicular emissions, construction activities, and industrial growth, contributes to elevated PM2.5 levels. However, despite the urgency of the issue, establishing effective PM2.5 monitoring systems in the city presents substantial hurdles (AA EP, 2021).

In addressing this challenge, this dissertation presents a low-cost method to measure PM2.5 in order to create a map of pollution in unmonitored locations in the first paper (Chapter Two). The second paper (chapter three) presents an approach suggesting a technique to strategically position stationary air quality monitors in Addis Ababa. This method strives to improve the positioning of monitors in urban areas of developing nations, given its ease of replication.

In the first paper of this dissertation we gather PM data with a low-cost hand-held air quality monitor (Dylos 1700), across four sub-cities situated at the heart of Addis Ababa.[3] This dataset comprises readings from 72 distinct sites, encompassing a diverse array of land uses. By utilizing a land use regression (LUR) model - a well-established technique within air quality research we establish correlations between the observed pollution levels and spatial land use information. This model, employing linear regression with input from GIS-derived land use variables with weather, time of day, and site-specific variables, offers insight into relations between pollution and its determinants, which then predicts air quality levels in unmonitored locations.

[2] https://www.airnow.gov/international/us-embassies-and-consulates/#Ethiopia$Addis_Ababa_Central

[3] http://www.dylosproducts.com/dcpmaqm.html

The outcomes of this study underscore the considerable impact of local land usage, traffic density, and weather conditions on the distribution of PM2.5. Particularly noteworthy is the identification of higher PM2.5 concentrations in commercial districts and regions characterized by substantial vehicular movement proxied by the presence of asphalt roads. This emphasizes the pivotal role that land usage plays in predicting levels of particulate matter. Furthermore, the study highlights the significant influence exerted by meteorological variables on pollution concentrations, surpassing the effects attributed to other factors such as patterns of land utilization.

The second paper examines the extent to which a single air quality monitor at the US Embassy provides a guide to air quality information across the city. It then puts forth a technique for locating stationary air quality monitors. In this chapter, we combine data from a high-quality monitoring station based at the US Embassy in Addis Ababa with spatially rich data obtained using a low-cost mobile sensor that we use to measure across the four sub-cities of Addis Ababa over six months in 2020 and 2021. The discrepancy between air quality readings from a single monitor and readings from a low-cost monitor in four sub-cities of Addis Ababa is analyzed. The study used linear difference and multinomial logit estimations to identify the sources of discrepancies in the readings.

We discovered a correlation between PM2.5 values measured using a low-cost monitor in the local area of Addis Ababa and those recorded at the US Embassy (fixed site). However, significant differences exist between the two data sources, which are systematically related to local environmental features and weather conditions. If the low-cost device is treated as accurate then, approximately half the time the guidance generated by the Embassy data is significantly inaccurate. The discrepancies are primarily influenced by land use, time, and weather variables, with the time of day playing the most significant role in the discrepancy. The findings suggest that relying on data from one air quality monitor positioned randomly does not provide a complete understanding of the intricate nature of air pollution. To achieve more precise measurements in the future, we propose a technique for positioning a second fixed air quality monitors to optimize monitor placement.

Our approach to the optimal location of a second fixed air quality monitor is linked to the maximal covering location problem (MCLP) first developed by (Church & Revelle, 1972) see also (Fazel Zarandi et al., 2011; ReVelle et al., 2008) where resources for facilities are scarce and the aim is to reach a maximum population coverage. The objective of the problem is to place facilities in eligible positions on a network so that the greatest possible population or other demand metric is met. A population is deemed covered if it is within a predetermined time or distance from one or more facilities. Over time, the problem has been adapted to a variety of scenarios.

To determine the placement of an additional fixed air quality monitor in Addis Ababa, we employed an optimization method to minimize the expected cost of total discrepancy. Assume that both sites (the currently available fixed monitor and the proposed monitor) produce information and that everyone bases their decisions on the nearest monitor's information. Then, the further away they are from a monitor, the greatest the discrepancy, and the cost of this discrepancy increases in its square. In other words, the cost of wrong advice is assumed to be proportional to the square of the discrepancy; the farther people are from the monitor, the greater the discrepancy is; this is because air pollution is related to local land use in our discrepancy regression, so we aimed to select a site that would result in the minimum total cost. We adjust longitude and latitude until the first two order conditions are close to zero or the gap is minimum and locate the new site at the point where it sets the discrepancy to a minimum.

We used a trial and error to find the optimal location; we started with a reasonable guess; a location that splits the sampling sites into half makes some sense since we want to reduce the bad (wrong) advice from the monitor and the discrepancy is affected by land use; therefore we first took a location which is at the mid-point of the monitoring sites (study area) and started the location adjustment from that point.

The outcomes of this study will contribute to enhancing the decision-making process and taking effective measures to mitigate air pollution not only in Addis Ababa but also in other cities encountering comparable issues. Furthermore, the method can guide the establishment of air quality monitoring systems in developing countries, offering more precise insights for the purpose of efficient air pollution management and safeguarding public health. Overall, this research sheds light on the challenges associated with monitoring air quality in developing regions and suggests measures to improve the accuracy and accessibility of air quality information.

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