Scientific summary for policy makers

AN ASSESSMENT OF PERSONAL EXPOSURE TO POLLUTION OF JEEPNEY DRIVERS: A HIGH-RISK OCCUPATIONAL GROUP IN METRO MANILA, PHILIPPINES

INTRODUCTION

Metro Manila is the center of politics, economy, and education in the Philippines. Its 12.8 million inhabitants occupy an area of 619 square kilometers, which translates into a population density of 20,785 per square kilometer [1]. Furthermore, an additional of 2-3 million people is estimated to come to the metropolis in the daytime to work and to do business. In 2015, Metro Manila contributed 36.6% to the country's gross domestic product and 61.6% to the total jobs generated [2]. Like most megacities, the rapid development and enormous amount of economic activities in Metro Manila came with detrimental effects on the environment, not least of which is the deterioration of air quality.

While there are mass transport systems such as the Metro Rail Transit (MRT) and the Light Rail Transit (LRT) operating in Metro Manila, these cannot accommodate the demand on transportation by the sheer volume of daily commuters. The result is a constantly high volume of private cars on the road as well as a hodgepodge of alternative public transport means such as buses, jeeps and tricycles. Needless to say, traffic has been a persistent problem in the highly urbanized megacity.

Based on the latest National Emissions Inventory conducted in 2015, the majority (65%) of air pollutants came from mobile sources such as cars, motorcycles, trucks and buses. Almost 21% were contributed by stationary sources (e.g. power plants and factories), and the rest (14%) were from area sources (e.g. construction activities, open burning of solid wastes and kaingin in the uplands). In comparison, the Emissions Inventory for NCR in the same year revealed that mobile sources had an even greater contribution to air pollution: an enormous 88% compared to 10% from stationary sources and a mere 2% from area sources [3].

This scientific brief focuses on fine particulate pollution specifically on $PM_{2.5}$, which are liquid and solid particles with aerodynamic diameter of less than or equal to 2.5 micrometers (20-28x smaller than an average human hair diameter, **Fig.1**).

In an urban environment, $PM_{2.5}$ is a highly relevant metric of traffic pollution and is strongly associated with health outcomes in epidemiological studies [4].

Air pollution accounts for an estimated 6.5 million deaths annually, of which 4.2 million premature deaths are due to outdoor air pollution and is considered as the world's largest environmental health risk [5]. Due to its small size, $PM_{2.5}$ can penetrate the lungs and bloodstream, and can cause respiratory and cardiovascular diseases. The World Health Organization (WHO) and Climate & Clean Air Coalition identified $PM_{2.5}$ as the air pollutant linked most closely to excess death and disease.

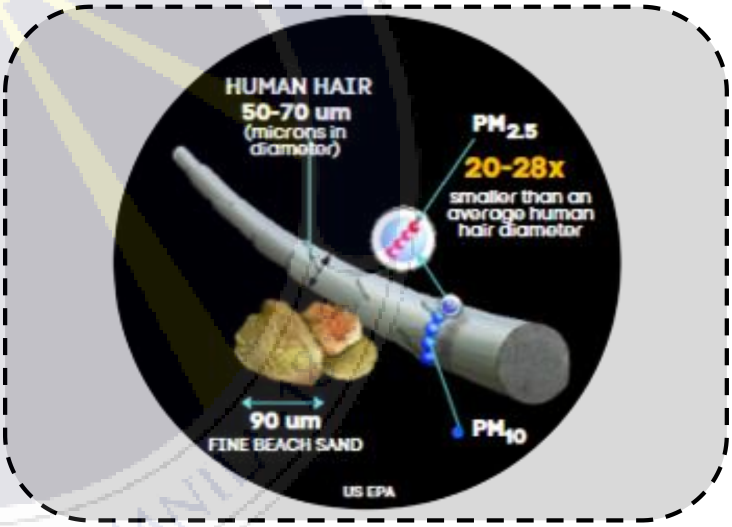

Fig. 1. Size comparisons for PM particles

Because of the hazardous effects of $PM_{2.5}$ on human health, the WHO and the US Environmental Protection Agency (EPA) ha set guideline values for $PM_{2.5}$ concentrations (**Table 1**). Also included in **Table 1** are the 24-hour and annual Philippine National Ambient Air Quality Guideline Values (NAAQGV) from RA 8749.

Table 1. Ambient air quality standard for $PM_{2.5}$ (in μg/m^3).

	WHO	US EPA	NAAQGV
24-hr mean	25	35	50
Annual mean	10	12	25

Objective of the Study

The objective of this study is to quantify the personal exposure of jeepney drivers of the UP Campus-Katipunan route to $PM_{2.5}$.

In 2017, the Metro Manila Development Authority (MMDA) reported Katipunan Avenue as the third most congested road in Metro Manila, with an average daily traffic volume of 218, 751 vehicles per day [6]. Jeepney drivers of the UP Campus-Katipunan route are on the road for 10-12 hours a day, six days a week. Due to the combined factors of the high traffic density along the route as well as the enormous amount of time that the jeepney drivers spend on the route, there is good reason to suspect that their personal exposures to particulate pollution are significantly elevated.

Design of the Study

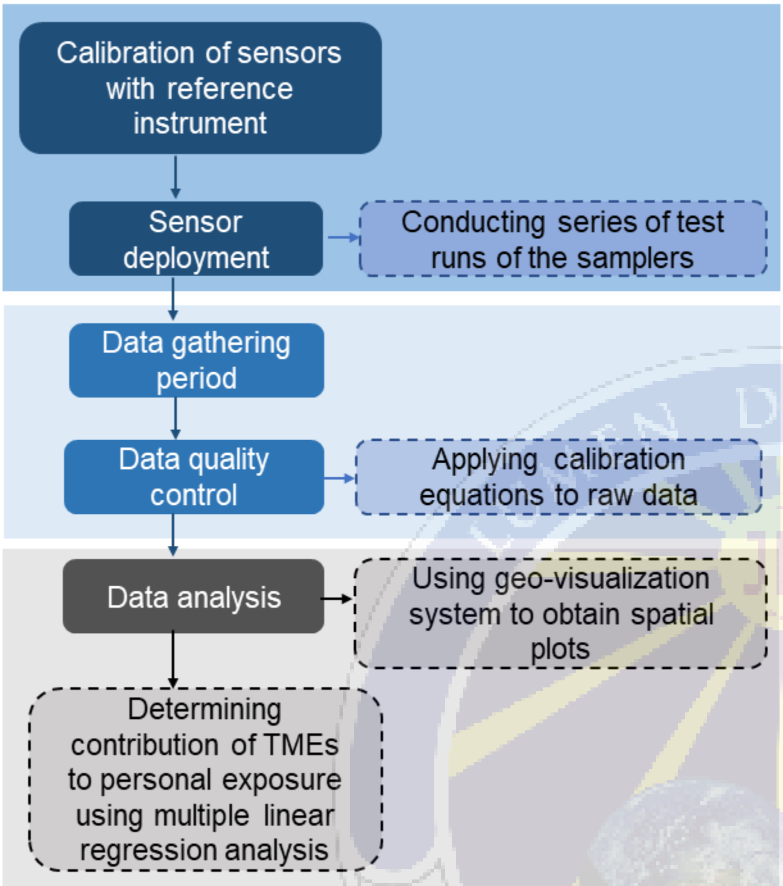

Fig. 2. Methodological flowchart of the study.

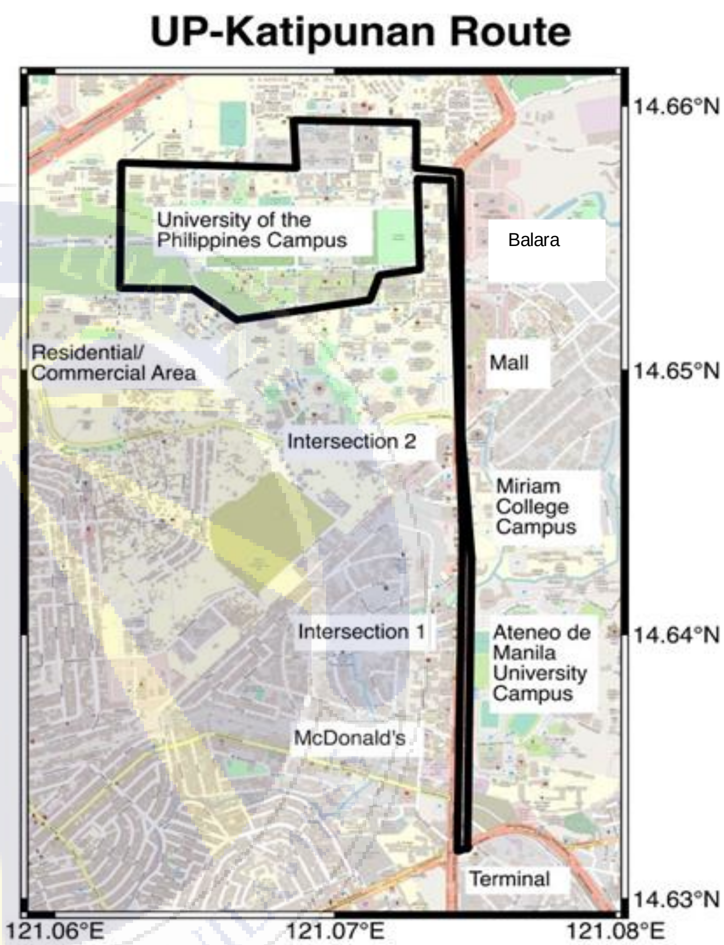

Fig. 3. Sampling Route

The measurement method was primarily designed to estimate the personal exposure of PUJ drivers to $PM_{2.5}$ along the UP Campus - Katipunan route (**Fig. 3**). To do this, sampling devices measuring the concentration of $PM_{2.5}$ in $\mu g/m^3$ were attached to the dashboard of jeepneys (shown in **Fig. 5**), an ideal location as it is within the driver's breathing zone.

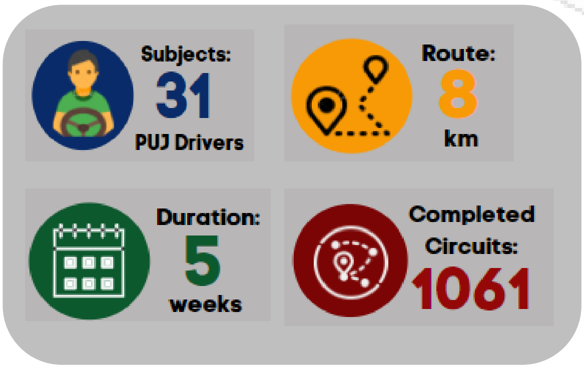

Fig. 4. Study Design

Fig. 5. Standard set-up of the portable sampler on the dashboard of the PUJ

To ascertain the accuracy of field measurements, the seven portable $PM_{2.5}$ samplers used in the study were collocated with a Beta Attenuation Monitor (BAM) for 16 days (N = 368, mean number of sampling points), showing strong linear relationship with the BAM for all seven sensors (r^2 = 0.83 to 0.85).

Seven AS LUNG (Academia Sinica-LUNG) samplers were taking measurements simultaneously for 7AM-6PM for 32 days from 12 Nov-15 Dec 2018. The sampling device takes a measurement of $PM_{2.5}$ every 15 seconds, and so around 450,000 $PM_{2.5}$ measurements were recorded. Each roundtrip takes 30 to 60 minutes, depending on traffic conditions. A total of 1061 roundtrips were monitored for the whole duration of sampling and a total of 31 drivers participated in this study (**Fig. 4**).

RESULTS

Average personal exposure of PUJ drivers to $PM_{2.5}$

Thirty-six microgram per cubic meter (μg/m³) was the hourly mean exposure level of PUJ drivers to $PM_{2.5}$ during the five-week sampling period.

It is important to consider that these PUJ drivers ply their routes for 10-12 hours a day, six days a week. Moreover, most of them have been in this occupation for many years and presumably will stay in this occupation for many years to come. Thus, they are chronically exposed to this level of $PM_{2.5}$ concentration. It is then logical to assume 36 (μg/m³) to be their long-term mean personal exposure. This number exceeds the annual guideline value set by the WHO (10 (μg/m³) by a factor of ~3.6. Therefore, this chronic exposure poses harm to the health of PUJ drivers that might manifest through time.

Observed Diurnal Patterns of $PM_{2.5}$ Concentration Levels

Peak concentrations were observed during the morning rush hours with the highest levels consistently recorded at 8AM. After 8AM, $PM_{2.5}$ concentrations started to decline gradually, reaching minimum values at around 2PM, after which a gradual incline was observed until the end of sampling hours (6PM). This pattern showed up consistently for all samplers, as shown in **Fig. 6**, and can be explained by a combination of anthropogenic and meteorological factors.

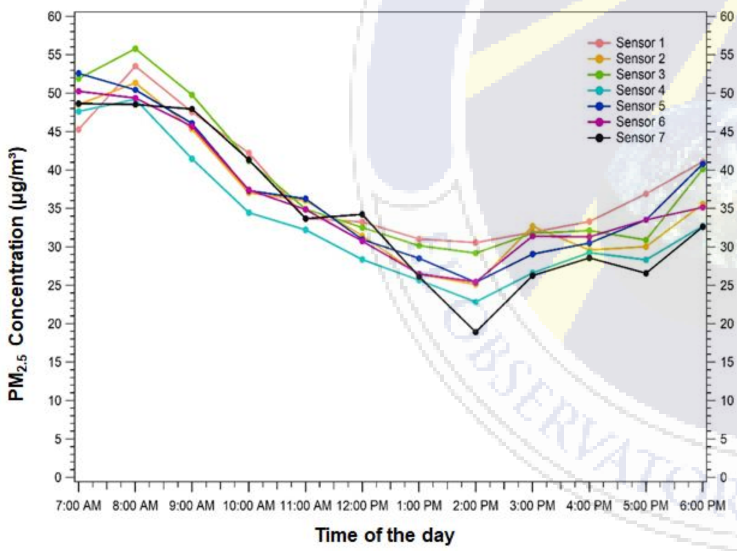

Fig. 6. Time series of hourly averages of $PM_{2.5}$ measurements taken by the AS-LUNG samplers for the whole sampling duration.

During rush hours (7AM to 9AM in the morning and 4PM to 6PM in the evening), traffic volume along the route in study is greater than during non-rush hours (10AM to 3PM). More emissions, and therefore higher detected levels of $PM_{2.5}$, are to be expected during rush hours than non-rush hours. While the sampling results show elevated levels of $PM_{2.5}$ for both AM and PM rush hours compared to non-rush hours, it is also evident that $PM_{2.5}$ levels during AM rush hours are much greater than those during PM rush hours.

It is relevant to note that the Katipunan area is home to three schools: UP, Ateneo and Miriam, all of which offer education at multiple levels, from grade school to college. Furthermore, a number of commercial establishments are also situated at or near the Katipunan area. One likely reason for greater traffic density during the AM rush hours than the PM rush hours is the fact that the start of classes and the start of work hours usually coincide within a small window of time, usually 8AM to 9AM, whereas there is a broader range of time in which people travel home. After school or work, there is greater flexibility in choosing what time to go home. Some people even opt to wait it out and travel after rush hours.

Meteorological factors, primarily the daily variations in air temperature and in atmospheric stability conditions, affects the distribution of particulate pollution in the surface layer. Air temperature near the earth's surface is lowest at 6AM and peaks at around 4PM [7]. During the AM rush hours (7AM to 9AM), emissions are high and at the same time, shallower boundary layer (i.e. the concentrations accumulate in smaller volume, which leads to higher PM concentration. During the PM rush hours (4PM to 6PM), emissions are also high, but the thermal convection is also stronger (increased in mixing) which leads to lower surface PM concentration. Even during non-rush hours at 10AM to 3PM when emissions are lower, $PM_{2.5}$ levels are noticeably higher in the morning than in the afternoon. This further evidences the contribution of meteorological factors to ground-level $PM_{2.5}$ concentrations.

Observed Geospatial Patterns of $PM_{2.5}$ Concentration Levels

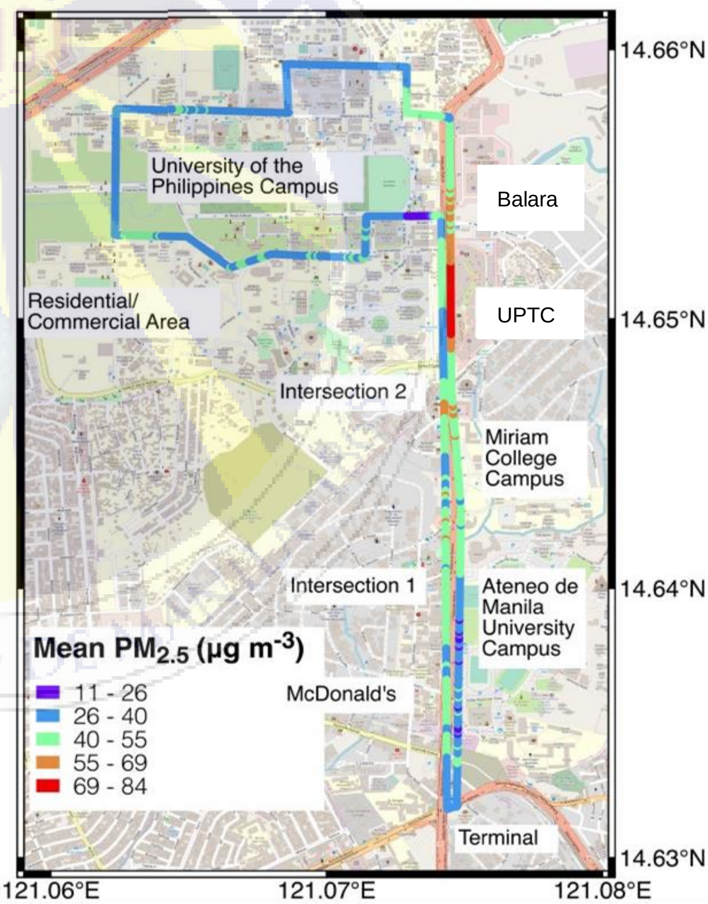

Fig. 7. Spatial distribution of all 15-s $PM_{2.5}$ measurements taken along the UP Campus-Katipunan route.

Geospatial averaging was performed on the ~450,000 15-sec measurements taken from 1061 total paths (roundtrips) along the UP Campus-Katipunan route. **Fig. 7** shows the overall spatial distribution of mean $PM_{2.5}$ concentrations from all 1061 paths. Each circle represents the average of all $PM_{2.5}$ measurements made within the 30-m diameter, and the center points are 10 m apart. The colors represent ranges of values as indicated on the map.

Overall, $PM_{2.5}$ concentrations along Katipunan Avenue are relatively higher than the concentrations inside UP Campus. Specific areas along the route or transportation microenvironments (TMEs) with relatively higher levels of $PM_{2.5}$ were also identified. Five TMEs were identified as $PM_{2.5}$ hotspots: the northbound sections of the route in front of Ateneo De Manila University (Ateneo), Miriam College (Miriam), UP Town Center (UPTC), Balara tricycle terminal (Balara), and the southbound section in front of McDonald's – Katipunan (McDo), all of which are along Katipunan Avenue. Among these, the UPTC TME had the highest $PM_{2.5}$ levels, as shown in **Fig. 8**.

The identified hotspots are not surprising. These are areas where there is frequent buildup of traffic. Some are situated near stoplights (UPTC, Miriam and Ateneo). Some lead to entrance/exit gates where vehicles need to stop (UPTC, Miriam and Ateneo). Some are roadside drop-off points (UPTC and McDo). In front of UPTC, there are three designated drop-off areas where many vehicles stop to drop-off mallgoers. McDo, on the other hand, is an unofficial drop-off point as well as drive-thru route. In addition, because McDo is one of, if not the most popular fast food joint in the area, it usually has a high volume of costumers with a fast turnover rate. Aside from traffic buildup caused by private vehicles, all five identified PM2.5 hotspots are also unofficial PUJ stops due to the relatively higher number of passengers alighting at these areas, further contributing to traffic congestion.

With the exception of UPTC, all TMEs showed a clear diurnal pattern where the highest $PM_{2.5}$ is observed during AM rush hour, followed by a gradual decrease throughout the day, followed by a detectable increase around PM rush hours. Unlike the other TMEs, $PM_{2.5}$ levels at the UPTC are consistently high throughout the day, with almost no diurnal variation.

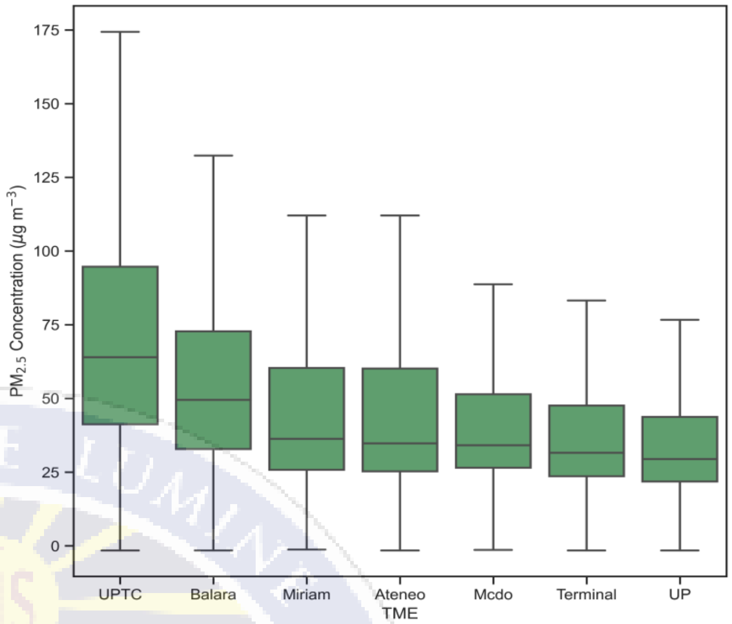

Fig. 8. Boxplot for all runs separated by TME. Gray line is the median value, and the whiskers are 5th and 95th percentile.

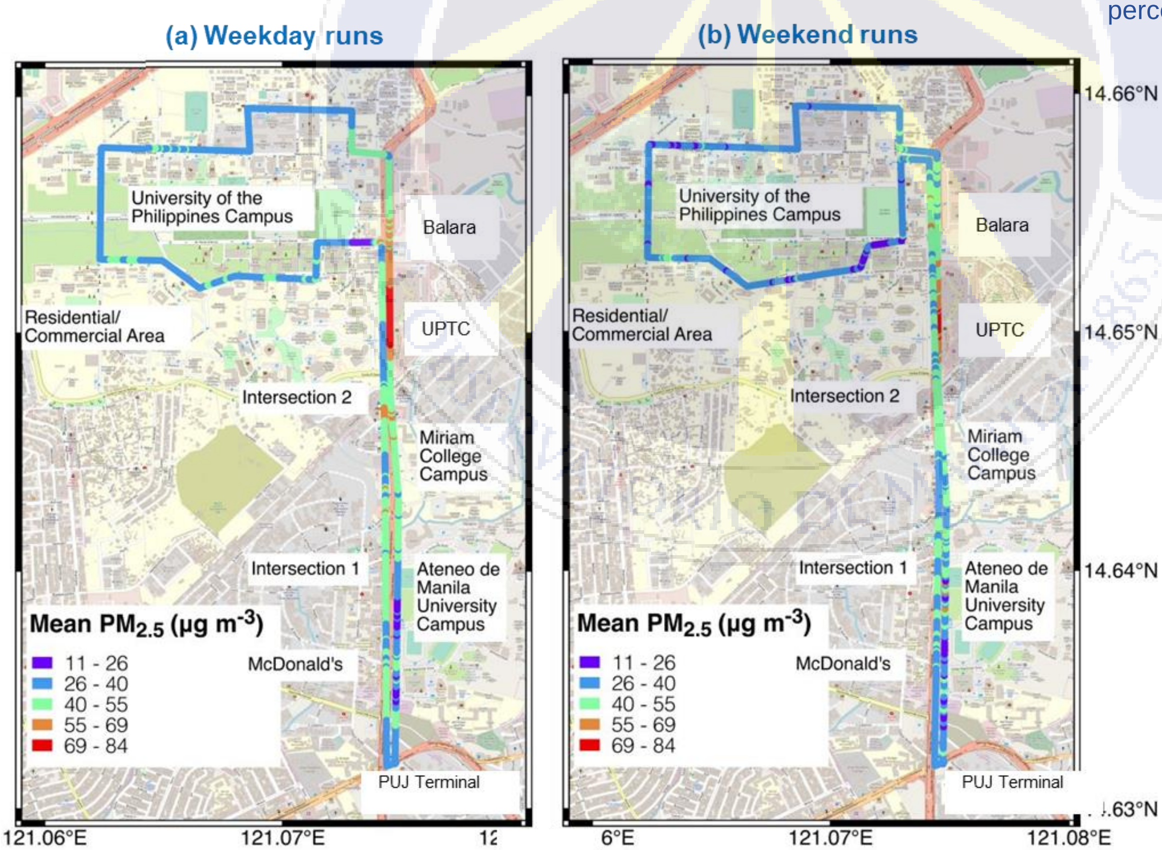

Fig. 9. Spatial distribution of mean $PM_{2.5}$ measurements taken along the UP Campus – Katipunan route during (a) weekdays and; (b) weekends from 12 Nov-15 Dec 2018.

Spatial trends of mean $PM_{2.5}$ concentrations during weekdays (Mon-Fri) and weekends (Sat-Sun) are plotted on **Fig. 9**. Both exhibit an almost similar spatial trend, but the concentrations are relatively higher during weekdays than weekends. $PM_{2.5}$ levels in front of Ateneo and Miriam and inside the UP campus are lower on weekdays than on weekends. For both weekday and weekend runs, $PM_{2.5}$ levels in the upper ranges (69-84 µg/m^3, indicated by the color red in the map) continued to be observed in front of UPTC (**Fig. 9**). This means that for the UPTC TME, there is hardly a difference in $PM_{2.5}$ levels between weekdays and weekends.

The result of the comparison of $PM_{2.5}$ levels between weekday and weekend runs is suggestive of the influence of anthropogenic activities to $PM_{2.5}$ concentrations. Whereas schools such as Ateneo, Miriam and UP have decreased activity during weekends, a shopping mall such as UPTC might not have a significant difference in activity level between weekdays and weekends.

Comparing the spatial trends of mean $PM_{2.5}$ concentrations of weekday AM rush hours and PM rush hours (shown in **Fig. 10**), it is evident that PM levels are significantly lower during PM rush hours than during AM rush hours. However, it is worth noting that the same pattern of which areas record relatively higher/lower $PM_{2.5}$ levels within the route is the same for both AM and PM rush hours.

RESULTS

The visualizations resulting from geospatial averaging clearly show persistent spatial patterns of $PM_{2.5}$ levels with small-scale variability, regardless of whether it is morning or afternoon, weekday or weekend Hence, the spatial population patterns can be attributed to local sources.

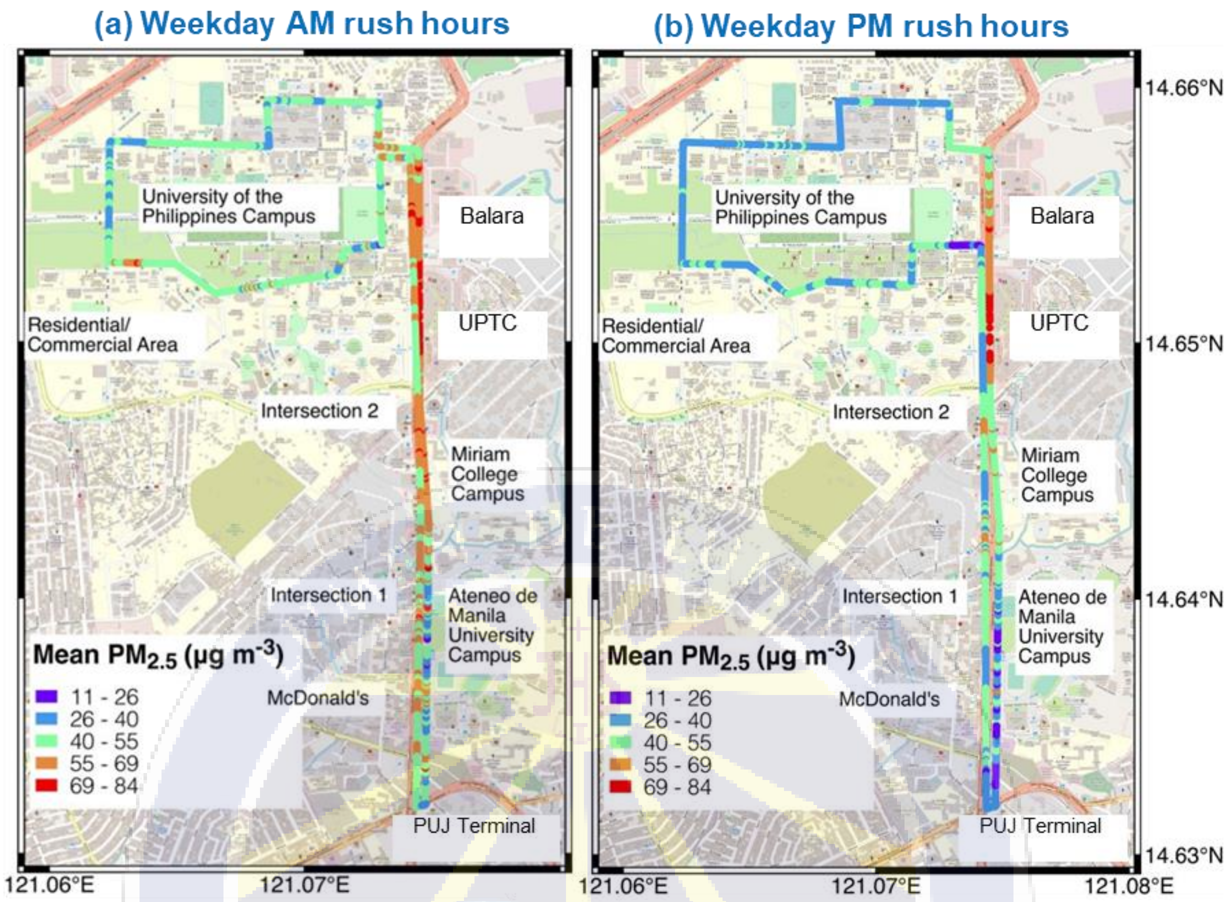

Fig. 10. Spatial distribution of mean $PM_{2.5}$ measurements taken along the UP Campus – Katipunan route during (a) AM rush hours and; (b) PM rush hours for all weekday runs from 12 Nov-15 Dec 2018.

RECOMMENDATIONS:

The results presented in this study clearly show the influence of vehicular emissions on $PM_{2.5}$ levels. Clearly, in order to improve air quality, there is a need to reduce vehicular emissions.

Specifically, the following actions are recommended:

(1) consistent monitoring of vehicle compliance to emission standards and shifting towards cleaner technologies for PUJs in the metropolis;

(2) initiatives of commercial establishment owners in planning and managing the traffic system of vehicles going in and out of their area to reduce traffic congestions, especially during rush hours, and;

(3) reassessment of current PUJ routes relative to current requirements and mass transport plans to determine feasibility of rerouting certain vehicles in the future.

The use of real-time and high-resolution data in this study shows that availability of high-resolution air quality data in highly urbanized areas like Metro Manila poses transformative implications for environmental management, air pollution science, epidemiology, public awareness, and policy. Comprehensive air quality studies and high-resolution air quality data may increase public awareness and enable broader societal consequences, which include shifts in urban planning and land-use decisions, and relevant updates in the transport system regulatory actions at the national level. Hence, this study calls for an urgent exploration of effective measures to monitor air pollution, especially those related to the palpable link between air pollution dynamics and existing transportation and traffic conditions in highly urbanized areas in the Philippines.

There is a need to recognize that the problem of air pollution is a complex one and it will require solutions that realistically may not be possible to be implemented immediately. As long as $PM_{2.5}$ levels in an area exceed guideline values, pollution will continue to be a persistent and chronic health hazard to its community and the most vulnerable will be certain occupational groups.

RECOMMENDATIONS:

While this study is limited only to investigating the personal exposure of PUJ drivers to $PM_{2.5}$, it is important to note that other occupational groups face the same, if not greater risk. These include drivers of other public utility vehicles, street vendors, traffic enforcers, street cleaners and security guards of roadside establishments. The hazard of air pollution is even greater for those whose occupations require them to stay for long periods of time in an area that was identified in this study as a $PM_{2.5}$ hotspot. Compared to PUJ drivers whose personal exposures are in a mix of hotspot and non-hotspot area in the course of plying their route, the personal exposure of these groups is always in a hotspot area. So while this study has found that the mean personal exposure of PUJ drivers is 36 μg/m^3, it is highly likely that theirs is even greater, and therefore poses even greater health risks.

It is recommended that for these high-risk occupational groups to wear masks with a $PM_{2.5}$ filter to mitigate the harmful effects of $PM_{2.5}$ on their health. However, even the best masks cannot filter out 100% of $PM_{2.5}$. Furthermore, graded masks which have been proven to filter out a significant percentage of $PM_{2.5}$ are usually expensive and at the same time disposable, meaning they will need to be purchased regularly. Seeing as these occupational groups are mostly minimum-wage or below-minimum-wage earners, they cannot practically afford to regularly wear masks that are effective at filtering out $PM_{2.5}$.

In actuality, the only effective means to reduce personal exposure levels is through improving the ambient air quality. This can be achieved through efforts in implementing effective policies on traffic-related air pollution, considering air pollution dynamics in urban planning, and investing in automated, real-time instruments that monitor air pollution.

The Public Utility Vehicle Modernization Program (PUVMP), involving the replacement of traditional jeepney with more efficient alternatives, including modern electric jeepneys, is one such initiative that can reduce ambient $PM_{2.5}$ levels. However, this program is encountering resistance from jeepney operators and drivers due to the cost of shifting from the traditional jeepney to a modern jeepney. Assistance is needed in order to make it economically viable for jeepney operators and drivers to modernize. If successfully modified and implemented, the PUVMP can be made economically viable for the jeepney operators and drivers while maintaining the jeepney to be an affordable means of transportation for the general public, and at the same time, improving the ambient air quality.

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