# Lab Activity No. 1: Observing the relationship between particulate matter concentration and meteorology from ground measurements

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## 1 General and Specific Objectives

### 1.1 General Objective

- To determine any relationship between air pollution data and ground-based meteorological data

### 1.2 Specific Objectives

- To investigate the diurnal variability of PM2.5 concentrations, air temperature and humidity, and wind speed
- To determine if changes in PM2.5 concentrations are related to changes in temperature, humidity, and wind speed
- To determine the days of the week with higher or lower PM2.5 concentrations
- To determine if the 24-hour average PM2.5 concentrations of sampling site exceed the National Ambient Air Quality Guideline (NAAQG) value of the Philippines, and of the World Health Organization

## 2 Description of Site/Sampling Area

The sample site (Fig. 1) is located in the Quezon Memorial Center (QMC), Quezon City, Metro Manila, Philippines ($14.65^oN$, $121.05^oE$). The QMC is a public park located in the middle of a highly urbanized city, surrounded by business hubs, malls, restaurants, transportation terminals, and public schools and university. Thus, despite being designated as a *green space*, QMC is surrounded by heavy vehicle and foot traffic. Sampling was done hourly from 01:00 August 1, 2015 to 23:00 September 17, 2015 (Philippine time).

The sampling data contains the following: date and time, PM2.5 concentrations ($\mu g/m^2$), air temperature ($^oC$), relative humidity, pressure ($mb$), wind speed ($m/s$), wind direction (in degrees), latitude ($^oN$), and longitude ($^oE$). The link to the data set is included in the Appendix.

## 3 Review of Related Literature

A location's meteorological conditions affect the dynamics of particulate matter, and in turn, its measured concentrations. In this paper, we consider the following meteorological conditions: temperature, relative humidity, wind speed and direction, and time of day. Relative humidity and wind speed depend heavily on temperature, which depends as well

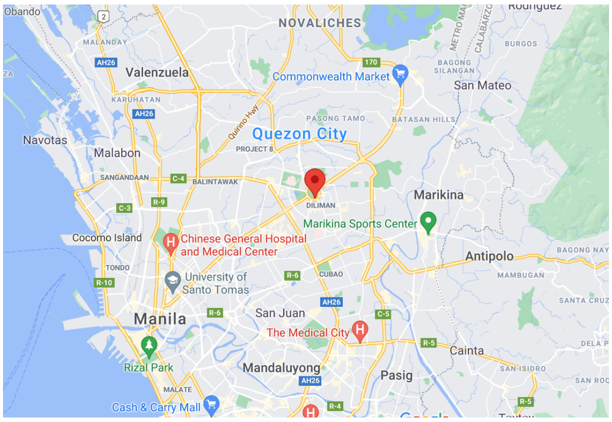



Figure 1: Location of sampling site (indicated by the red marker) obtained from Google Maps.

on the time of day. We expect the temperature to be higher during the day (when the sun is visible), and lower during the night (when the sun is not visible).

Relative humidity forms an inverse relationship with temperature—as temperature increases, relative humidity decreases [1]. At night, the air cools, thereby decreasing the amount of water vapor the air can hold. The opposite occurs during the day. Assuming that the amount of water vapor in the air remains more or less constant throughout the day, relative humidity should increase at night, and decrease during the day.

On the other hand, wind speed follows a direct relationship with temperature—as temperature increases, so does wind speed. At night, cold temperatures tend to keep higher winds aloft. During the day, as surface temperatures increase, the higher winds gradually drop down near the surface. Thus, wind speed decreases at night, and increases during the day.

In summary, as temperature increases, relative humidity decreases, while wind speed increases, and vice versa. Now, we discuss how we expect each meteorological parameter to affect particulate matter (PM2.5) concentrations.

We expect PM2.5 concentrations to increase at low wind speeds, decreased at mid-wind speeds, and increase again at high wind speeds [2, 3]. At low wind speeds, PM2.5 concentrations tend to accumulate near the surface, but the accumulated PM2.5 begins to scatter as winds strengthen. However, at much stronger wind speeds, particulate matter from surrounding areas may get blown away and travel towards the measuring site, thereby increasing PM2.5 concentrations.

On the other hand, we expect PM 2.5 concentrations to decrease as relative humidity decreases, and vice versa [4, 5]. Water soluble compounds in the atmosphere (such as nitrate, sulfates, inorganic carbon) tend to increase with increasing relative humidity. Also, at high relative humidity, the internal combustion of engines from vehicles undergo incomplete combustion due to reduced oxygen intake. Thus, vehicles tend to exhaust more particulate matter at higher relative humidity.

## 4 Methods Framework

I set the following as the parameters for analysis: PM2.5 concentrations, air temperature, relative humidity, wind speed, and wind direction. The pressure and coordinates more or less remained constant throughout the whole sampling period, since only one sampling site was considered.

First, I obtained the hourly averages of all our parameters, then I superimposed each pair of parameters in one plot. I also included the hourly averages for each day of the week. The parameter pairs are as follows

- temperature and humidity
- wind speed and PM2.5 concentrations
- temperature and PM2.5 concentrations
- relative humidity and PM2.5 concentrations

Next, I obtained daily average PM2.5 concentrations, with a separate plot for a 24-hour moving average for a cleaner view of possible trends.

Lastly, I obtained a wind rose plot of the PM2.5 concentrations, and wind speed and direction. In this plot, the radius corresponds to the wind speed, the polar angle corresponds to the wind direction, and the color map corresponds to the concentrations.

## 5 Results and Discussion

### 5.1 Correlation of Parameters

First, we look at the hourly averages of our sampling parameters (Fig. 2). Temperature begins to increase around sunrise (6:00), peaks at noon (12:00), and begins to decrease at sunset (18:00). From sunset to early morning, the sun, our primary source of heat, is not visible, while during noon, it is directly overhead. Thus, the results are as expected.

On the other hand, relative humidity tends to decrease when temperature is high, and vice versa (Fig. 2a). Relative humidity peaks during the night, but drops during the day. The wind speed follows a similar pattern to temperature (Fig. 2b)—wind speed decreases at night, and increases during the day. Our meteorological parameters behaved as we expected.

Now, let us look at how the measured meteorological parameters relate to PM2.5 concentrations. Concentrations seem to follow an inverse relation with wind speed (Fig. 2b), as expected. The wind speeds maintain weak enough speeds such that particulate matter from surrounding areas do not reach the sampling site. Concentrations follow the opposite relation with relative humidity—when RH decreases, so do concentrations—as expected (Fig. 2d). The inverse relation of concentration and temperature can be attributed as a consequence of the high dependence of RH and wind speed on temperature.

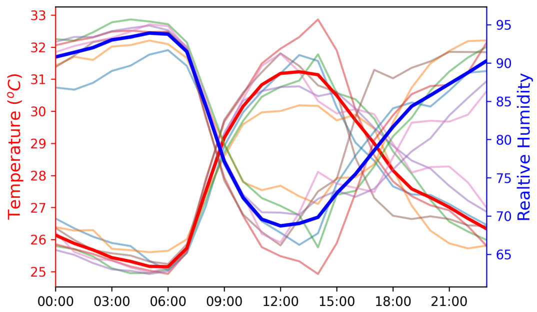
### 5.2 Days of the Week Variation

We compare the hourly averages of all parameters for each day of the week with the overall hourly averages (Fig. 2 & 3). We find that both follow the same trend. Thus, hourly averages present minimal changes for each day of the week.

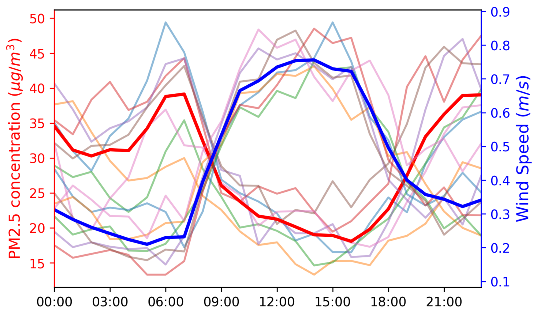
Looking more closely at the diurnal variations, we notice two peaks in the average hourly PM2.5 concentrations: at 6:00 and 21:00 (Fig. 3). We consider these times of the day as *rush hours*. Starting at 6:00, people leave their residences and travel via public transportation or private vehicles to go to work or school. Starting at 18:00, people leave work or school, then travel again to their respective residences. Vehicle traffic typically intensifies during these times, so pollution from vehicle exhausts boost up.

### 5.3 Weekend-Weekday Variation

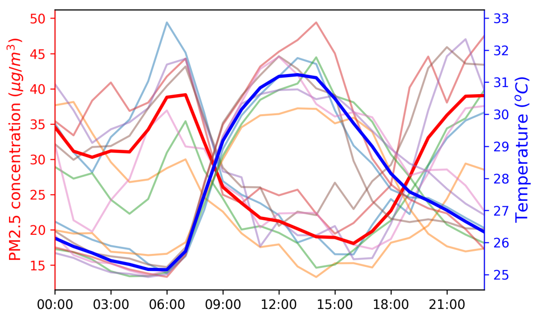
The Quezon Memorial Circle lies in the middle of a prominently urban area, so we consider vehicle exhausts as the primary source of pollution. Thus, we expect busy days (weekdays)



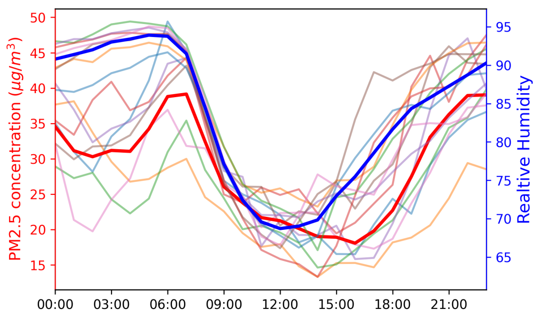

(a) Temperature and Humidity




(b) Wind Speed and PM2.5 Concentrations




(c) Temperature and PM2.5 Concentrations




(d) Humidity and PM2.5 Concentrations

Figure 2: Superimposed hourly averages of sampling parameters. The hourly averages for each day of the week are included in the colored background plots.

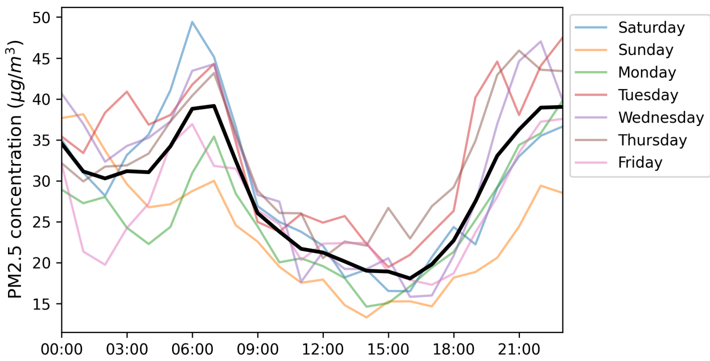
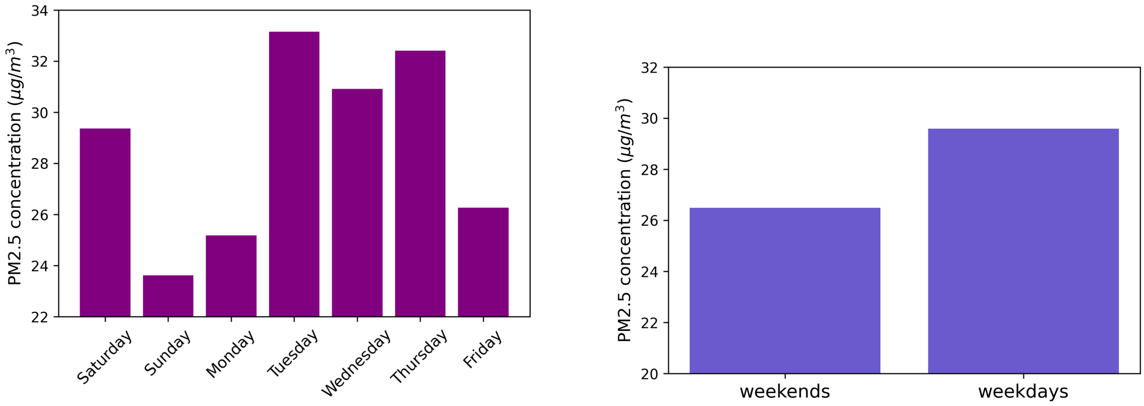



Figure 3: Hourly average PM2.5 concentrations for each day of the week (in color), and for all days (in black)




(a) (b)

Figure 4: Total average PM2.5 concentrations (a) for each day of the week, and (b) for weekends and weekdays.

to possess higher PM2.5 concentrations than idle days (weekends). According to the two sample $t$-test, the difference between the mean PM2.5 concentrations between weekends and weekdays (Fig. 4b) is statistically significant.

We see that concentrations tend to peak during the busiest days of the week, Tuesday to Friday, and drop during Sunday and Monday (Fig. 4a). We expect lower concentrations during Sundays, because we consider Sundays as *rest days* or *family days*. Since people tend to stay indoors or in their homes, travel by public transportation or private vehicles decline.

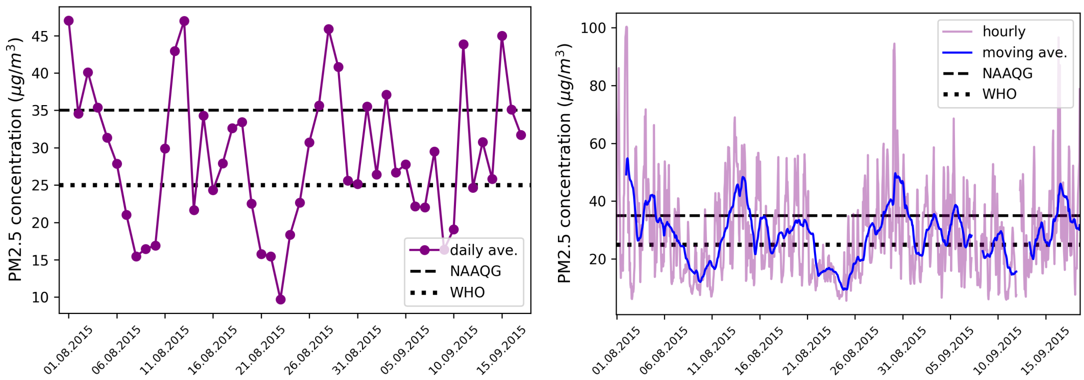
The average concentration for Saturdays is higher than I expected. Possibly, as a public recreation area, people tend to leave their homes and travel to QMC to attend public events or weekend bazaars.

The average concentration for Mondays is also lower than I expected, since Monday marks the beginning of the work days. QMC resides near a public university, and majority of classes begin during Tuesdays and can extend until Saturdays. Possibly, fewer students travel outside of their homes during Mondays, so fewer vehicles exhaust fumes.

### 5.4 PM2.5 Concentrations Time Series Variation

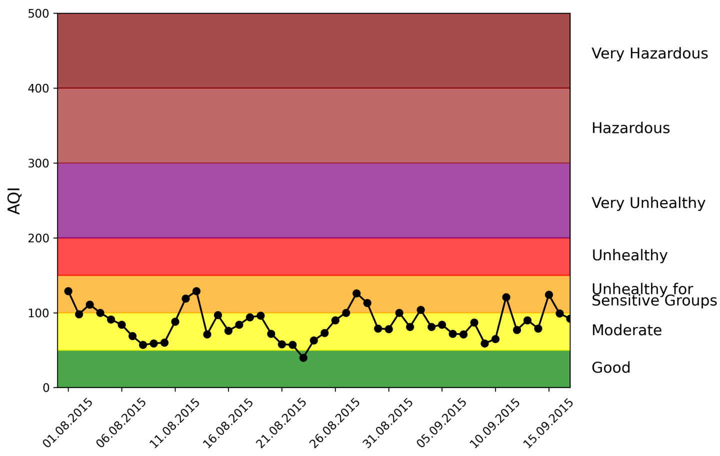
From the daily average PM2.5 concentrations (Fig. 5), we see that concentrations shot up far higher than the NAAQGV around particular days: August 1 (Saturday), 13 (Thursday) and 28 (Friday), and September 11 (Tuesday) and 15 (Friday). Concentrations dropped down on particular days as well: August 8 (Saturday) and 23 (Sunday), and September 9 (Wednesday). PM2.5 concentrations seem to cycle between low (lower than WHO Guidelines), and high (higher than NAAQGV) values weekly.

The Philippines implemented less ambitious guidelines than the WHO for PM2.5 concentrations, so we expect more days to exceed the latter. Based on the daily average concentrations, more than half of the days in the sampling period exceeded 25 $\mu g/m^3$, while only less than half exceeded 35 $\mu g/m^3$. By calculating the Air Quality Index for PM2.5 (using https://aqicn.org/calculator/), we see that the concentrations remain within the *Moderate* to *Unhealthy for Sensitive Groups* (Fig. 6).



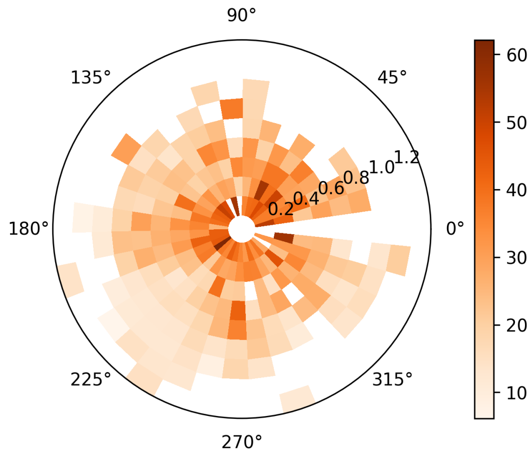

(a) (b)

Figure 5: (a) Daily, and (b) 24-hour running average PM2.5 concentrations for whole sampling period. The Philippine NAAQGV and WHO Guidelines are shown in the horizontal lines.




(a)

Figure 6: Daily air quality index based on daily average PM2.5 concentrations.




(a)

Figure 7: Wind rose plot containing PM2.5 concentrations, and wind speed and direction.

### 5.5 Relation of PM2.5 Concentrations to Wind Speed & Direction

The wind rose plot (Fig. 7) further illustrates that weaker wind speeds result to lower PM2.5 concentrations. Concentrations for different wind wind directions are more or less spread out, though winds from the northeast and east seem to carry higher concentrations. -

## References


[1] C. D. Ahrens, *Third Edition Essentials of Meteorology* (2000), ISBN 9780123736154.

[2] Q. Yin, J. Wang, M. Hu, and H. Wong, Estimation of daily PM2.5 concentration and its relationship with meteorological conditions in Beijing, *Journal of Environmental Sciences (China)* **48**, 161 (2016), ISSN 18787320.

[3] J. Wang and S. Ogawa, Effects of Meteorological Conditions on PM2.5 Concentrations in Nagasaki, Japan., *International journal of environmental research and public health* **12**, 9089 (2015), ISSN 1660-4601 (Electronic).

[4] R. Zalakeviciute, J. López-Villada, and Y. Rybarczyk, Contrasted Effects of Relative Humidity and Precipitation on Urban PM 2.5 Pollution in High Elevation Urban Areas (2018).

[5] Y. Cheng, K. B. He, Z. Y. Du, M. Zheng, F. K. Duan, and Y. L. Ma, Humidity plays an important role in the PM2.5 pollution in Beijing, *Environmental Pollution* **197**, 68 (2015), ISSN 18736424.


## Appendix

The data set can be found in:
https://drive.google.com/file/d/1zXPyVpaQFAbbR4ybwI0nQY1zkhremsd0/view?usp=sharing.