Comparative Study and Analysis of Particulate Matter Concentrations in the Eastern part of Metro Manila, Philippines

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Abstract: Particulate matter (PM) is a major air pollutant that is made up of a heterogeneous combination of solid, liquid, and gaseous particles. Particles with sizes fewer than 10 g/m^3, often known as PM_{10}, are of particular interest. PM_{10} can be further subdivided into coarse ($PM_{2.5\text{-}10}$) and fine ($PM_{2.5}$) fractions. The samples were collected from January - February 2020. Gravimetric analysis was used to determine the amount of particulate matter present. The 2020 PM data was compared to the previously collected data from the Asia-Pacific Aerosol Database (APAD) of the International Atomic Energy Agency (IAEA) for the years 2001, 2005, 2009, and 2013. The average PM_{10} and $PM_{2.5}$ concentrations were found to exceed the World Health Organization's annual guideline standards in all monitoring years, while the $PM_{2.5}$ concentrations in the years 2009 and 2020, complied with the 1999 Philippine Clean Air Act criteria. For the years 2001, 2005, 2009, and 2013, the PM_{10} concentrations were dominated by the $PM_{2.5}$ load, which may be indicative of inefficient combustion sources and traffic dynamics in the area. The average $PM_{2.5}$ emissions decreased in 2020, presumably as a result of government-enforced steps to reduce these emissions, such as the anti-smoke belching campaign, which was launched in late 2014. This study might be used as a framework to analyze possible health risks and to assist targeted traffic management initiatives to improve urban air quality in the future. Moreover, it might be shared with local government officials to assist them in the implementation of applicable regulations, which would contribute to the reduction of air pollution.

Key Words: particulate matter; gravimetry; air pollution

1. INTRODUCTION

Air pollution is a persisting global problem that affects both the biotic and abiotic systems of the planet. A decline in the quality of air causes health problems in humans and animals, endangers agriculture and ecosystems, damages infrastructure, and reduces air visibility (Balali-Mood et al., 2016). Air pollution is caused by natural and artificial substances injected into the atmosphere called air pollutants. There are six key air pollutants (ground-level O_3, SO_2, NOx, particulate matter, CO, and lead) whose concentrations are being monitored as they influence the quality of air the most (Environmental Protection Agency, 2021). Among these six, particulate matter is accountable for some of the worst effects attributed to air pollution.

Particulate matter (PM) is a suspension of all the tiny solid and liquid particles of varying composition, shapes, and sizes in the atmosphere. It is an air pollutant composed of a complex mixture of organic and inorganic particles (Adams et al., 2015). PM of significant relevance to environmental and physical health are inhalable PM (PM_{10}) or those with diameters less than 10um. This represents the particle mass that enters the respiratory tract and is responsible for its negative health effects. Inhalable PM is further divided into the coarse ($PM_{2.5\text{-}10}$) fraction and the fine ($PM_{2.5}$) fraction. The coarse ($PM_{2.5\text{-}10}$) fraction contains particles with a diameter of 2.5-10 µm while the fine ($PM_{2.5}$) fraction contains particles with a diameter of less than 2.5 µm (Pfeiffer, 2005; Khan et al., 2010).

Particulate matter is an indicator of air pollution from different natural and human activities. It has caused 2.1 million deaths globally each year and is associated with heart disease, decreased lung function, and several respiratory diseases. Its sources may come from factories, power plants, refuse incinerators, motor vehicles, construction activity, dust and has been suggested that exposure to particulate matter may cause life-shortening (Kim, Kabir, & Kabir, 2015).

Air pollution is a common problem in industrialized cities, more so during the early development where there is extensive construction activities, increased domestic fuel burning activities, and increased vehicular and industrial emissions (Parrish, 2017). Due to city development, a jump in human and vehicle population, traffic congestion, and large-scale building activity, Quezon City (QC) is one of the most urbanized and densely inhabited cities on the eastern portion of Metro Manila. As a result, QC's air quality is far from ideal. QC is the Philippines' 8th worst city in terms of air quality index (AQI).

This study aims to assess the long-term trends in PM concentrations along Katipunan Avenue from 2001 to 2020. The PM concentration in 2020 was compared to previously available data from the IAEA/RCA Ambient Air Database for the years 2001, 2005, 2009, and 2013.

2. METHODOLOGY

2.1 Preparation of Filters

Two Nuclepore™ polycarbonate filters with pore sizes of 8 µm and 0.4 µm were used to filter out the coarse ($PM_{2.5\text{-}10}$) and fine ($PM_{2.5}$) fractions. The filters were weighed in the Mettler MT5 Analytical microbalance after being run through Americium to remove static. Following that, the filters were equilibrated for at least 24 hours in a holding chamber that maintained a constant temperature and humidity. The filters were weighed again, labeled, and kept in the holding chamber until use. Otherwise, the equilibration and weighing processes were repeated until two weights were reported with a 0.01 mg variation. The initial weight of the filter was calculated by averaging two filter weights with a 0.01 mg difference.

2.2 Sample Collection

A Gent dichotomous sampler was installed at the Manila Observatory in Ateneo de Manila University (ADMU) to collect air samples at a site that is away from any direct influence of PM sources. A Gent sampler works by drawing air using a vacuum pump into a size-selective inlet and a stacked filter unit (SFU). A double stacked filter cassette unit equipped with pre-conditioned Nuclepore polycarbonate coarse and fine filters was used to ensure the sequential separation of particles in the coarse ($PM_{2.5\text{-}10}$) fraction and fine ($PM_{2.5}$) fraction. Other parameters (i.e. hour meter, rotameter, flow meter, and vacuum gauge) were also noted for the maintenance of instrument accuracy and precision, as well as the calculation of particulate matter concentration. The sampling site and two highways near the site are shown in Fig. 1.

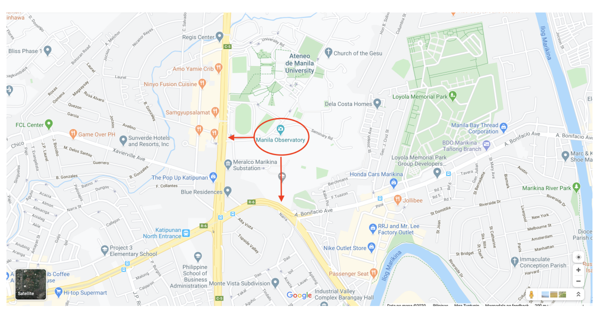

Fig. 1. Sampling site of the study (in red circle) and two highways (red arrow) nearby (adopted from Google Maps).

2.3 Particulate Matter Concentration Analysis

After sampling, the filters were collected and stored in the holding chamber for at least 24 hours of equilibration. The samples were passed through Americium and the previous step was repeated and applied.

Concentrations of two particulate matter fractions ($PM_{2.5\text{-}10}$ and $PM_{2.5}$) were determined using gravimetric methods, and statistical analysis was carried out using Microsoft Excel. In order to calculate the net sample mass, final and initial filter weights were subtracted from the total sample mass, and the PM mass concentration was calculated by dividing the net mass by the entire volume of sampled air.

3. RESULTS AND DISCUSSION

Between January and February in the years 2001, 2005, 2009, 2013, and 2020, a total of fifty-five data points were collected. The average PM_{10} and $PM_{2.5}$ concentrations measured were compared to the WHO's yearly requirements and the Philippine Clean Air Act's (RA 8749) National Ambient Air Quality Guideline Values (NAAQGV). The average $PM_{2.5}$ concentrations ranged from 20.27± 7.96 to 52.23± 31.61 μg/m³ whereas the average PM_{10} concentrations ranged from 31.7 ± 10.26 to 92.59 ± 43.22 μg/m³. All of these readings surpassed the WHO's more stringent international requirements. In the same way, almost all of the sampling years except the year 2009, does not meet the Philippine Clean Air Act's annual limit for PM_{10} while the average $PM_{2.5}$ in the years 2009 and 2020 complied accordingly. This indicates that the sample area's air quality may be hazardous to human health. $PM_{2.5}$ emissions increased from 2001 to 2005, but declined significantly in 2009, then surged again in 2013, before declining in 2020.

The national government-set limit is a more appropriate recommendation since it is based on extensive study on the country's pollutant emissions, socioeconomic status, combustion efficiency, and other criteria used in routine air quality monitoring (DENR, 2020). As seen in Table 1, the greatest average coarse fraction concentration is seen in the year 2020. Increased particle load in the coarse $PM_{2.5\text{-}10}$ fraction may be linked to increased building activity in the region as a result of the government's Build Build Build program. In January 2020, the Department of Public Works and Highway (DPWH) announced that continuing road reconstruction was taking place on highways in the vicinity, including Katipunan Avenue/C-5.

At the moment, no criteria or limits for the coarse $PM_{2.5\text{-}10}$ fraction has been defined.

Table 1. Particulate matter concentrations in January-February 2001, 2005, 2009, 2013, and 2020, along with annual air quality standards.

Year	PM_{10} Mean ± SD (μg/m³)	$PM_{2.5\text{-}10}$ Mean ± SD (μg/m³)	$PM_{2.5}$ Mean ± SD (μg/m³)
2001	78.30 ±33.46	36.50 ± 13.49	41.8 ± 21.6
2005	92.59 ± 43.22	40.36 ± 21.94	52.23 ± 31.61
2009	31.7 ± 10.26	11.43 ± 7.68	20.27 ± 7.96
2013	60.46 ± 14.77	28.19 ± 9.87	32.28 ± 7.75
2020	69.92 ± 36.42	48.26 ± 22.96	21.66 ± 12.84

WHO PM_{10} limit=15 μg/m³ ; Philippine PM_{10} limit= 60 μg/m³
WHO $PM_{2.5}$ limit= 5 μg/m³ ; Philippine $PM_{2.5}$ limit = 25 μg/m³

A time series plot was constructed to be able to visually compare daily concentrations during the aforementioned years. Day to day $PM_{2.5}$ and PM_{10} concentrations are shown in Figures 2 and 3, respectively, compared to the accepted daily values set by the WHO and the Philippine Clean Air Act of 1999.

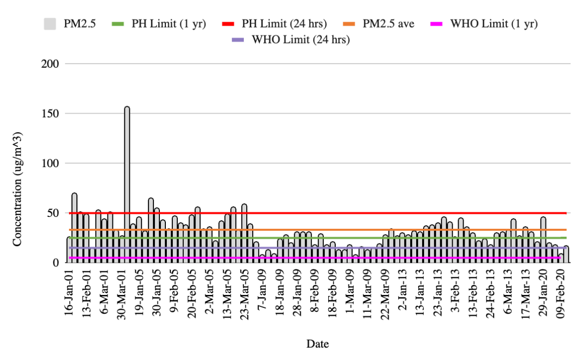

Fig. 2. Time-series plot for $PM_{2.5}$ concentrations in ADMU from 2001 to 2020.

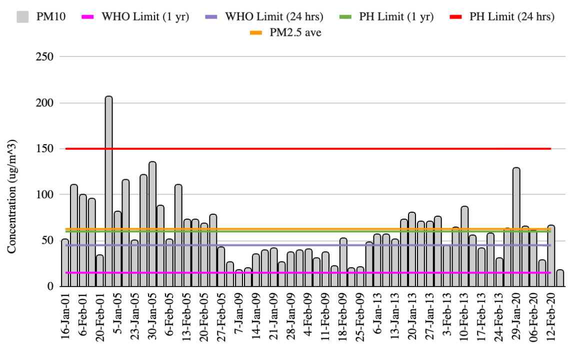

Fig. 3. Time-series plot for PM_{10} concentrations in ADMU from 2001 to 2020.

On January 2, 2005, a PM_{10} concentration of 206.71 g/m^3 was measured (see Fig. 3), exceeding both the PH Clean Air Act and WHO requirements. During this sampling date, the fine $PM_{2.5}$ fraction accounted for about 76 percent of PM_{10} emissions, or 157.1 g/m^3 (see Fig. 2). $PM_{2.5}$ levels are likely to rise during and after events involving firework displays, such as new year celebrations (Seidel & Birnbaum, 2015). This spike may be attributed to fireworks that created a toxic fog of heavy metals, particulate matter, and harmful chemicals in the atmosphere which can lead to the reduction of atmospheric visibility, and cause short-term adverse health effects (Moreno et al., 2010; Lorenzo et al., 2021). In a rather short amount of time, firework displays secrete high concentrations of $PM_{2.5}$ that remain in the atmosphere for days and can increase $PM_{2.5}$ amount by 300% (Chhabra et al., 2020; Bach, 1975). Moreover, fireworks can potentially cause wildfires and infrastructure fires leading to the destruction of property and even afflict harm to humans. Another probable event that caused this was a fire in Bocaue, Bulacan on December 31, 2004, that killed 8 people, injured 3, and destroyed 100 firework stalls and residential properties (The Manila Times, 2005).

The highest concentration of PM_{10} was recorded on January 29, 2020, at an amount of 128.7 μg/m^3 which may be due to the Taal Volcano eruption that generated a plume of ashfall that spread as far as Quezon City and Caloocan (PHIVOLCS, 2020). Previously in 2011, the eruption of Puyehue in Chile released ashes and dust that led to more than twice the monthly PM_{10} average in Montevideo, Uruguay (Balsa et al., 2016).

From the graph in Fig. 4, it can be deduced that fine $PM_{2.5}$ particles in Jan-Feb 2001, 2005, 2009, and 2013 dominated PM10. Fine PM is generally derived from anthropogenic combustion activities that produce primary and secondary pollutants while coarse PM contributions are mainly from fugitive dust from long-distance transport (Yue et al., 2010). The opposite applies for 2020 where the coarse $PM_{2.5\text{-}10}$ fraction dominates PM10, implying that combustion sources have improved compared to 2001-2013. In Tokyo, the decreasing levels of $PM_{2.5}$ were attributed to the stricter rules enforced by the government on combustion sources such as vehicular and traffic-related emissions (Hara et al., 2013).

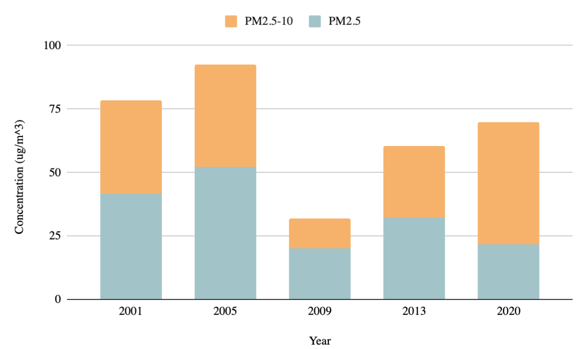

Fig. 4. Concentration Distribution of Fine ($PM_{2.5}$) and Coarse ($PM_{2.5\text{-}10}$) Particles in 2001, 2005, 2009, 2013, and 2020.

According to the 2002 National Air Quality Status Report, the construction of the MRT along Katipunan which was started in 2001 contributed to higher particulate loadings. Also, the particulate load could have been influenced by the construction of mobile phone transmission towers (DENR, 2002). Other significant contributors from anthropogenic sources were domestic and industrial activities. In 2009, more than half of PM emissions in the country were from area sources such as gasoline refilling stations, domestic household activities (DENR, 2016). There are multiple gasoline stations and residential zones near Manila Observatory which may have contributed to PM emissions. Another major PM source is vehicular emissions. There were 3.8 million registered vehicles in 2001 that significantly contributed to PM emissions in the country. Based on DENR reports, the total number of registered vehicles spiked to 6 million and further grew to 7.5 million in 2013. In contrast, a sharp decrease in all PM emissions was observed for the year 2009. A study by Yumul et al. noted that in the year 2009, the Philippines was riddled with multiple natural hazards and disasters. Luzon was characterized by too much precipitation. Another study by Magtaas et al. in 2019 reported that low PM concentrations were observed on days where it rained in the sampling area. Hence, it may be possible that a washing effect induced by too much precipitation decreased the concentration of PM around the area in 2009 (Kim et al., 2014).

4. CONCLUSIONS

Particulate matter concentrations were determined between January and February in 2001, 2005, 2009, 2013, and 2020. To assess air quality, the 2020 measurements were compared to IAEA-APAD data taken in January and February 2001, 2005, 2009, and 2013. Except for 2009, average PM_{10} levels in all sample years exceed the national government's 1999 Philippine Clean Air Act guidelines and the WHO one-year limit. In all the given sampling years, the average $PM_{2.5}$ concentration was above the WHO yearly threshold, yet the average $PM_{2.5}$ concentrations between 2009 and 2020 were deemed acceptable under the Philippine Clean Air Act.

It is recommended that a larger sample size and a longer sampling time be utilized to account for the region's diverse weather patterns, such as the Amihan and Habagat seasons. Additional analyses, such as elemental analyses and source apportionment, are required to depict the path of particulate matter sources.

5. ACKNOWLEDGMENTS

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6. REFERENCES

Adams, K., Greenbaum, D., Shaikh, R., van Erp, A., & Russell, A. (2015). Particulate matter components, sources, and health: Systematic approaches to testing effects. Journal Of The Air & Waste Management Association, 65(5), 544-558.

Bach, W., Daniels, A., Dickinson, L., Hertlein, F., Morrows, J., Margolis, S., & Dinh, V. D. (1975). Fireworks pollution and health. *International Journal of Environmental Studies*, *7*(3), 183–192.

Balali-Mood, M., Ghorani-Azam, A., & Riahi-Zanjani, B. (2016). Effects of air pollution on human health and practical measures for prevention in Iran. Journal of Research in Medical Sciences, 21(1), 65.

Balsa, A. I., Caffera, M., & Bloomfield, J. (2016). Exposures to Particulate Matter from the Eruptions of the Puyehue Volcano and Birth Outcomes in Montevideo, Uruguay. *Environmental Health Perspectives*, *124*(11), 1816–1822.

Chhabra, A., Turakhia, T., Sharma, S., Saha, S., Iyer, R., & Chauhan, P. (2020). Environmental impacts of fireworks on aerosol characteristics and radiative properties over a mega city, India. City and Environment Interactions, 7, 100049.

Criteria Air Pollutants. (2019, December 18). Retrieved February 22, 2022, from https://www.epa.gov/criteria-air-pollutants

Department of Environment and Natural Resources. (2002). *National air quality status report 2001*. Retrieved March 22, 2022, from http://air.emb.gov.ph/wp-content/uploads/2016/04/DenrAirQualityStatReport2002.pdf

Department of Environment and Natural Resources. (2016). *National air quality status report 2008-2015*. Retrieved March 22, 2002, from https://air.emb.gov.ph/wp-content/uploads/2016/04/DenrAirQualityStatReport10-11.pdf

Department of Environment and Natural Resources. (2020). Clean air program. Retrieved March 22, 2002, from https://www.denr.gov.ph/images/DENR_Accomplishment_Report/Clean_Air_Program.pdf

Environmental Protection Agency. (2021, August 16). *Criteria Air Pollutants*. EPA. Retrieved March 31, 2022, from https://www.epa.gov/criteria-air-pollutants

GMA News Online. (2006, January 1). *Major firecracker-related fire incidents*. Retrieved March 22, 2022, from https://www.gmanetwork.com/news/news/content/25169/major-firecracker-related-fire-incidents/story/

Hara, K., Homma, J., Tamura, K., Inoue, M., Karita, K., & Yano, E. (2013). Decreasing trends of suspended particulate matter and PM2.5 concentrations in Tokyo, 1990–2010. *Journal of the Air & Waste Management Association*, *63*(6), 737–748.

Kim, K.-H., Kabir, E., & Kabir, S. (2015). A review on the human health impact of airborne particulate matter. Environment International, 74, 136–143.

Khan, M. F., Shirasuna, Y., Hirano, K., & Masunaga, S. (2010). Characterization of PM2.5, PM2.5–10 and PM>10 in ambient air, Yokohama, Japan. *Atmospheric Research*, *96*(1), 159–172.

Lorenzo, G. R., Bañaga, P. A., Cambaliza, M. O., Cruz, M. T., AzadiAghdam, M., Arellano, A., Betito, G., Braun, R., Corral, A. F., Dadashazar, H., Edwards, E. L., Eloranta, E., Holz, R., Leung, G., Ma, L., MacDonald, A. B., Reid, J. S., Simpas, J. B., Stahl, C., Sorooshian, A. (2021). Measurement report: Firework impacts on air quality in Metro Manila, Philippines, during the 2019 New Year revelry. Atmospheric Chemistry and Physics, 21(8), 6155–6173.

Magtaas, R. A., Tuso, C. A., Punzalan, J., Yee, J. R., Bautista VII, A., & Pabroa, P. C. (2019). Air particulate matter, black carbon, and elemental concentrations and source apportionment in Calaca, Batangas. *Philippine Journal of Science*, *149*(S1), 117–127.

Moreno, T., Querol, X., Alastuey, A., Amato, F., Pey, J., Pandolfi, M., Gibbons, W. (2010). Effect of fireworks events on urban background trace metal aerosol concentrations: Is the cocktail worth the show? *Journal of Hazardous Materials*, *183*(1–3), 945–949.

Parrish, D. D. (2017). Urbanization and air pollution: Then and now. Retrieved March 20, 2022, from https://eos.org/features/urbanization-air-pollution-now

Pfeiffer, R. L. (2005). Sampling for PM10 and PM2.5 Particulates. Publications from USDA-ARS / UNL Faculty, 227-245. Retrieved March 20, 2022, from http://digitalcommons.unl.edu/usdaarsfacpub/1393

PHIVOLCS. (2020). Taal Volcano Bulletin. Retrieved March 20, 2022, from https://www.phivolcs.dost.gov.ph/index.php/taal-volcano-bulletin-menu/9698-taal-volcano-bulletin-26-january-2020-8-00-am-4

Seidel, D. J., & Birnbaum, A. N. (2015). Effects of Independence Day fireworks on atmospheric concentrations of fine particulate matter in the United States. *Atmospheric Environment*, *115*, 192–198.

The Manila Times. (2005, January 2). 8 killed as blast starts fire in Bocaue fireworks stores. https://www.manilatimes.net/2005/01/02/news/regions/8-killed-as-blast-starts-fire-in-bocaue-fireworks-stores/699168

Yan, B., Kennedy, D., Miller, R. L., Cowin, J. P., Jung, K., Perzanowski, M., Chillrud, S. N. (2011). Validating a nondestructive optical method for apportioning colored particulate matter into black carbon and additional components. Atmospheric Environment, 45(39), 7478–7486.

Yue, D. L., Hu, M., Wu, Z. J., Guo, S., Wen, M. T., Nowak, A., Zhang, Y. H. (2010). Variation of particle number size distributions and chemical compositions at the urban and downwind regional sites in the Pearl River Delta during summertime pollution episodes. *Atmospheric Chemistry and Physics*, *10*(19), 9431–9439.

Yumul, G. P., Dimalanta, C. B., Servando, N. T., & Cruz, N. A. (2013). Abnormal weather events in 2009, increased precipitation and disastrous impacts in the Philippines. *Climatic Change*, *118*(3–4), 715–727.