# Assessment of air quality using portable sensors in Tokyo metro stations and underground mall

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**KEY WORDS:** air quality, portable sensor, train arrival, train departure

**ABSTRACT:** 91% of the world's population lives in areas where air quality exceeds WHO standards. Indoor air pollution, in particular, household air pollution causes 3.8 million deaths globally according to the World Health Organization. Household pollution is due to incomplete burning of fuels used for cooking and heating the room. Indoor pollution is not just limited to household exposure; it also includes transport systems, offices, factories, malls and other buildings. It seems like the subway system is free from any emission as it is powered by electricity, but it can even have more particulate matter as compared to ambient air. Also, though commuters spend a short time at metro stations, if the level of particulate matter (especially $PM_{2.5}$) is high, it can be harmful to human health. According to the Tokyo Metro Association, there were around 26.5 million daily commute trips (average in the year 2016). Air quality on the platform can vary on a variety of factors such as whether the station is above the ground or below the ground, ambient air quality, train frequency, no. of commuters, ventilation in the platform, braking system of the train, structure of the tunnel (if it is underground), material of current supplying wires and collectors attached to the train. Also, the air quality in the underground malls is affected by the ventilation system, activity in the mall/shop, no. of visitors, ambient air quality. It can be possible that the indoor (i.e. the metro stations and underground malls) may have more particulate matter as compared to outside environment where there are lots of vehicles, restaurants and factories contributing towards the air pollution. The objective of my research is to examine the air quality ($PM_{2.5}$) within the platforms at several points and compare these values with the air quality inside the trains and outside the platforms. Also, I would analyze the air quality in underground malls. Portable sensors are used to detect the value of $PM_{2.5}$ and $PM_{10}$ inside the trains, on platforms, underground malls and for ambient air quality.

## 1. INTRODUCTION

Metro systems or trains are one the major means of transport systems in today's world. Tokyo Metro has been operational since December 30, 1927 (Tokyo Metro) and is used by many people in their day to day lives. The subway, being an electrical system and one of the cleanest public transport systems in large urban agglomerations, is the most appropriate public transport since it diverts the burdens of superficial traffic congestion(Martins,2015). But, since it is used by a major part of the population in Tokyo, it is necessary to confirm whether the air inside the subway stations and platforms is within permissible limits. In this study, PM values are measured at six lines at the Shibuya Station, which is one of the major subway stations in Tokyo.
In some researches (Martins, 2016), it was observed that higher particulate matter concentration at train edges and in the areas closer to commuters' access to the platforms (near escalators, elevators and stairs). So, there is a need to check the PM values at different parts of the platform and see the effect of train arrival and train departure on PM values at those positions. Washing the tracks and walls can reduce the concentration of particulate matter as observed by Johansson, C, 2002 in Stockholm subway system.

Also, there is development of malls around big subway stations, as large number of people use these stations and are likely to go these malls for shopping. Some of these malls are developed within the station, whereas some others are nearby to it.

The objective of this study is to study the effect of train arrival and train departure on PM value at different positions on the platform. Also, comparing the PM values at various lines at the same station (underground and above the ground).

## 2. METHODOLOGY

### 2.1 Study Area

The data for particulate matter was collected using portable sensors in both malls, subway station and platforms. Since, in the underground it is difficult to detect GPS or it may be inaccurate, hence, the sources and explanations

were noted down at the time of data collection.
For malls two buildings were selected near Shibuya Station, and air quality was measured at the basement floors and on above the ground floors as well
For stations, readings were taken at 6 lines at different positions on the platform, and timings of train arrival and departure were noted down as well. Also, data was collected inside the station (on the way to platform).

### 2.2 Data Collection Methods

The particulate matter readings were taken on both weekday and weekend for in total six lines at Shibuya Station. Out of these six lines, four of these lines were underground and two among them were above the ground. Line 1 and Line 2 are above the ground, Line 3 and Line 4 are at the level of basement 3, and Line 4 and Line 5 are at the level of Basement 5.
Abbreviations have been used for train arrival and train departure. Train arrival and train departure, on the platform where data have recorded has been abbreviated as TAN (Train Arrival Near) and TDN (Train Departure Far). Furthermore, there can be more platforms in the same tunnel (same environment), train arrival and train departure on those platforms has been abbreviated as TAF (Train Arrival Far) and TDF (Train Departure Far) and effect of those have also been observed at the point of observation.

## 3. RESULTS

### 3.1 Inside Underground Malls

The readings in both the malls were within the permissible limits. Furthermore, in one mall the average values of $PM_{2.5}$ and $PM_{10}$ were less than 10. In the other mall the average value of $PM_{2.5}$ and $PM_{10}$ was 24 and 27 respectively, with not much variation during its observation.

### 3.2 Inside Metro Stations

Line 1 has five cars. So, the readings were taken at 3 positions along the platform, two at the ends and one in the middle as shown in Fig. 11. Also, there are two platforms for Line 1, and the readings were taken at Platform 2. The following readings are taken on a weekday (Fig. 1) and weekend (Fig. 2).

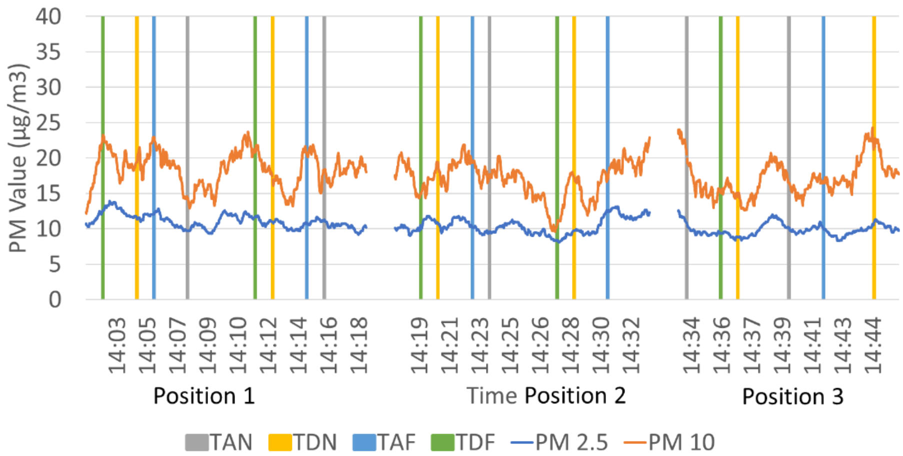


Fig. 1 Concentration profiles of $PM_{2.5}$ and $PM_{10}$ on different positions on Line 1 on a weekday [Sampling date 15$^{th}$ August 2019] (TAN: Train Arrival Near, TDN: Train Departure Far, TAF: Train Arrival Far and TDF: Train Departure Far)

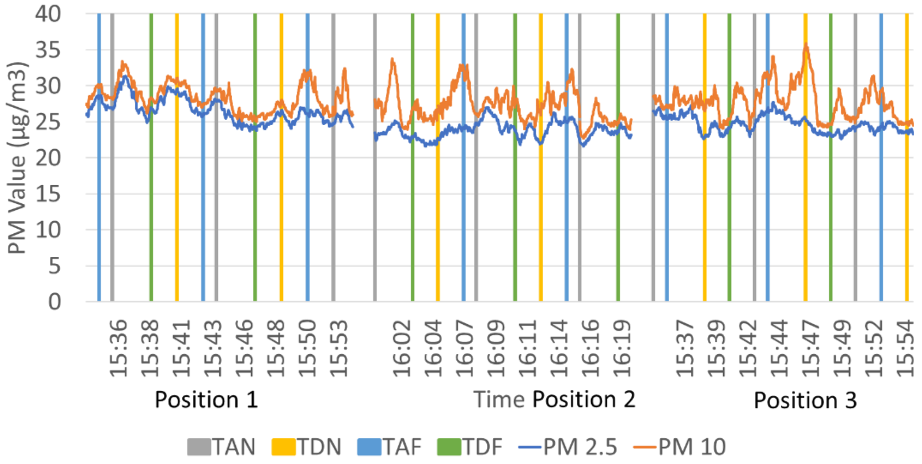


Fig. 2 Concentration profiles of $PM_{2.5}$ and $PM_{10}$ on different positions on Line 1 on a weekend [Sampling date 17th August 2019]

Line 2 has six cars. So, the readings were taken at 3 positions along the platform, two at the ends and one in the middle as shown in Fig. 12. The following readings are taken on a weekday (Fig. 3) and weekend (Fig. 4)

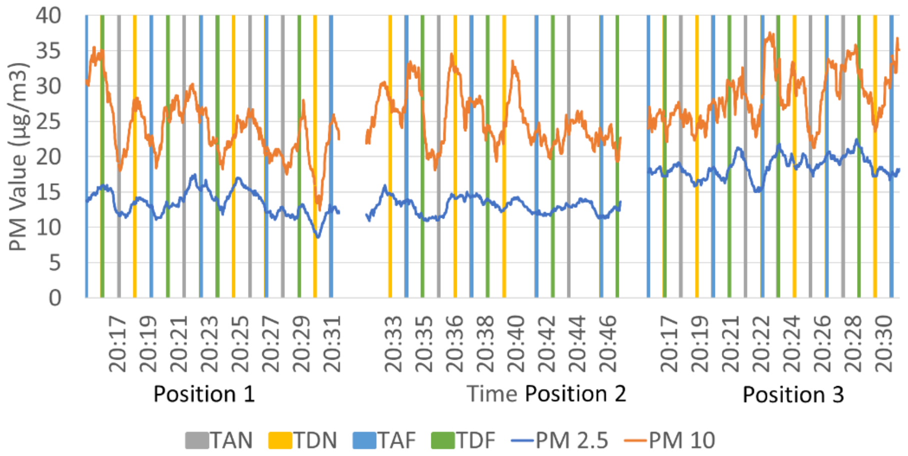


Fig. 3 Concentration profiles of $PM_{2.5}$ and $PM_{10}$ on different positions on Line 2 on a weekday [Sampling date 15th August 2019]

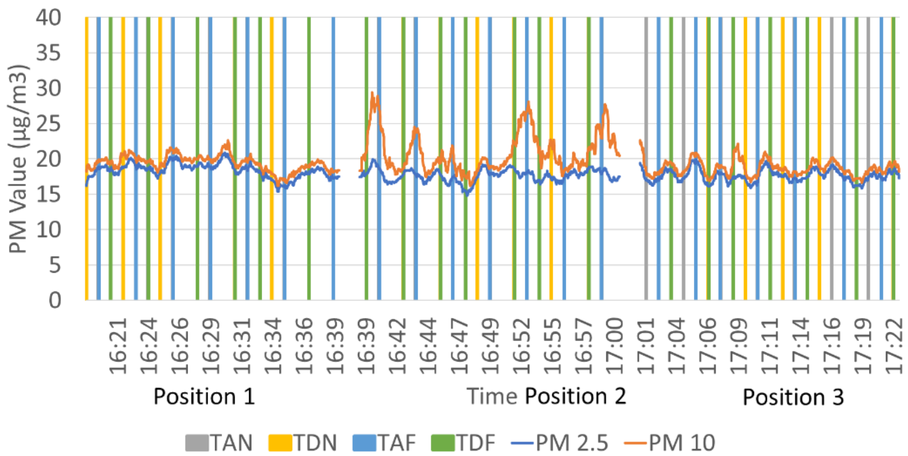


Fig. 4 Concentration profiles of $PM_{2.5}$ and $PM_{10}$ on different positions on Line 2 on a weekend [Sampling date 18th August 2019]

Line 3 and Line 4 are in front of each other, they are at basement level 3 (there are only Line 3 and Line 4 in that tunnel), and in one direction it is Line 3 and in opposite direction it is Line 4, and there is one platform for each line at Shibuya Station. Both the lines have the capacity of 10 cars, so the readings are taken at 4 positions, 2 at the end and 2 in the middle. Also, since both the lines are in the same tunnel and there are only two rail lines, one for each, out of those 4 locations two are at line 3 and two are at line 4. Position 1(at the end) and Position 2 (3 cars away from position 1) are at Line 3. Position 3 (3 cars away from Position 2)  and Position 4 (at the other end of the platform) are at Line 4 (Fig. 13). The following readings are taken on a weekday (Fig. 5) and weekend (Fig. 6)

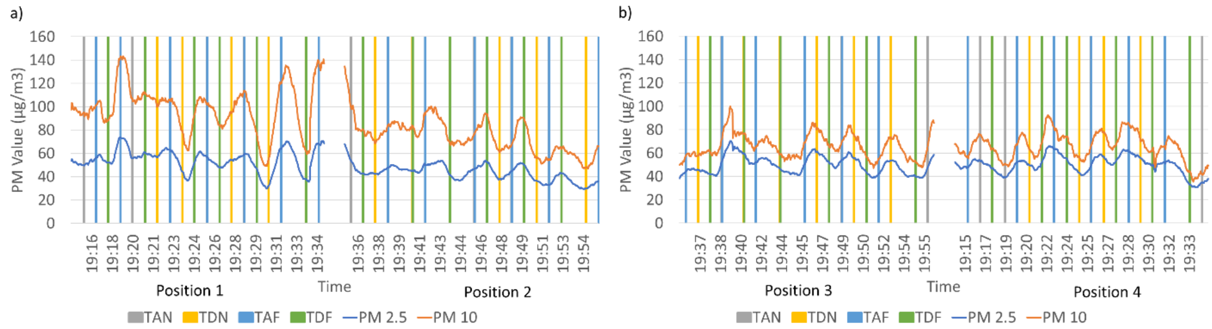


Fig. 5 Concentration profiles of $PM_{2.5}$ and $PM_{10}$ on different positions on Line 3 and Line 4 on a weekday [Sampling date 15th August 2019]

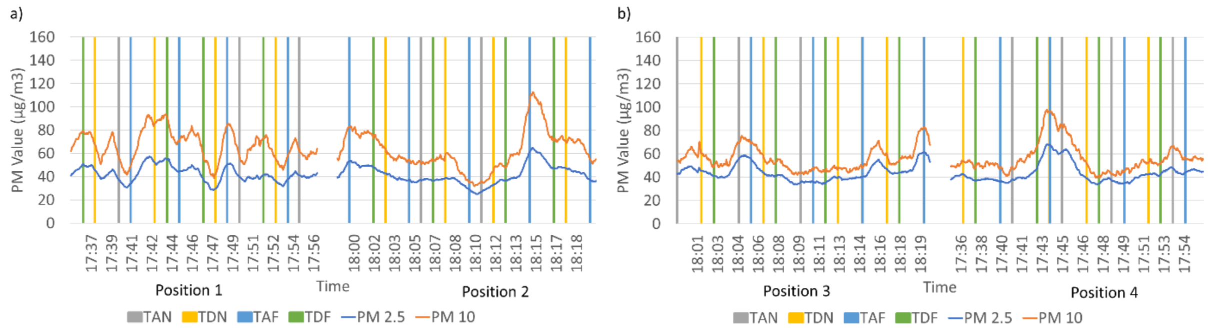


Fig. 6 Concentration profiles of $PM_{2.5}$ and $PM_{10}$ on different positions on Line 3 and Line 4 on a weekend [Sampling date 18$^{th}$ August 2019]

Line 5 and Line 6 are at basement level 5. There are two rail lines for each line, adjacent to each other, so there are a total of 4 rail lines in that tunnel (two lines of Line 5 and two lines of Line 6). Both the lines have the capacity of 10 cars, so the readings are taken at 4 positions at each line, 2 at the end and 2 in the middle. It was observed that that train running farthest from the point of observation also have the effect on PM value, hence all the timings of train arrival and train departure of other three platforms were noted down as well to see their effect on PM value. Position 1 and Position 4 are in the corner, and Position 2 and Position 3 are in the middle. Also, since each line has two platforms, two readings were taken at each of these platform (Fig. 14). The following readings are taken on a weekday (Fig. 7) and weekend (Fig. 8) for Line 5. For Line 6 weekday is represented by Fig. 9 and weekend is represented by Fig. 10.

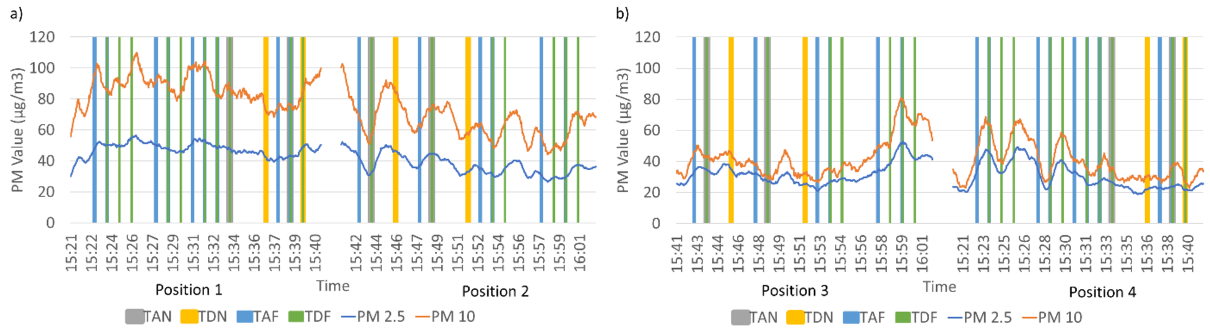


Fig. 7 Concentration profiles of $PM_{2.5}$ and $PM_{10}$ on different positions on Line 5 on a weekday [Sampling date 15th August 2019]

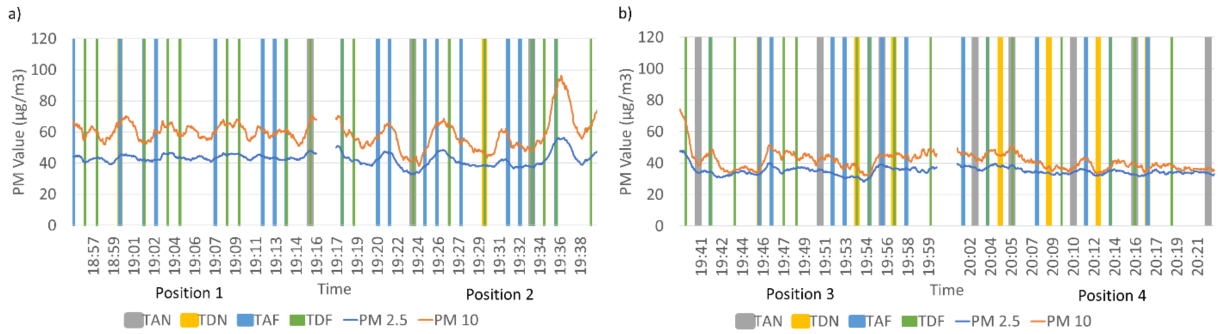


Fig. 8 Concentration profiles of $PM_{2.5}$ and $PM_{10}$ on different positions on Line 5 on a weekend [Sampling date 17th August 2019]

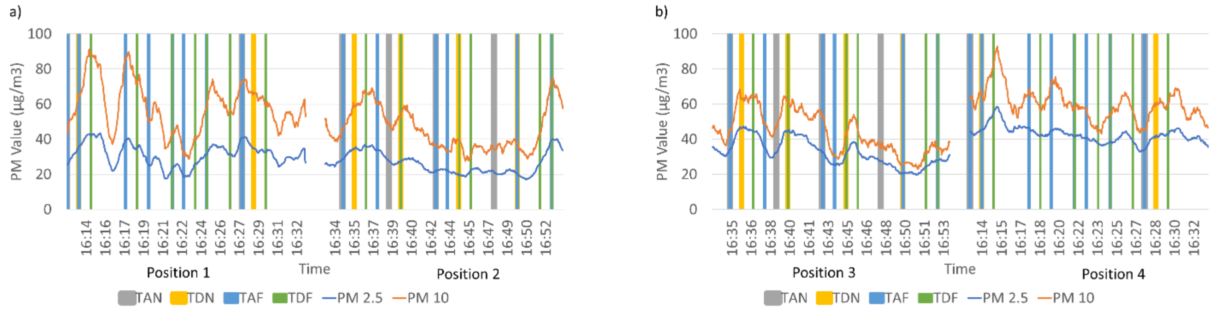


Fig. 9 Concentration profiles of $PM_{2.5}$ and $PM_{10}$ on different positions on Line 6 on a weekday [Sampling date 15th August 2019]

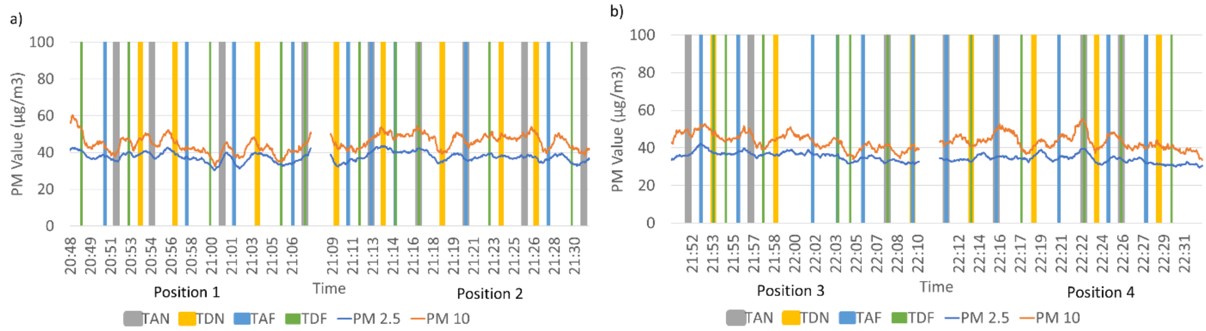


Fig. 10 Concentration profiles of $PM_{2.5}$ and $PM_{10}$ on different positions on Line 6 on a weekend [Sampling date 17th August 2019]

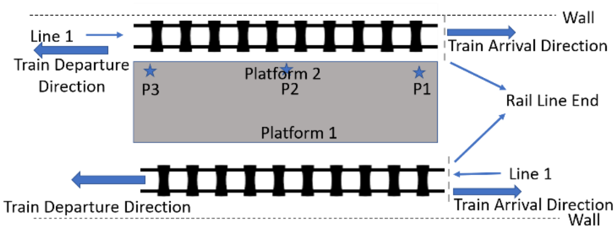


Fig. 11 Plan View for Line 1

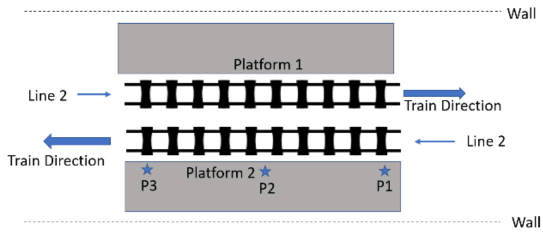


Fig. 12 Plan View for Line 2

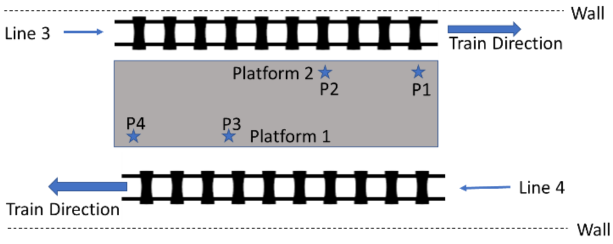


Fig. 13 Plan View for Line 3 and Line 4

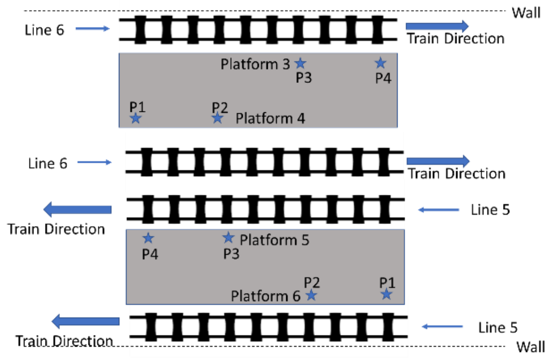


Fig. 14 Plan View for Line 5 and Line 6

## 4. DISCUSSION

It can be seen from Fig. 1 to Fig. 10, that in underground lines (Line 3, 4, 5 and 6) have more particulate matter as compared to the ones above the ground (Line 1 and 2).
In Line 1, it was observed that even though $PM_{2.5}$ and $PM_{10}$ values were less than 25 and 50 for both weekday and weekend, but on the weekend the values were higher as compared to that on weekday. The readings were taken in the afternoon, and Line 1 is usually crowded in the morning and evening due to daily commutation by office workers. In Line 2, the values were almost the same for weekday and weekend. For Line 3 and Line 4, the average value for PM values decreased for the weekend. For Line 5, the values were almost the same for weekday and weekend. For Line 6, there was no common observation, for some position PM values were higher on weekend while on some others it was higher for weekday.
It is obvious from the Fig. 1 to Fig. 10, that train arrival and train departure have a major impact on PM on the platforms. Also, the train arrival and departures at far away platforms have a major role in peaks of PM value as compared to the near ones. This can be explained by the train piston effect, even though this effect helps to reduce the PM value in the air inside the station as when train enters the tunnel it drags the air to flow with due to fluid viscosity, and drags in fresh air from the other end (if a ventilation is provided at the other end), so eventually, on the train arrival time, at the train exit point (where the train leaves the platform) it accumulates the PM at that end. It is explained by Moreno T, 2014 in Barcelona subway system.
For instance, in Line 1, at position 1 on a weekday [Fig. 1], the peak value if 23.2 µg/m3 for $PM_{10}$ whereas the average value at that position is 18.4 µg/m3. Also, there are more peaks at or near train arrival and departures. There is a similar observation for Line 2. At position 1 on Line 3 on a weekday [Fig. 5(a)] the value for $PM_{10}$ reaches up to 142.8 µg/m3 due to arrival at the other platform and at the same location the average value is 99.4 µg/m3. Similarly, for Line 5 the peak at position 1 due train departure at other far platform is 107.3 whereas the average is 86.4. Moreover, at Line 6 at positions 1 and 4, the peak is observed at 91.7 due to train departure at other platform whereas the average value is around 60 for both. It is difficult to explain train piston effect at other platforms is more prominent as compared to ones at the same platform.
It can be noted that on above ground rail lines (Line 1 and Line 2), there is very less difference at various positions on the platform (position 1,2 and 3). This is because train piston effect is prominent in closed tunnels. However, the underground rail lines (Line 3,4 and 5), there is some difference at various positions, especially it is higher at position 1 (which is train exit point for Line 3,4 and 5) as compared to other positions. Moreover, on Line 6, it almost same at all the positions, it was observed that the platforms have air conditioners on the platform unlike any other line.
According to WHO guidelines (WHO Air Quality Guideline Values), the concentration of Fine Particulate Matter ($PM_{2.5}$) should be less than 25 $\mu g/m^3$ for 24 hour mean and the concentration of Coarse Particulate Matter ($PM_{10}$) should be less than 50 $\mu g/m^3$ for 24 hour mean. So, according to these guidelines Line 1 and 2 are within the limit (assuming the 24 hour mean for these lines would be average value for period of observation). However, Line 3 and 4 are not within the permissible limits. Moreover, in Line 5, Position 1 and 2 are above the allowable limits, interestingly, position 3 and position 4 are slightly above this threshold. Also, Line 6 is slightly above the permissible limits. Even though Line 5 and Line 6 are in the same tunnel but there is difference in the PM values in these two lines, as Line 6 platforms (i.e. Platform 3 and 4; Fig. 14) have air conditioners on the platform. Since, Line 5 and Line 6 are in a wider tunnel (has 4 platforms) as compared to Line 3 and Line 4 which are in narrower tunnel (has two platforms), the air quality is better for Line 5 and 6 as compared to Line 3 and 4 (Moreno T, 2014).
The least count of train arrival and train departure time is 1 minute, which is not very accurate, had it been more precise it would have given better interpretation about its effect on PM values. However, it was noted when the train's door opens (the air inside in the train has less PM values as compared to platform in the beginning), there is

a exchange of air inside the train and at the platform. It was observed that PM value of the air inside the air increases gradually and the PM value on the platform decreases gradually.
One more observation was that difference in the $PM_{10}$ and $PM_{2.5}$ values was large at the peaks of $PM_{10}$ and very less during the depression (local minima), which at this point of time cannot be explained.
The readings were taken on all the three days (i.e. 15$^{th}$, 17$^{th}$ and 18$^{th}$ August) inside the station(on the way to platform), and it was observed both $PM_{2.5}$ and $PM_{10}$ were within the permissible limits except on 17$^{th}$ August, the average value $PM_{2.5}$(for 15 minutes) was 35 which is higher than the permissible value.

## 5. CONCLUSION

It can be summarized from the above findings that the above the ground train lines have better air quality as compared to underground train lines, due to better exchange of air with the environment. In a tunnel, the PM values vary laterally along the platform due to train piston effect. However, it also depends on various other factors such as the train speed and frequency, wheel materials and braking mechanisms, station depth and design (Querol, X, 2012), ( Xu, B, 2017) which were difficult to examine at this point of time.

## 6. REFERENCES


Johansson, C. & Johansson, P. Å. Particulate matter in the underground of Stockholm. Adv. Air Pollut. 11, 541–549 (2002).

Martins, V. et al. Exposure to airborne particulate matter in the subway system. Sci. Total Environ. (2015). doi:10.1016/j.scitotenv.2014.12.013

Martins, V. et al. Factors controlling air quality in different European subway systems. Environ. Res. 146, 35–46 (2016).

Moreno, T. *et al.* Subway platform air quality.Assessing the influences of tunnel ventilation, train piston effect and station design. *Atmos. Environ.* **92**, 461–468 (2014).

Querol, X. *et al.* Variability of levels and composition of PM 10 and PM 2.5 in the Barcelona metro system. *Atmos. Chem. Phys.* **12**, 5055–5076 (2012).

Tokyo Metro History, Tokyo Metro Corporation https://www.tokyometro.jp/lang_en/corporate/profile/history/index.html

World Health Organisation Air Quality Guideline Values for Particulate Matter https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

Xu, B. & Hao, J. Air quality inside subway metro indoor environment worldwide: A review. Environ. Int. 107, 33–46 (2017).