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# Spatial distribution of particulate matter ($PM_{10}$ and $PM_{2.5}$) in Seoul Metropolitan Subway stations

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**Abstract**

The aims of this study are to examine the concentrations of $PM_{10}$ and $PM_{2.5}$ in areas within the Seoul Metropolitan Subway network and to provide fundamental data in order to protect respiratory health of subway workers and passengers from air pollutants. A total of 22 subway stations located on lines 1–4 were selected based on subway official's guidance. At these stations both subway worker areas (station offices, rest areas, ticket offices and driver compartments) and passengers areas (station precincts, subway carriages and platforms) were the sites used for measuring the levels of PM. The mean concentrations of $PM_{10}$ and $PM_{2.5}$ were relatively higher on platforms, inside subway carriages and in driver compartments than in the other areas monitored. The levels of $PM_{10}$ and $PM_{2.5}$ for station precincts and platforms exceeded the 24-h acceptable threshold limits of 150 $\mu g/m^3$ for $PM_{10}$ and 35 $\mu g/m^3$ for $PM_{2.5}$, which are regulated by the U.S. Environmental Protection Agency (EPA). However, levels measured in station and ticket offices fell below the respective threshold. The mean $PM_{10}$ and $PM_{2.5}$ concentrations on platforms located underground were significantly higher than those at ground level ($p < 0.05$).


*Keywords:* Seoul; Subway; PM; Underground; Ground level

## 1. Introduction

In modern times, a city's quantitative expansion and its corresponding traffic congestion have been the main reasons for encouraging people to use the local subway. However, in the Seoul Metropolitan Subway System, there is the concern that various types of hazardous pollutants remain accumulated indoors due to the deterioration of ventilation systems particularly on lines 1–4 which were constructed more than 10 years ago. As a large number of Seoul citizens use the subway everyday, constant exposure to such pollutants presents a health risk both for passengers and subway workers. Moreover, public concern about indoor air quality has notably increased [1].

Field research measuring and assessing the levels of PM accumulating inside subway networks has been carried out in cities throughout the world such as New York, USA [2], London, England [3], Berlin, Germany [4], Stockholm, Sweden [5], Helsinki, Finland [6], Tokyo, Japan [7], Mexico City, Mexico [8], Guangzhou, China [9] and Hong Kong [10]. However, there has never been any field research measuring the level of PM in any of the Korean cities that have a subway system. Since it has been reported that exposure to PM can cause respiratory disorders like asthma, rhinitis and bronchitis in specially sensitive people [11], there is an urgent need for field research to be performed in the Seoul subway system in order to establish a management plan against exposure to PM.

Therefore, this research investigated the pollution levels of PM that accumulates inside the subway network within high activity areas of both underground and ground level stations i.e. in station and ticket offices, worker rest areas, platforms, driver compartments and inside subway carriages. The aim of this research is to provide fundamental research data which can be used to minimize the health risks posed to subway passengers and subway workers.

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## 2. Materials and method

### 2.1. Study area selection

This research was performed from November 2004 to February 2005 at 22 stations within Seoul Metropolitan Subway System on lines 1–4. These lines are the oldest ones representing the phase 1 of Seoul's subway construction plan. After consulting a subway official's opinion, 22 stations were selected because of their higher proportion of passengers and workers than other subway stations. Out of these stations, 8 were ground level stations and 14 were underground. For each station, measurements were carried out at subway worker main activity areas (station offices, rest areas, ticket offices and driver compartments) and passenger main movement areas (station precincts, platforms and passenger carriages). To carry out a comparison assessment of subway indoor pollution levels, an outdoor location 1 m away from each subway station was additionally investigated on the same day of each measurement. The selected site was 1.5 m above ground level and for the study period each site was monitored for 24 h twice. The 24-h average value obtained from duplicate monitoring was considered as the representative level.

### 2.2. Measurement

A device for monitoring PM was the direct-reading measuring instrument (Dustmate, Turnkey Instruments, Northwich, England). Its principle is to utilize a light scattering technique in order to determine the concentration of particulate matter. It was calibrated and operated for 20 min prior to field monitoring to stabilize the instrument.

### 2.3. Data analysis

By using an SAS package (SAS/Stat 9.1, SAS Institute, Cary, USA), the Shapiro–Wilk statistical test was applied to evaluate data normality. After it was demonstrated by this test that obtained data did not follow a normal distribution, the geometric mean (GM) and the geometric standard deviation (GSD) were employed to characterize the log-normally distributed data. The ANOVA and Duncan's multiple comparison analysis methods were applied for significantly demonstrating the difference in PM concentration levels between each monitored site corresponding to worker and passenger activity area. The concentration difference between a ground level station and an underground station was analyzed for its statistical significance with Student's *t*-test.

## 3. Results and discussion

### 3.1. Concentration distribution of $PM_{10}$ and $PM_{2.5}$ in areas of a subway station

Results for subway worker activity areas, as indicated in Table 1, show the geometric mean concentrations of the logarithmically transformed $PM_{10}$ and $PM_{2.5}$ data for station offices as 75.1 and 56.7 μg/m$^3$, respectively, for rest areas as 84.4 and 65.6 μg/m$^3$, for ticket offices as 93.2 and 65.0 μg/m$^3$, and for driver compartments as 271.2 and 127.8 μg/m$^3$. These results showed that the highest concentration levels were observed in the driver compartments ($p < 0.05$) and that the other three analyzed locations were not statistically different to each other ($p > 0.05$). The mean concentrations of $PM_{10}$ and $PM_{2.5}$ taken at the outdoor sites were measured to be 154.5 and 102.1 μg/m$^3$, respectively, which shows that concentrations of $PM_{10}$ and $PM_{2.5}$ in three

Table 1
Distribution of $PM_{10}$ and $PM_{2.5}$ in subway station areas

| | $PM_{10}$ (μg/m$^3$) | | | $PM_{2.5}$ (μg/m$^3$) | | |
|---|---|---|---|---|---|---|
| | [*]GM | [†]GSD | Range | GM | GSD | Range |
| Worker activity areas | | | | | | |
| Station office | 75.1[a] | 33.3 | 38.2–146.3 | 56.7[a] | 45.4 | 29.2–120.9 |
| Bedroom | 84.4[a] | 56.9 | 36.2–293.3 | 65.6[a] | 33.7 | 26.7–160.4 |
| Ticket office | 93.2[a] | 38.9 | 40.7–167.3 | 65.0[a] | 31.9 | 38.7–138.9 |
| Driver's seat | 271.2[b] | 105.5 | 185.9–425.3 | 127.8[b] | 51.9 | 79.3–184.8 |
| Passenger activity areas | | | | | | |
| Station precinct | 182.1[a] | 97.2 | 122.6–310.1 | 87.7[a] | 39.0 | 48.9–126.8 |
| Passenger carriage | 311.5[b] | 26.6 | 28.68–356.1 | 125.5[b] | 14.5 | 115.2–135.7 |
| Platform | 359.0[b] | 171.3 | 237.8–480.1 | 129.0[b] | 67.0 | 81.6–176.3 |
| Outdoor | 154.5 | 55.0 | 78.6–253.5 | 102.1 | 43.7 | 41.3–174.2 |
| | 150.0 | | | 35.0 | | |
| Standard | U.S. EPA[c]; outdoors | | | U.S. EPA[c]; outdoors | | |
| | Korea[c]; indoors | | | | | |

[a] Averaged values within the column by the same letter are not significantly different.
[b] Averaged values within the column by the same letter are not significantly different.
[c] Geometric means marked by the same letter within the column are not significantly different.
[*] GM, geometric mean.
[†] GSD, geometric standard deviation.

of the four worker related areas were lower than their correspondent outdoor values. Driver compartment was the only area displaying levels higher than those observed outside.

Apart from the concentration of $PM_{10}$ measured in driver compartments, PM concentration levels in all other subway worker areas fell below the indoor environment standard of Korea (150 $\mu g/m^3$). With respect to $PM_{2.5}$, there is no currently an indoor regulation in Korea as well as in other countries. On the other hand, the indoor value obtained from this study cannot be directly compared with the U.S. Environmental Protection Agency (EPA)'s regulation standard of $PM_{2.5}$ because the EPA's regulation standard is based on the arithmetic average values of the original outdoor concentration data. The indoor concentration levels of $PM_{2.5}$ for station offices, rest areas and ticket offices, however, were generally below or similar to the EPA' regulation standard of $PM_{2.5}$ (35 $\mu g/m^3$). For driver compartments, however, both concentrations of $PM_{10}$ and $PM_{2.5}$ were higher than their respective national or EPA regulation standards. Considering the fact that most particulate pollutants distributed within areas of subway operation are derived from metallic PM, like airborne heavy metals which are dispersed into air by the friction between the moving subway train motion and railway line [2,12,13], preventive measures such as a more efficient ventilation system would be needed to decrease the exposure level of subway operation workers in the near future. Preventative measures would correspond to periodic examination of the railway condition, observation of operation procedures to avoid hastily starting and braking, compulsory wearing of protective equipment during operation and so forth.

For passenger related areas (station precincts, passenger carriages and platforms), the lowest values of $PM_{10}$ and $PM_{2.5}$, which by the way were statistically significant ($p < 0.05$), occurred on the station precincts. There was no significant difference in any of the PM fractions between the correspondent passenger carriages and platforms ($p > 0.05$). The mean concentrations of $PM_{10}$ and $PM_{2.5}$ for station precincts were 182.1 and 87.7 $\mu g/m^3$, respectively. Passenger carriages had $PM_{10}$ and $PM_{2.5}$ concentration levels at 311.5 and 125.5 $\mu g/m^3$, respectively. Finally, the PM concentration levels on platforms were 359.0 $\mu g/m^3$ for $PM_{10}$ and 129.0 $\mu g/m^3$ for $PM_{2.5}$. $PM_{10}$ concentration levels at all three points in the passenger activity areas were shown to be higher than the outdoor mean concentration (154.5 $\mu g/m^3$), while $PM_{2.5}$ in the passenger carriages and on platform areas was found to be higher than its respective outdoor mean concentration levels. Station precincts had levels lower than the outdoor mean values (102.1 $\mu g/m^3$).

Exposure levels to particulate pollutants in passenger activity areas were found to be higher than all worker areas with the exception of the driver compartments area. If we compare these results with previous foreign studies measuring the concentrations of particulate pollutants on subway platforms and passenger carriages, there is a remarkable variation among respective results. This could be explained by differences in the monitoring conditions at each measurement point, such as measurement time, place, equipment, and the year of construction of each subway among other conditions. Also the influence of seasonal and outer climactic conditions cannot be excluded. Research by Furuya et al. [7], reported that the concentration of PM pollutants vary greatly according to the season. Excluding the concentration value of $PM_{2.5}$ in the station precincts, all other concentration levels were found to be 1.2–2.3 times higher than the corresponding foreign research results which reported higher concentration levels of PM pollutants in passenger carriages and platforms than outdoor concentration levels [14]. Among platforms, passenger carriages and driver compartments considered as subway operation space, the concentration of PM pollutants was highest on the platforms. This could be explained by the natural ventilation process that takes place during subway operations in which passenger carriage and driver compartment PM concentration levels are diluted because ventilation inside a moving subway train is relatively higher than that of a platform.

Taking both worker and passenger areas into consideration, the concentration of PM was relatively higher on platforms, in passenger carriages and in driver compartments, all of which are part of the subway operation space. It has been concluded that the main cause of PM production is related to the dispersion into the air of inorganic metallic dust which is a result of the deterioration of the subway station's internal facilities as well as the friction between the railway line and the train wheels during normal operation.

Sitzman et al. [15], who researched exposure to $PM_{10}$ of motorcycle riders and a subway passengers, reported that the exposure level to $PM_{10}$ of a passenger is lower than that of a motorcycle rider in terms of numbers, but higher in terms of mass; so that in the subway's internal space, PM is larger in size than those on the ground, while the ground has relatively higher levels of PM concentration. Such a large-sized PM is thought to contain heavy metal substances like iron, dispersed into the air by the friction between the subway train and the railway during operation. Based on the findings of Chan et al. [10] that most car exhaust flows into subway tunnels by air streams, it is assumed that the small-sized PM distributed in the subway's internal space is derived from car exhaust.

### *3.2. Comparison of the concentrations of indoor PM monitored in an underground and a ground level subway station*

Fig. 1 shows the comparison of the indoor mass concentrations of $PM_{10}$ and $PM_{2.5}$ for station precincts, platforms, station offices and ticket offices which were measured at 12 underground station areas and 10 ground level station areas. Although main results show that ground level station areas have higher PM concentrations than underground ones (except in the case of the platform area), there was not a significant statistical difference between them ($p > 0.05$). However, the concentration levels of $PM_{10}$ and $PM_{2.5}$ on the platform area were higher on the underground station areas than on the ground level ones. In this case there was a significant statistical difference between both results ($p < 0.05$).

From the results of this research, the concentration of particulate pollutants in subway areas showed a dramatic difference between a ground level platform area and an underground

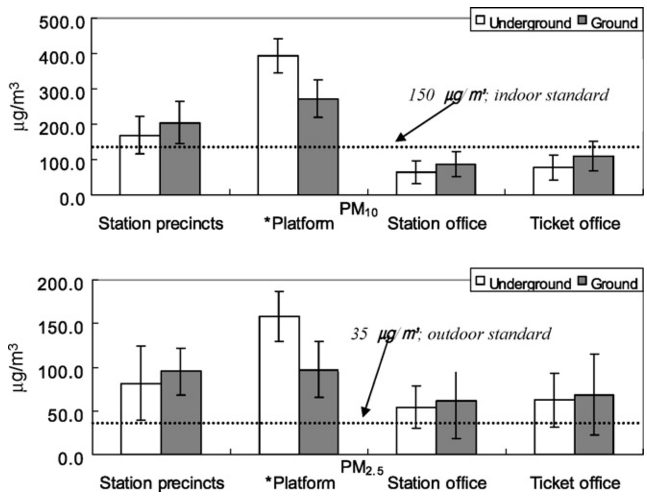


Fig. 1. Comparison of concentrations of $PM_{10}$ and $PM_{2.5}$ between underground and ground level subway station areas ($^{*}p < 0.05$).

one. These findings correspond exactly with preceding overseas research. [6,7]. It is assumed that metallic dust, caused by train's deterioration and the friction between train wheels and the railway line, remained underground because the subway stations were not properly ventilated. This explains the high concentration levels of PM on underground platforms. Regardless of the division between ground level and underground stations, the mean concentrations of $PM_{10}$ and $PM_{2.5}$ in station precincts and on platforms exceeded the regulated EPA standard while those in station offices and ticket offices did not exceed the referred standard. Thus, a plan to decrease PM concentration levels in the near future in relation to the indoor air quality of station precincts and platforms is required.

## 4. Conclusions

For subway lines 1–4, the concentrations of $PM_{10}$ and $PM_{2.5}$ in worker and passenger activity areas were found to be higher on platforms, in passenger carriages and in driver compartments, all of which are part of the subway operation space. The concentration levels of $PM_{10}$ and $PM_{2.5}$ analyzed according to whether a station was at ground or underground level showed significantly higher concentrations on the underground platforms. The mean concentrations of $PM_{10}$ and $PM_{2.5}$ in station precincts and platforms exceeded the EPA regulated standard while those in station offices and ticket offices were below the standards. According to related researches, most of the PM pollutant can be assumed as coming from inorganic metallic dust dispersed into the air by the deterioration of the subway station's internal facilities and the friction between the railway line and the train wheels during normal operation of the subway system.

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