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# INVESTIGATION OF TSP, $PM_{10}$, $PM_{2.5}$ CONCENTRATIONS IN UNDERGROUND AND GROUND – LEVEL STATIONS OF TEHRAN METRO SYSTEMS

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**ABSTRACT:**

**Introduction**: Among air pollutants, particles are the primary and major pollutant. Particulate matters in closed environments like underground subway stations have many severe effects on human health. The aim of this study was to evaluate the concentration of PM in various parts of indoor and outdoor air line 1 of Tehran subway stations.

**Materials and methods**: Surveys were conducted during peak- hours of working days in January 2016 using a portable photometric aerocet 531 sampler. Samples were taken from indoor and outdoor air at each station from platform.

**Results:** The highest PM concentration was observed at Darvazeh Dowlat Station ( $PM_{2.5}$, $PM_{10}$ and TSP were 48, 108 and 140 µg/m$^3$ ). The highest PM concentration is related to the evening, beginning of the platforms and the lowest PM concentration is related to the before noon. As can be seen, $PM_{2.5}$ / $PM_{10}$ ratio ranges from 0.45 to 0.50 and $PM_{10}$ / TSP ratio from 0.55 to 0.65.

**Conclusions:** The results of this study indicate that the average concentration of $PM_{2.5}$ in Tehran metro stations was higher than EPA and there was a strong correlation between PM concentrations at platform station and outdoor air. Also air quality in metro stations was inappropriate.

## INTRODUCTION

Metro systems are globally a major public transport method in many cities due to their comfort, security, efficiency, and wide transportation capacity [1, 2]. Furthermore, one of the most proper policies to control traffic compaction and enlarge the welfare of urban areas is promote of high-quality subways [3]. In recent years, serious attention has been paid to the study of air quality in transport microenvironments and mainly in the underground subway microenvironment [4, 5]. In big cities, people spend 4– 8% (1–2 h) of their daily time by metro and as has been pointed out in several studies, during this time they are probably exposed to high PM concentrations [6]. With such large population of metro riders,

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metro systems not only need to provide the economic benefits, but also a safe and healthy environment for both passengers and workers [7]. For all countries, the metro air research work always began from the measurement of pollutant exposure level and the identification of pollutant chemical speciation [8]. Exposure to particulate matters (PM) is a major health concern in big cities across the world [9, 10]. Many studies have revealed that air pollution can adversely affect their health [11, 12]. PM Concentrations in subway environment could pose health effects on both passengers and subway staff members. Epidemiological studies have shown that long time exposure to PM especially to $PM_{2.5}$, can easily deposit in the bronchi and lungs, causing multiple diseases such as respiratory infections, lung cancer, and cardiovascular diseases [13, 14]. Some studies have investigated exposure to $PM_{10}$ ( $\leq$ 10 μm), $PM_{2.5}$ ( $\leq$ 2.5 μm) shown significant differences in exposure levels among various commuting modes, such as car, bus, subway, bicycling and walking [15]. Former studies in the subway lines of several cities throughout the world show that particulate matter (PM) concentrations significantly higher than those measured in ambient air are generally found in these environments [16, 17]. There is a large variety of factors influencing the concentration PM in subway systems. The main sources of PM in subway system are in the depth and design of the stations and tunnels, system age, wheel and rail track materials and braking mechanisms, train speed and frequency, passenger densities, ventilation and air conditioning systems and cleaning frequencies [18]. Raised PM concentrations have been found in the subway systems of Hong Kong [19], Beijing [20], Shanghai [21], Guangzhou [22], Tianjin [23], Seoul [24], Milan [2], Frankfurt [25], and Barcelona [3] (Seen Table 1). Table 1 reports a review of PM measurements in different cities around the world. Among these studies, higher concentrations PM ( average concentrations of $PM_{10}$ and $PM_{2.5}$ ) were observed in the Shanghai and Barcelona metro with average PM concentration equal to respectively 366 and 287 (μg/m$^3$), were about 10 times higher than in the external urban environment (outdoors). The highest $PM_{10}$ concentrations.in metro platforms were reported in the study of Ye et al. (2008) on the metro of Shanghai, where average $PM_{10}$ concentration was equal to 366 μg/m$^3$ and in the study of Querol et al.(2012) on the metro of Barcelona, where the average $PM_{10}$ concentration measured was equal to 343 μg/m$^3$. In the majority of the studies conducted in metros, particle concentration was significantly higher (2- 8 times) in the metro microenvironment than outdoors [26]. Considering hazards associated with exposure to particulate matters, and absence study about particulate matter concentration on

Table 1. A comparison of $PM_{10}$ and $PM_{2.5}$ average concentrations between different underground railway systems

| City | Measurement year | $PM_{10}$ (μg/m$^3$) | $PM_{2.5}$ (μg/m$^3$) | Reference |
|---|---|---|---|---|
| Hong Kong | 1996 | 120 | 10.2 | [19] |
| Beijing | 2014 | 108 | 36.9 | [20] |
| Shanghai | 2008 | 366 | 287 | [21] |
| Guangzhou | 2002 | 44 | 55 | [22] |
| Tianjin | 2015 | - | 151.4 | [23] |
| Seoul | 2008 | 150 | 118.2 | [24] |
| Milan | 2012 | 188 | - | [2] |
| Frankfurt | 2013 | 180 | - | [25] |
| Barcelona | 2012 | 346 | 125 | [3] |

selected subway stations in Tehran, this study aimed to measure $PM_{2.5}$, and $PM_{10}$ and TSP in indoor and outdoor air line 1 of Tehran subway stations.

## MATERIALS AND METHODS

### *Case study*

The sample case study was the Tehran metro line 1 (Fig. 1). It is about 39 km long with 29 stations (9 ground - level and 20 underground) and is used by about 800 thousand users per day. The characteristics of the stations are summarized in Table 2 describing: station type, platform depth, number passenger in stations and outdoor urban traffic conditions.

### *Monitoring instrument and quality*

PM was measured with a portable, laser operated aerosol mass analyzer (Aerocet 531, Met one Instruments Inc, USA) with readings every two minutes. The instrument calculates PM concentrations ($PM_1$, $PM_{2.5}$, $PM_7$, $PM_{10}$, TSP), expressed in $\mu g/m^3$. TSP, $PM_{10}$ and $PM_{2.5}$ were chosen as representative of pollution (see Discussion). The instrument is calibrated and validated by comparison with gravimetric EPA FRM (polystyrene latex) calibration particles (appendix 2 of D.P.C.M. 28/03/1983). The analyzer is pocket-sized, operates automatically with battery autonomy for up to 8 h; data are stored on the internal memory, can be visualized immediately on display and subsequently downloaded on a computer.

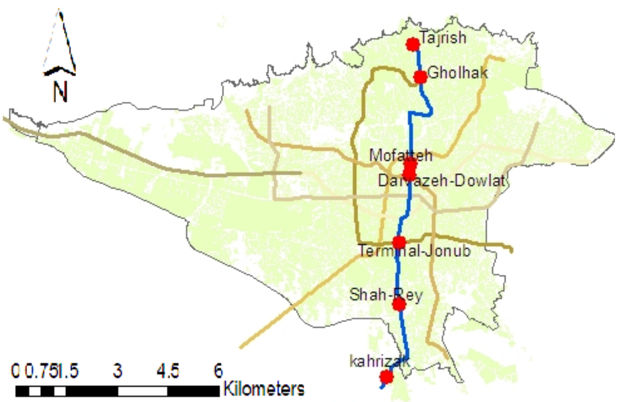


Fig. 1. Line 1 of the Tehran metro system.

### *Measurement campaigns*

Surveys were conducted during peak-hours of working days in January 2016. TSP, $PM_{10}$ and $PM_{2.5}$ concentrations were measured in seven station platforms (Three ground - level and four underground) and their respective urban environments (outdoors). The measurements were conducted close to the first, center, end and exit of the platforms and the samples were collected roughly 1.65 m above the platform floor. In the outdoor environment the measurements were performed at about 10- 15 m from the entrance of the stations. Measurements at station platforms and outdoor environment were taken every 2 min between 8 AM and 9 PM.

Table 2. Characteristics of Tehran metro line 1 and the area surrounding the station entrance.

| Station | Station type | Platform depth (m) | Passenger (per day) | Outdoor ambient |
|---|---|---|---|---|
| Kahrizak | ground-level | - | 35900 | Urban - low traffic |
| Shahr-Rey | ground-leve | - | 37560 | Urban - low traffic |
| Terminal-Jonub | ground-leve | - | 14950 | Urban-high traffic |
| Darvazeh-Dowlat | underground | - 12 | 45730 | Urban - high traffic |
| Mofatteh | underground | -14.5 | 19850 | Urban - high traffic |
| Gholhak | underground | -14.3 | 21830 | Urban - high traffic |
| Tajrish | underground | -51 | 27690 | Urban - high traffic |

## RESULTS AND DISCUSSION

### *PM concentration in stations*

Table 3 shows the comparison of the mean particulate matter (PM) concentration at the stations (ground- level with underground) with outside environment. The mean concentration of $PM_{2.5}$ had exceeded the EPA standard (35 µg/m$^3$) at all stations. The highest PM concentration was observed at Darvazeh - dowlat ($PM_{2.5}$, $PM_{10}$ and TSP 48,108 and 140 µg/m$^3$) station that is an intersection station and has a high population density and a large number of trains compared to other stations. In general, it is observed that the mean PM concentration at underground stations was much higher than ground-level stations. It seems that bilaterally opened platforms of ground- level stations and the presence of air flow on the platforms were of the reasons for lower PM concentration in ground - level stations in comparison with underground stations .The study in 2011 was conducted at the ground - level and underground stations on the Los Angeles metro. The results showed that PM concentration in underground stations was twice higher that PM concentration in ground - level stations [1]. Comparison of PM concentration in stations with outside environment showed that PM concentration in outside environment was often higher than selected stations. The study stations were selected based on locations with high traffic and pollution. PM concentrations are high usually at these sites. Significant relationship ($P_{value}$ < 0.05) was found in PM concentration between outside environment and stations, indicating the dependence between environmental factors and PM concentration at stations. The relationship between PM concentration in the outside environment and the indoor stations was showed in the other study by Hosseini (2016) [27].

### *PM concentration at different sections station platforms*

Table 4 shows the changes in PM concentration in different sampling sites. The results indicate that PM concentration changes at the entrance to the platform and outlet of the station were higher than other sampling points. Increased concentration was observed at the entrance to the station apparently due to the arrival of the train into the station at a high speed, the creation of blow on the platform and positioning the air conditioner system at the beginning of the platform. Since most of the stations are located in close proximity to busy and high-traffic streets, the city traffic, arrival and departure of passengers to the station were the factors influencing the high PM concentration in these two sampling sites [28].

As the train enters the station, the released PM along the route is deposited in the engine, train body and railroad tracks, is released into the station space due to the airflow caused by train traffic and causes increased PM concentration at the beginning of the platform. In the middle of the platform, train speed is decreased. As a result, PM concentrations along the route are reduced

Table 3. Distribution of indoor (station platform) and outdoor (urban environment) PM measured mass concentrations (µg/m$^3$)

| Stations | $PM_{2.5}$ | | $PM_{10}$ | | TSP | |
|---|---|---|---|---|---|---|
| | Platform | Outdoor | Platform | Outdoor | Platform | Outdoor |
| Kahrizak | 40 ± 11 | 42 ± 9 | 75 ± 15 | 91 ± 21 | 173 ± 16 | 191 ± 23 |
| Shahr-Rey | 35 ± 17 | 37 ± 11 | 78 ± 18 | 89 ± 14 | 148 ± 13 | 170 ± 32 |
| Terminal-Jonub | 38 ± 14 | 41 ± 18 | 77 ± 13 | 91 ± 15 | 130 ± 11 | 167 ± 17 |
| Darvazeh-Dowlat | 48 ± 19 | 47 ± 14 | 108 ± 23 | 96 ± 12 | 140 ± 37 | 166 ± 18 |
| Mofatteh | 40 ± 13 | 46 ± 17 | 78 ± 14 | 86 ± 18 | 146 ± 21 | 170 ± 16 |
| Gholhak | 43 ± 11 | 47 ± 13 | 86 ± 19 | 88 ± 21 | 166 ± 31 | 195 ± 27 |
| Tajrish | 53 ± 21 | 56 ± 16 | 95 ± 14 | 114 ± 22 | 175 ± 32 | 197 ± 28 |

by lowering train speed and airflow velocity. This study is consistent with the results of Querol on the metro in Barcelona. They showed that PM concentration is decreased along the platform by reducing train speed and airflow velocity. They reported that entering, leaving and stopping the train at the station, respectively, increased, decreased and stabilized PM concentration [3].

***PM concentration in peak hours at station***

Based on different sampling times in Darvazeh-dowlat station, the results indicate that the highest PM concentration is related to the evening and the lowest PM concentration is related to the before noon. It seems that turned off ventilation system and station fans and population density were factors influencing PM concentration in these two periods (Table 5). Raei Shaktaie conducted a study on PM concentrations in Tehran metro and reported the highest PM concentration at noon and night [29].

***Particle ratio***

Most studies have been conducted on $PM_{10}$ and the majority of standards and guidelines have been defined for these particles. The values for different particle sizes can be determined using the ratio of particles. The most commonly used ratio of particles is $PM_{2.5}$ to $PM_{10}$ ratio. $PM_{10}$ can penetrate into the respiratory tract. The accumulation of these particles due to continuous and long - term exposure can lead to increased respiratory problems and other body organs, resulting in severe health complications [30]. Therefore, knowledge about the size of the resulting particles is very important to achieve a therapeutic effect. Fig. 2 shows the heat map diagram of the particle concentration ratio at different stations. As can be seen, $PM_{2.5}$ / $PM_{10}$ ratio ranges from 0.45 to 0.50 and $PM_{10}$ / TSP ratio from 0.55 to 0.65, which both ratios were higher in underground compared to ground - level stations. The highest ratio of particles was found in the Darvazeh- dowlat metro station. Hosseini conducted a study in 2016 on Tehran metro and reported that the $PM_{2.5}$ / $PM_{10}$ ratio was up to 0.73. This high ratio was attributed to inability of air conditioning system to remove the $PM_{2.5}$ from the stations [27].

## CONCLUSIONS

PM concentrations in subway environment could pose health effects on both passengers and subway staff members. Starting from this consideration, an intensive particulate sampling campaign was carried out in January 2016 to measure the particulate matter concentrations for the Tehran metro line 1, both at station platforms and outdoor.

Table 4. Average PM concentrations (in µg/m³) in different sections on the Darvazeh - dowlat station platform.

| Sections of the platform | $PM_{2.5}$ | $PM_{10}$ | TSP |
|---|---|---|---|
| Entrance | 66 ± 17 | 126 ± 11 | 262 ± 38 |
| Middle | 38 ± 14 | 88 ± 15 | 150 ± 24 |
| End | 43 ± 21 | 104 ± 17 | 241 ± 39 |
| Exit | 51 ± 22 | 113 ± 13 | 170 ± 28 |

Table 5.average PM Concentrations (in µg/m³) over time (peak- hour) on the Darvazeh- dowlat station platform.

| Daytime, peak hour, working day | $PM_{2.5}$ | $PM_{10}$ | TSP |
|---|---|---|---|
| 7-7.5 | 49±18 | 81±13 | 173±28 |
| 10-10.5 | 38±14 | 69±15 | 144±16 |
| 5-5.5 | 63±21 | 108±17 | 205±31 |
| 8-8.5 | 51±17 | 83±13 | 175±18 |

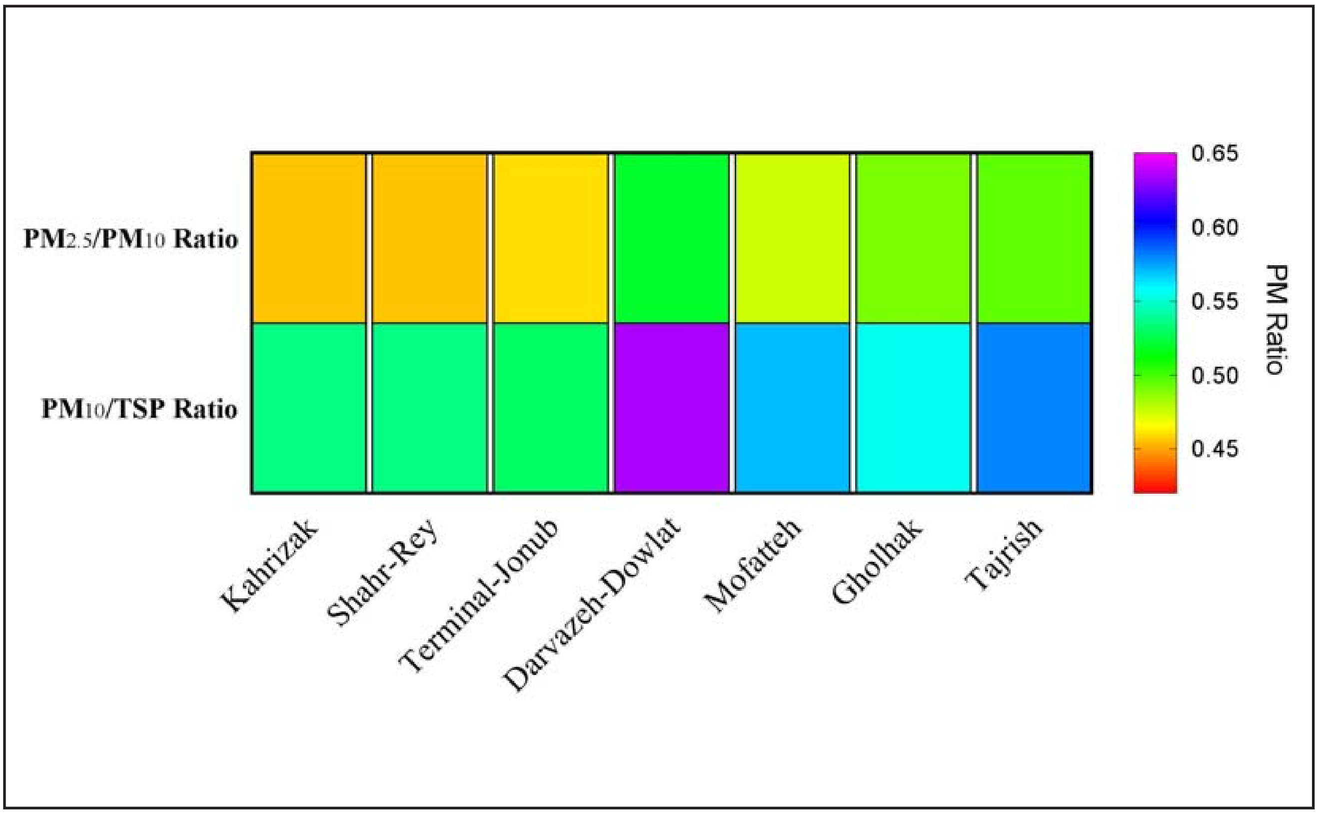


Fig. 2. $PM_{2.5}$ / $PM_{10}$ and $PM_{10}$ / TSP ratios at different sampling locations

Experimental results show that the average $PM_{2.5}$ concentration measured in the monitored station was exceeded the EPA standard (35 µg/m$^3$). The results indicate that PM concentration changes at the entrance to the platform and outlet of the station were higher than other sampling sites. Highest PM concentration is related to the evening and the lowest PM concentration is related to the before noon. A high $PM_{2.5}$ / $PM_{10}$ and $PM_{10}$ /TSP ratio was attributed to inability of air conditioning system to remove the $PM_{2.5}$ from the stations.

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The financial support of the study was done by author team.

## COMPETING INTERESTS

There is not any competing interests between authors.

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## ETHICAL CONSIDERATIONS

The authors state that they have no ethical considerations.

## REFERENCES

[1] Kam W, Cheung K, Daher N, Sioutas C. Particulate matter (PM) concentrations in underground and ground-level rail systems of the Los Angeles Metro. Atmospheric Environment. 2011;45(8):1506-16.
[2] Colombi C, Angius S, Gianelle V, Lazzarini M. Particulate matter concentrations, physical characteristics and elemental composition in the Milan underground transport system. Atmospheric environment. 2013;70:166-78.
[3] Querol X, Moreno T, Karanasiou A, Reche C, Alastuey A, Viana M, et al. Variability of levels and composition of PM10 and PM2.5 in the Barcelona metro system. Atmospheric Chemistry and Physics. 2012;12(11):5055-

76.

[4] Jung H-J, Kim B, Ryu J, Maskey S, Kim J-C, Sohn J, et al. Source identification of particulate matter collected at underground subway stations in Seoul, Korea using quantitative single-particle analysis. Atmospheric Environment. 2010;44(19):2287-93.

[5] Loxham M, Cooper MJ, Gerlofs-Nijland ME, Cassee FR, Davies DE, Palmer MR, et al. Physicochemical characterization of airborne particulate matter at a mainline underground railway station. Environmental science & technology. 2013;47(8):3614-22.

[6] Martins V, Moreno T, Minguillón MC, Amato F, de Miguel E, Capdevila M, et al. Exposure to airborne particulate matter in the subway system. Science of the Total Environment. 2015;511:711-22.

[7] Martins V, Moreno T, Minguillón MC, van Drooge BL, Reche C, Amato F, et al. Origin of inorganic and organic components of PM2.5 in subway stations of Barcelona, Spain. Environmental Pollution. 2016;208:125-36.

[8] Xu B, Hao J. Air quality inside subway metro indoor environment worldwide: A review. Environment International. 2017;107:33-46.

[9] Zhang Z-H, Khlystov A, Norford LK, Tan Z-K, Balasubramanian R. Characterization of traffic-related ambient fine particulate matter (PM2.5) in an Asian city: Environmental and health implications. Atmospheric Environment. 2017;161:132-43.

[10] Bahrami Asl F, Kermani M, Aghaei M, Karimzadeh S, Salahshour Arian S, Shahsavani A, et al. Estimation of Diseases and Mortality Attributed to NO2 pollutant in five metropolises of Iran using AirQ model in 2011-2012. Journal of Mazandaran University of Medical Sciences. 2015;24(121):239-49.

[11] Lu F, Xu D, Cheng Y, Dong S, Guo C, Jiang X, et al. Systematic review and meta-analysis of the adverse health effects of ambient PM2.5 and PM10 pollution in the Chinese population. Environmental research. 2015;136:196-204.

[12] Kermani M, Aghaei M. Estimation of cardiovascular death, myocardial infarction and chronic obstructive pulmonary disease (COPD) attributed to PM and SO2 in the air of Tehran metropolis. Journal of Research in Environmental Health. 2016;2(2):116-26.

[13] Atkinson R, Kang S, Anderson H, Mills I, Walton H. Epidemiological time series studies of PM2. 5 and daily mortality and hospital admissions: a systematic review and meta-analysis. Thorax. 2014:thoraxjnl-2013-204492.

[14] Marzouni MB, Moradi M, Zarasvandi A, Akbaripoor S, Hassanvand MS, Neisi A, et al. Health benefits of PM10 reduction in Iran. International Journal of Biometeorology. 2017:1-13.

[15] Kaur S, Nieuwenhuijsen MJ, Colvile RN. Fine particulate matter and carbon monoxide exposure concentrations in urban street transport microenvironments. Atmospheric Environment. 2007;41(23):4781-810.

[16] Suárez L, Mesías S, Iglesias V, Silva C, Cáceres DD, Ruiz-Rudolph P. Personal exposure to particulate matter in commuters using different transport modes (bus, bicycle, car and subway) in an assigned route in downtown Santiago, Chile. Environmental Science: Processes & Impacts. 2014;16(6):1309-17.

[17] Martins V, Moreno T, Mendes L, Eleftheriadis K, Diapouli E, Alves CA, et al. Factors controlling air quality in different European subway systems. Environmental research. 2016;146:35-46.

[18] Braniš M. The contribution of ambient sources to particulate pollution in spaces and trains of the Prague underground transport system. Atmospheric Environment. 2006;40(2):348-56.

[19] Chan L, Chan C, Qin Y. The effect of commuting microenvironment on commuter exposures to vehicular emission in Hong Kong. Atmospheric Environment. 1999;33(11):1777-87.

[20] Li T-T, Bai Y-H, Liu Z-R, Liu J-F, Zhang G-S, Li J-L. Air quality in passenger cars of the ground railway transit system in Beijing, China. Science of the total environment. 2006;367(1):89-95.

[21] Ye X, Lian Z, Jiang C, Zhou Z, Chen H. Investigation of indoor environmental quality in Shanghai metro stations, China. Environmental monitoring and assessment. 2010;167(1):643-51.

[22] Chan L, Lau W, Zou S, Cao Z, Lai S. Exposure level of carbon monoxide and respirable suspended particulate in public transportation modes while commuting in urban area of Guangzhou, China. Atmospheric Environment. 2002;36(38):5831-40.

[23] Wang B-Q, Liu J-F, Ren Z-H, Chen R-H. Concentrations, properties, and health risk of PM2. 5 in the Tianjin City subway system. Environmental Science and Pollution Research. 2016;23(22):22647-57.

[24] Kim K-H, Ho DX, Jeon J-S, Kim J-C. A noticeable shift in particulate matter levels after platform screen door installation in a Korean subway station. Atmospheric environment. 2012;49:219-23.

[25] Gerber A, Bohn J, Groneberg DA, Schulze J, Bundschuh M. Airborne particulate matter in public transport: a field study at major intersection points in Frankfurt am Main (Germany). Journal of Occupational Medicine and Toxicology. 2014;9(1):13.

[26] Findeis L. Exposure concentration levels to ultrafine particles and black carbon along a pedestrian route in Milan. 2014.

[27] Naddafi K, Hoseini M, Nabizadeh R, Mahdavi Y, Safari GH, Shirmardi M, et al. Concentrations of airborne particulate matters in underground and surface stations of Tehran subway system. Journal of Air Pollution and Health. 2015;1(1):7-14.

[28] Motesaddi Zarandi S, Raei Shaktaie H, Yazdani Cheratee J, Hosseinzade F, Dowlati M. Evaluation of PM2. 5 concentration and determinant parameters on its distribution in Tehran's Metro System in 2012. Journal of Mazandaran University of Medical Sciences. 2013;22(2):37-46.

[29] Raa'ee Shaktaie H, Motesaddi Zarandi S, Zazouli MA, Yazdani Cheratee J, Hosseinzade F, Dowlati M. Study Concentration of particulate matter with aerodynamic diameter less than 10 micron (PM10) in the metro underground transport system of Tehran. Journal of Mazandaran University of Medical Sciences. 2017;27(151):166-79.

[30] Kermani M, Dowlati M, Jonidi Jafari A, Rezaei Kalantari R. Health impact caused by exposure to particulate matter in the air of Tehran in the past decade. Tehran University Medical Journal TUMS Publications. 2017;74(12):885-92.