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CONCENTRATIONS OF AIRBORNE PARTICULATE MATTERS IN UNDERGROUND AND SURFACE STATIONS OF TEHRAN SUBWAY SYSTEM

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ABSTRACT

Introduction: Air pollution in closed environments like underground subway stations has many severe effects on human health. This study was performed to investigate the concentrations of PM_{10} and $PM_{2.5}$ in the air of platforms, office areas, and adjacent outdoor air of two stations in Tehran subway system.
Materials and Methods: Sampling was conducted in April to September 2011 using a portable GRIMM dust monitor. Samples were taken from indoor air at each station from platform and ticket office area also from adjacent outdoor air of each station.
Results: The concentrations of PM_{10} ranged from 33 µg/m³ at the office area of Imam Khomeini station to 160 µg/m³ at the outdoor air of Sadeghiye station. The $PM_{2.5}$ concentrations varied from 10.9 to 97.7 µg/m³. Based on results of regression analysis the PM_{10} and $PM_{2.5}$ concentrations at the platform of Sadegiye station are strongly associated with adjacent outdoor levels (R^2 =0.77 and 0.67 respectively), while PM_{10} and $PM_{2.5}$ concentrations in the platform of Imam Khomeini are less influenced by adjacent outdoor levels (R^2 =0.36 and 0.4 respectively). Spearman's correlations were high for both platform $PM_{2.5}$ and PM_{10}, since the outdoor/indoor coefficient of $PM_{2.5}$ was 0.58, whereas $PM_{10outdoor}$/ $PM_{10indoor}$ coefficient was 0.62, indicating an important influence of outdoor particles introduced through the ventilation systems and by passengers.
Conclusions: Results showed that there was a strong correlation between PM concentrations at platform of Sadegiye station (surface station) and outdoor air representing air quality in the platform of this station influenced by outdoor air.

INTRODUCTION

Subsurface transport systems - or common words subway systems have become intensively used as a principal methods of public transportation in large cities around the world in order to improve the quality of transport, reduce traffic and air pollution [1, 2]. The extension of subway systems has led to the development of an underground space in which daily commuters spend significant part of their time and a large number of employees are working [3, 4]. These enclosed public spaces based on some features

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such as being trapped, often limited ventilation, special sources of pollutant release and specific environmental conditions, have become a unique microenvironment [5, 6].

The earliest studies regarding effects of pollutants on subway passengers have been performed in the late 1980s in the state of Boston [7, 8]. Thereafter, many studies performed to measure levels of different air pollutants, including particulate matter (PM), in metro systems. High concentrations of PM have been measured in many subway systems, such as London [4, 9], Stockholm [10], Prague [11], Rome [12], Berlin [13], Seoul [14, 15] , and Istanbul [16]. There are, however, very limited information and studies regarding concentration of PM in Tehran's subway system.

It has been shown that the concentration and distribution characteristics of the particulate matters in the indoor air of subway can be substantially different from the outdoor air of the adjacent street [2, 6]. Epidemiological studies have well documented the association between exposure to PM, particularly fine PM or $PM_{2.5}$ (aerodynamic diameter less than 2.5 mm), and adverse human health effects such as cardiovascular disease [17-19], pulmonary injury [20], and neurodegenerative disorders [21].

Considering hazards associated with exposure to particulate matters, and lack of any study regarding measurement of particulate matters (PM) in Tehran subway stations, this study aimed to determine the $PM_{2.5,}$ and PM_{10} concentrations in platform, office area and outdoor air of Tehran subway stations and assess the relationship between concentrations of these particles in indoor air and adjacent outdoor air.

MATERIALS AND METHODS

Study area

The research field in this study was subway stations in Tehran. Within the stations of four operating lines two stations with different location, structure and crowding rate, of lines 1 and 2 of Tehran subway system, were selected. The first station, "Imam Khomeini", is an underground station located at cross point of two most busy lines. It is equipped by mechanical ventilation systems and maintained under positive pressure to remove pollutants. The second station, "Sadeghiye", is a surface station except for its ticket office area which is underground. It is characterized by good natural ventilation and fewer passengers' density. Two sampling points were chosen within each station, platform and office area. For the comparative assessment, one additional outdoor spot was investigated adjacent to each station.

Monitoring method and measurement equipment

A portable GRIMM dust monitor model 1.108 was used to measure $PM_{2.5}$ and PM_{10} concentrations in indoor and outdoor air. GRIMM dust monitor can measure $PM_{2.5}$ and PM_{10} concentrations based on the method of light scattering. The air was drown into the unit via an internal volume-control pump at a rate of 1.2 l/min. The air samples passed through the sample cell, past laser diode detector and were collected onto a 47-mm PTFE filter, and then concentrations of particles displayed on LCD and also stored in the data storage card. Originally, this instrument was calibrated by its company. Sampling was conducted once every 6 days for 6 months from April to September 2011. The sampling time was from 9:00 AM to 6:00 PM [22, 23].

RESULTS AND DISCUSSION

PM_{10} and $PM_{2.5}$ concentrations

Concentrations of PM_{10} and $PM_{2.5}$ in indoor and the outdoor air of different sampling locations are shown in table 1. As represented in the table, the concentrations of PM_{10} and $PM_{2.5}$ varied widely at different sampled locations. The concentrations of PM_{10} ranged from 33 μg/m^3 at the office area of Imam Khomeini station to 160 μg/m^3 at the outdoor air of Sadeghiye station. Regarding $PM_{2.5}$ the concentrations varied from 10.9 µg/m^3 at the outdoor air of Sadeghiye station to 97.7 µg/m^3 at the platform of Imam Khomeini station. The highest mean concentrations of $PM_{2.5}$ and PM_{10} were observed at the platform of Imam Khomeini station (56.3 µg/m^3) and the office area of Sadeghiye station (110.6 µg/m^3) respectively. The results of study showed that the concentrations of PM_{10} and $PM_{2.5}$ at the underground station (Imam Khomeini) were higher than the corresponding concentrations for the surface station (Sadegiye station), indicating that underground subway's commuters are exposed to higher PM concentrations than the surface station's commuters. This fact can be due to more ventilation in the surface station platform than underground one. Concentrations of particle matter in indoor air of different subway stations around the world are vary. In a similar study performed at the Seoul metropolitan subway stations, the mean concentrations of PM_{10} and $PM_{2.5}$ were 123 and 115.6 µg/m^3 respectively (Park and Ha 2008). In another study performed at indoor air of subway stations in Los Angeles, the mean concentrations of PM_{10} and $PM_{2.5}$ were 78 and 56.7 µg/m^3 [24]. According to Cheng et al (2008) the concentrations of PM_{10} and $PM_{2.5}$ in subway stations in Taipei ranges from 11–137 and 7–100 µg/m^3 respectively [25]. In subway stations in Stockholm the mean concentrations of PM_{10} and $PM_{2.5}$ have been reported 469 and 258 µg/m^3 [10].

$PM_{2.5}/PM_{10}$ ratios can be used to identify suspension and re-suspension patterns of particulate matters [26]. The $PM_{2.5}/PM_{10}$ ratios at different sampled environments in this study are given in Fig.1 The $PM_{2.5}/PM_{10}$ ratio in platform of Sadegiye station (surface station) ranged 0.3 to 0.76 (mean 0.48). The corresponding ratios were 0.1 to 0.59 (mean 0.29), at the outdoor air and 0.2 to 0.65 (mean 0.33) at the office area of this station. The mean $PM_{2.5}/PM_{10}$ ratios at the platform, outdoor air and office area of Imam Khomeini station (underground station) were 0.57, 0.28, and 0.55 respectively. The results showed that this ratio at enclosed sampled environments (platform and office areas) was higher than those at outdoor air. This can be attributed to the fact that the ventilation system of the subway system could filter out some coarse particulates, but did not remove fine particulates [27]; thus the proportion of $PM_{2.5}$ was relatively higher in the enclosed sampled environments than outdoors. In a similar study performed at Los Angeles subway system, average $PM_{2.5}/PM_{10}$ ratio at a platform was 0.73 [24]. In another study in Hong Kong Chan et al., 2002 found that a non-air-conditioned transport system had a significantly lower $PM_{2.5}/PM_{10}$ ratio (0.63-0.68) than an air-conditioned system (0.71-0.78) [27].Also in Seoul subway station $PM_{2.5}/PM_{10}$ ratio was 0.45 [28].

Table 1. Concentrations of $PM_{2.5}$ and PM_{10} at different sampling locations.

Stations	Statistical index	Platform		Office area		Outdoor air	
		$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
Imam Khomeini	Range	11.2-97.7	34.4-133.3	24.3-65.7	33-133.6	12.2-67.3	54-160
	Mean ± SD	56.30 ± 24.30	99.80 ± 27.70	51.90 ± 6.30	98.40 ± 22.10	29.80 ± 15.02	107.00 ± 29.00
Sadeghiye	Range	20.85-90.3	57.6-137.8	16.25-61.23	73.8-132.5	10.9-59.4	71.9-156
	Mean ± SD	46.40 ± 18.60	94.40 ± 21.80	36.30 ± 9.00	110.60 ± 15.30	30.02 ± 15.00	105.70 ± 23.80

PM: Particulate matter, SD: Standard deviation

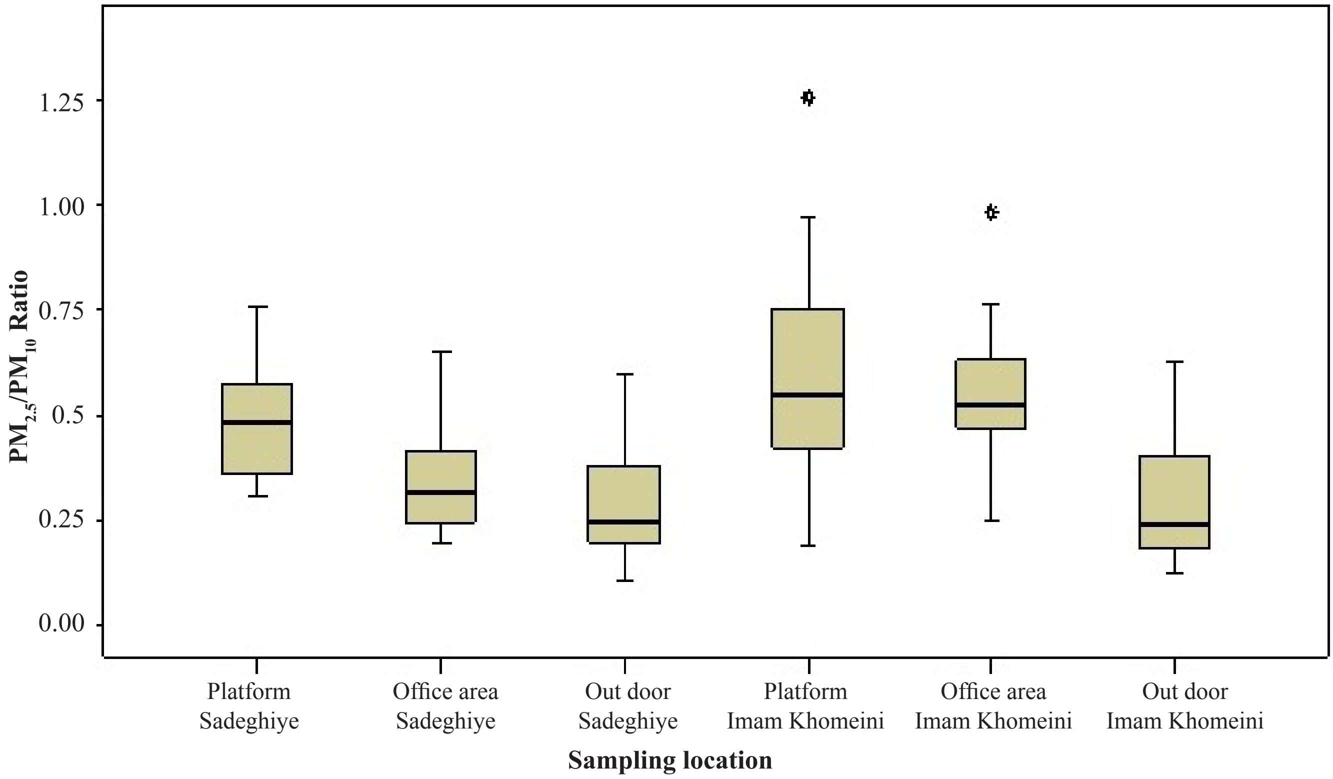

Fig. 1. $PM_{2.5}/PM_{10}$ ratios at different sampling locations

Correlation between PM concentrations in indoor and outdoor air

To investigate the influence of outdoor PM concentrations on platform and influence of platform PM concentration on the office area in two stations, platform PM concentrations are plotted against both ambient and office area PM concentrations. Correlations between platform $PM_{2.5}$ and PM_{10} concentrations and adjacent outdoor air as well as platform and office area for underground and surface stations are sown in Figs.2 and 3 (a-d). Based on the results of linear regression analysis, there was a weak correlation between $PM_{2.5}$ concentrations at the platform of Imam Khomeini station and outdoor level (R^2=0.36) (Fig.2 a), however the $PM_{2.5}$ concentrations at the platform of Sadegiye station had a strong positive correlation with outdoor levels (R^2=0.67) (Fig.2 b). The highest correlation was found between the PM_{10} concentrations at the platform and office area of Sadegiye station (R^2=0.77) (Fig.2 d). These results demonstrate that the surface station is more influenced by outdoor PM levels than the underground station, particularly for PM_{10} levels. Spearman's correlations were high for both platform $PM_{2.5}$

and PM_{10}, since the outdoor/indoor coefficient of $PM_{2.5}$ was 0.58, whereas $PM_{10outdoor}$/ $PM_{10indoor}$ coefficient was 0.62, indicating an important influence of outdoor particles introduced through the ventilation systems and by passengers. As the correlation coefficients depart from 1 it indicates that other sources within the underground are contributing to the particulate matters mass [29]. The results of similar studies have also represented that there is a meaningful relationship between the concentration of PM in the indoor air of different buildings and outdoor air. In a similar study performed in Bangkok, the mean Indoor/Outdoor ratio of PM_{10} was 0.33 [30]. In another study done in Australia I/O ratio was 1.07 and the researchers found that under natural air conditioning conditions the concentration of fine particulate matters in indoor air of building are depend on the concentration of particles in outdoor air [31].

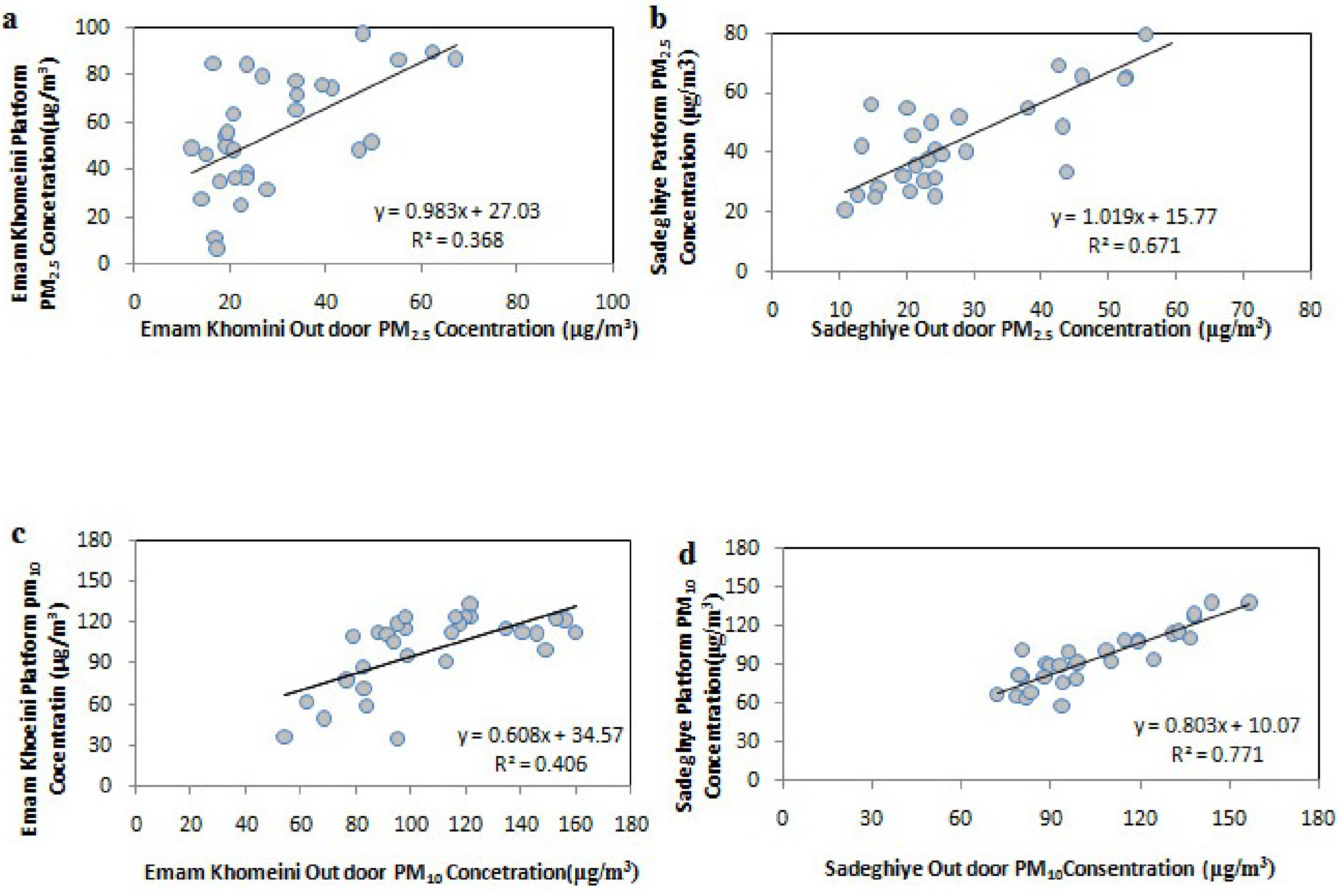

Fig.2. Correlations between $PM_{2.5}$ (a and b) and PM_{10} (c and d) concentrations at the platforms and outdoor at the Imam Khomeini and Sadegiye stations.

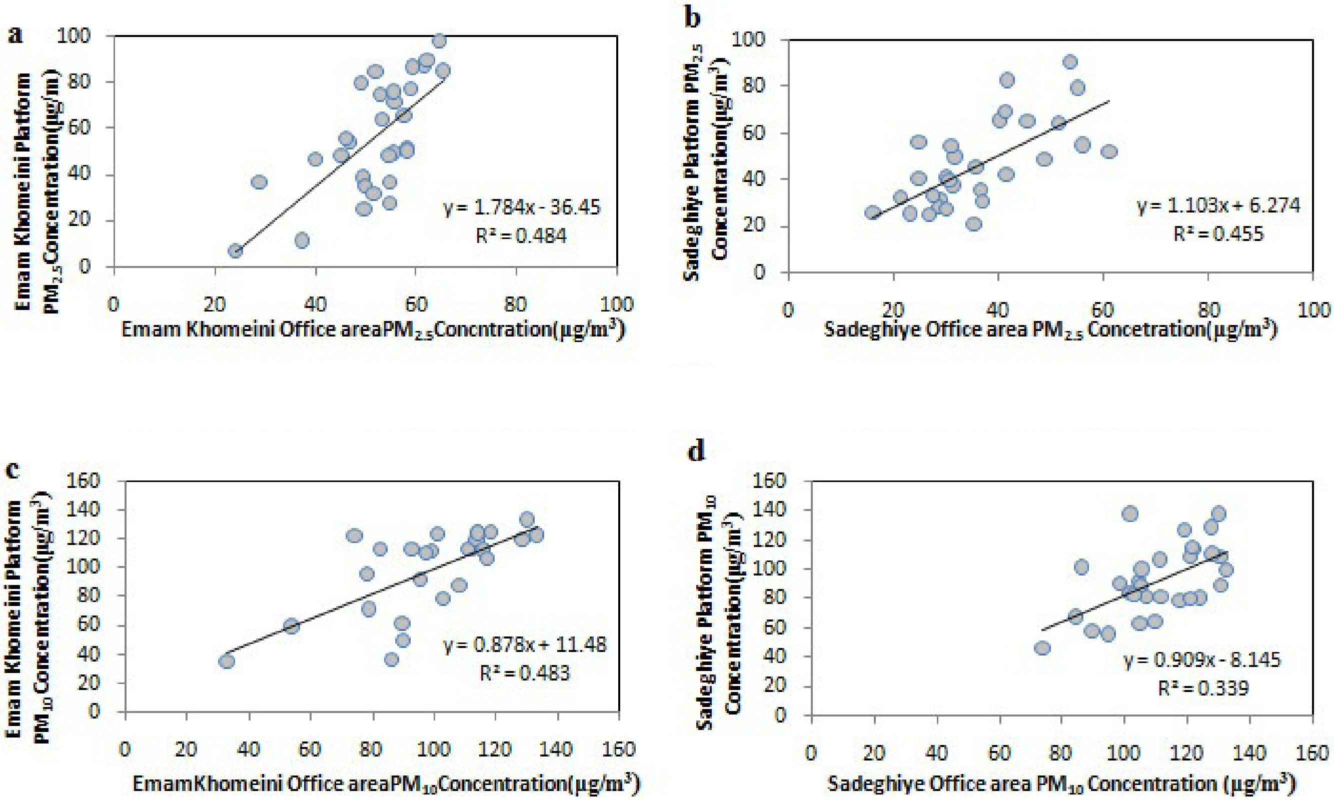

Fig.3. Correlations between $PM_{2.5}$ (a and b) and PM_{10} (c and d) concentrations in platforms and office areas at the Imam Khomeini and Sadegiye stations

CONCLUSIONS

An intensive particulate sampling campaign was conducted in April to September 2011 to compare the concentration of PM at two types of stations, underground (Imam Khomeini) and surface station (Sadegiye). This study provides the first set of ranges of the concentration of PM reported at the indoor air of Tehran subway system which can be used for comparative purposes in future studies. Based on the obtained results, the commuters of the underground station are exposed to higher PM concentrations than surface station. It was observed that concentrations of $PM_{2.5}$ in indoor air of stations were significantly higher than the US NAAQS $PM_{2.5}$ standards. Also, $PM_{2.5}/PM_{10}$ ratio in platform and office area of underground station (Imam Khomeini) was higher than surface station (Sadegiye).This result indicates that the subway environment was polluted by fine particulates. Results of regression analysis showed that there was a strong relationship between PM concentrations at platform of Sadegiye station (surface station) and outdoor air indicating air quality in the platform of this station influenced by outdoor air.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

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ETHICAL CONSIDERATIONS

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc) have been completely observed by the authors.

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