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

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**ARTICLE INFORMATION**

**Article Chronology:**
Received 5 April 2017
Revised 6 May 2017
Accepted 10 June 2017
Published 29 June 2017

**Keywords:**
Airborne particulate matters; PM$_{10}$; PM$_{2.5}$; metro; subway system

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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,
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] (See 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 ($\mu$g/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 $\mu$g/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 $\mu$g/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>
<thead>
<tr>
<th>City</th>
<th>Measurement year</th>
<th>PM$_{10}$ ($\mu$g/m$^3$)</th>
<th>PM$_{2.5}$ ($\mu$g/m$^3$)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong</td>
<td>1996</td>
<td>120</td>
<td>10.2</td>
<td>[19]</td>
</tr>
<tr>
<td>Beijing</td>
<td>2014</td>
<td>108</td>
<td>36.9</td>
<td>[20]</td>
</tr>
<tr>
<td>Shanghai</td>
<td>2008</td>
<td>366</td>
<td>287</td>
<td>[21]</td>
</tr>
<tr>
<td>Guangzhou</td>
<td>2002</td>
<td>44</td>
<td>55</td>
<td>[22]</td>
</tr>
<tr>
<td>Tianjin</td>
<td>2015</td>
<td>-</td>
<td>151.4</td>
<td>[23]</td>
</tr>
<tr>
<td>Seoul</td>
<td>2008</td>
<td>150</td>
<td>118.2</td>
<td>[24]</td>
</tr>
<tr>
<td>Milan</td>
<td>2012</td>
<td>188</td>
<td>-</td>
<td>[2]</td>
</tr>
<tr>
<td>Frankfurt</td>
<td>2013</td>
<td>180</td>
<td>-</td>
<td>[25]</td>
</tr>
<tr>
<td>Barcelona</td>
<td>2012</td>
<td>346</td>
<td>125</td>
<td>[3]</td>
</tr>
</tbody>
</table>
selected subway stations in Tehran, this study aimed to measure PM$_{1.5}$, 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 µg/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.

**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.

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

<table>
<thead>
<tr>
<th>Station</th>
<th>Station type</th>
<th>Platform depth (m)</th>
<th>Passenger (per day)</th>
<th>Outdoor ambient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kahrizak</td>
<td>ground-level</td>
<td>-</td>
<td>35900</td>
<td>Urban - low traffic</td>
</tr>
<tr>
<td>Shahr-Rey</td>
<td>ground-level</td>
<td>-</td>
<td>37560</td>
<td>Urban - low traffic</td>
</tr>
<tr>
<td>Terminal-Jonub</td>
<td>ground-level</td>
<td>-</td>
<td>14950</td>
<td>Urban-high traffic</td>
</tr>
<tr>
<td>Darvazeh-Dowlat</td>
<td>underground</td>
<td>-12</td>
<td>45730</td>
<td>Urban - high traffic</td>
</tr>
<tr>
<td>Mofatteh</td>
<td>underground</td>
<td>-14.5</td>
<td>19850</td>
<td>Urban - high traffic</td>
</tr>
<tr>
<td>Gholhak</td>
<td>underground</td>
<td>-14.3</td>
<td>21830</td>
<td>Urban - high traffic</td>
</tr>
<tr>
<td>Tajrish</td>
<td>underground</td>
<td>-51</td>
<td>27690</td>
<td>Urban - high traffic</td>
</tr>
</tbody>
</table>

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Fig. 1. Line 1 of the Tehran metro system.
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 than 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$^3$)

<table>
<thead>
<tr>
<th>Stations</th>
<th>PM$_{2.5}$ Platform</th>
<th>PM$_{2.5}$ Outdoor</th>
<th>PM$_{10}$ Platform</th>
<th>PM$_{10}$ Outdoor</th>
<th>TSP Platform</th>
<th>TSP Outdoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kahrizak</td>
<td>40 ± 11</td>
<td>42 ± 9</td>
<td>75 ± 15</td>
<td>91 ± 21</td>
<td>173 ± 16</td>
<td>191 ± 23</td>
</tr>
<tr>
<td>Shahr-Rey</td>
<td>35 ± 17</td>
<td>37 ± 11</td>
<td>78 ± 18</td>
<td>89 ± 14</td>
<td>148 ± 13</td>
<td>170 ± 32</td>
</tr>
<tr>
<td>Terminal-Jonub</td>
<td>38 ± 14</td>
<td>41 ± 18</td>
<td>77 ± 13</td>
<td>91 ± 15</td>
<td>130 ± 11</td>
<td>167 ± 17</td>
</tr>
<tr>
<td>Darvazeh-Dowlat</td>
<td>48 ± 19</td>
<td>47 ± 14</td>
<td>108 ± 23</td>
<td>96 ± 12</td>
<td>140 ± 37</td>
<td>166 ± 18</td>
</tr>
<tr>
<td>Mofatteh</td>
<td>40 ± 13</td>
<td>46 ± 17</td>
<td>78 ± 14</td>
<td>86 ± 18</td>
<td>146 ± 21</td>
<td>170 ± 16</td>
</tr>
<tr>
<td>Gholhak</td>
<td>43 ± 11</td>
<td>47 ± 13</td>
<td>86 ± 19</td>
<td>88 ± 21</td>
<td>166 ± 31</td>
<td>195 ± 27</td>
</tr>
<tr>
<td>Tajrish</td>
<td>53 ± 21</td>
<td>56 ± 16</td>
<td>95 ± 14</td>
<td>114 ± 22</td>
<td>175 ± 32</td>
<td>197 ± 28</td>
</tr>
</tbody>
</table>
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 in the metro line 1, both at station platforms and outdoor. Raei also conducted a study in 2016 on Tehran metro and reported that the 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].

**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.

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Table 4. Average PM concentrations (in μg/m$^3$) in different sections on the Darvazeh-dowlat station platform.

<table>
<thead>
<tr>
<th>Sections of the platform</th>
<th>PM$_{2.5}$</th>
<th>PM$_{10}$</th>
<th>TSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance</td>
<td>66±17</td>
<td>126±11</td>
<td>262±38</td>
</tr>
<tr>
<td>Middle</td>
<td>38±14</td>
<td>88±15</td>
<td>150±24</td>
</tr>
<tr>
<td>End</td>
<td>43±21</td>
<td>104±17</td>
<td>241±39</td>
</tr>
<tr>
<td>Exit</td>
<td>51±22</td>
<td>113±13</td>
<td>170±28</td>
</tr>
</tbody>
</table>

Table 5. Average PM Concentrations (in μg/m$^3$) over time (peak-hour) on the Darvazeh-dowlat station platform.

<table>
<thead>
<tr>
<th>Daytime, peak hour, working day</th>
<th>PM$_{2.5}$</th>
<th>PM$_{10}$</th>
<th>TSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-7.5</td>
<td>49±18</td>
<td>81±13</td>
<td>173±28</td>
</tr>
<tr>
<td>10-10.5</td>
<td>38±14</td>
<td>69±15</td>
<td>144±16</td>
</tr>
<tr>
<td>5-5.5</td>
<td>63±21</td>
<td>108±17</td>
<td>205±31</td>
</tr>
<tr>
<td>8-8.5</td>
<td>51±17</td>
<td>83±13</td>
<td>175±18</td>
</tr>
</tbody>
</table>

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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].

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.

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

COMPETING INTERESTS
There is not any competing interests between authors.

ACKNOWLEDGEMENTS
The authors acknowledge Iran University of Medical Sciences (IUMS).

ETHICAL CONSIDERATIONS
The authors state that they have no ethical considerations.

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