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RESEARCH PAPER

Investigation of Suspended Particle Concentrations (PM_{10}, $PM_{2.5}$, TSP) in Tehran Subway Line one Stations in the Spring and Autumn

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ABSTRACT
Today, indoor air pollution is a major concern. So far, many quantitative and qualitative studies have been conducted on particulate matter pollution in closed environments, but not much research has been done to measure air pollution in subway station. In this study, we have investigated the concentrations of PM_{10}, $PM_{2.5}$ and TSP particles in 12 underground stations on the oldest and main Tehran metro line, in two seasons, autumn and spring. For sampling suspended particles, we have used a portable direct reading device for monitoring suspended-particles (HAZDUST EPMA5000). We also used Pair T- test to compare the particle concentrations in different modes of the ventilation system (on, off, and inlet air) and Three-way variance analyze. According to the results, the mean concentrations of PM2.5-PM10 - TSP values in line-1 on the station platforms are significantly higher in spring than in autumn, off state of the ventilation system than on state of the ventilation system ($P < 0.001$). Also, the concentration of particles measured in the air of subway stations is higher in the off state of ventilation systems, compared to Inlet air to stations ($P<0.001$). There is a correlation between concentration of particles measured in different sampling season, condition of the ventilation mode (on, off, inlet air) ($P<0.001$). Improving the efficiency of ventilation systems (equipped with a suitable filter) and fan in stations is suggested as one of the factors to reduce the concentration of particles, especially in spring.

KEYWORDS: air pollution, underground stations, ventilation, monitoring.

INTRODUCTION

Today, air pollution is one of the most important environmental problems that, according to research, pollution in recent decades has been the result of human activities. Air pollution has received an increasing amount of attention recently, and the reason is that in these years, harmful chemical compounds in the atmosphere have increased significantly. Metro is a transportation system for millions of passengers each year in many cities around the world. Therefore, the contact of metro passengers with air pollution cannot be considered a trivial issue (Braniš 2006). According to a number of previous studies, the concentration of PM particles in the air inside the subway is higher than the air outside the subway (Bolourchi et al., 2020; Hoseini et al., 2013; Kamani et al., 2014; Kwon et al., 2015; Aarnio et al., 2005; Barmparesos et al., 2016; Onat and Stakeeva, 2014; Hwang and Park, 2019; Correia et al.,

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2020; Olivero-Verbel et al., 2021; Wang et al., 2016; Smith et al., 2020) Contrasting results have been reported in a number of studies. According to metro studies in some countries such as Barcelona (Querol et al., 2012; Martins et al., 2016) Bangkok (Cheevaporn et al., 2004) Stockholm (Cha et al., 2018) the United States (Gendron-Carrier et al., 2018) Seoul (Kim et al., 2016) and a review study by Bin Xu et al (Xu and Hao 2017) the average amount of PM particles was lower than the standard. In these studies, air quality of tunnel environment and platforms. Also, internal ventilation systems have been studied and based on the results, internal ventilation has a key role in maintaining cleaner air in the metro system and reducing the concentration of $PM_{2.5}$ and PM_{10} particles. In a study by Jihwan Son et al. In 2021, it was reported that with a well-ventilated system, the average PM concentration was reduced by 80% at the metro station (Son et al.,2021). According to a 2020 study by Yueming Wen et al., Ventilation is the main measure for optimizing the complex physical environment at a subway station. Assessing and managing the health risks associated with subway ventilation is essential to achieve a healthy subway environment (Wen et al. 2020). Various factors can affect the increase in the concentration of particles in the subway air. Only by knowing and recognizing this issue, it is possible to prevent or reduce its risks as mentioned by Hoseinzadeh, et al., (Hoseinzadeh et al., 2017). Based on the evidence, the concentration of solid particles (PM) in the subway environment is higher than in outdoors, which may be related to the following reasons;1. The subway environment is relatively closed, where the air inside cannot circulate completely and mix with a sufficient amount of fresh air .2. Due to the abundance of internal pollution sources, air quality is poor .3. Erosion of wheels and rails due to train braking, are the main sources of airborne particles inside the subway as mentioned by adams, et al., 2001(Adams et al. 2001). One of the most important factors in dealing with the high concentration of particles in the subway is what time of day and what day of the week it is used. The study by M.C. Mingilon et al. in Barcelona reported a 56% decrease in $PM_{2.5}$ particle concentrations over the weekends (Minguillón et al., 2018). In another study by Luglio et al., It is more during rush hours (Luglio et al., 2021). According to the study of Grydaki et al. In the Athens metro, the concentration of PM10 particles during the day and the first day of the week were higher than the night and weekend (Grydaki et al. 2021). Based on the study of Joo et al., in the South Korean metro, the maximum concentration of PM10 particles was reported between the peak hours in the morning and afternoon (Jo et al. 2020). Also, in the Kelley study in Lubbock, the concentration of PM2.5 particles was reported to be lower on weekends than on other days (Kelley et al. 2020). While several factors affect the concentration in subway systems, a key control for the subway worldwide is the type of ventilation present in tunnels and subway stations (Moreno et al. 2015). Therefore, this study was designed for the first time to determine the concentration of particles in different ventilation conditions in Tehran Metro Line 1, that is the oldest and main metro line in Tehran and is located in the north-south direction of Tehran and has different geographical diversity and population density at stations. Based on the research results, if necessary, suggestions should be made to improve the weather conditions of subway stations of line 1, which is one of the busiest subway lines.

MATERIALS AND METHODS

In this experimental study, the concentration of airborne particles was measured on the platforms of Tehran Metro Line 1 stations. The measured particles were measured in three sizes TSP-PM_{10}- $PM_{2.5}$ during the two seasons of autumn and spring, at 10-15 hours from the middle of the week, Due to the high density of passengers in this period. Tehran Metro Line 1 is one of the busiest lines in Tehran Metro. Additionally, Tehran Metro Line 1 has 29 stations with a length of 39 km. Given that approximately 2 million passengers travel daily on the platforms to use the subway and wait for the train (Raa'ee Shaktaie et al., 2017). Of these 29 stations, 7 stations are above ground (ground stations do not have the mechanical ventilation system and work with natural ventilation) and 21 underground stations are equipped with the mechanical ventilation system. In this study, the criterion for selecting the stations was the existence of a mechanical ventilation system in which 12 underground stations (with a mechanical ventilation system) were randomly selected with different depths and geographical locations. To determine the effect of the ventilation system on the particle concentration, we have measured the particle concentration in the on and off ventilation system modes at three points, the beginning, the middle, and the end of the platforms at each station. the concentrations of $PM_{2.5}$, PM_{10}, TSP particles in the inlet air to the station aerators (the aerators are outside the station) and the air distributed by the air conditioning systems on the platforms of the stations (in the on and off state of the air conditioners) Was studied. To measure the concentration of suspended particles $PM_{2.5}$, PM_{10}, TSP, a portable direct reading suspended particle - monitoring device called HAZ DUST model 5000 EPMA was used. Additionally, to measure the particles in the inlet air the aerator of the stations in this case, is similar to the method for measuring the air inside the stations. The particle measurement method was performed according to OSHA CIM instructions. In this method air is drawn by a vacuum pump through a 47 mm diameter FRM style membrane filter and dust particles are detected every second. The sampling flow rate was 1- 4.3 liters per minute, working temperature was -10ºC to 50ºC, humidity was 95%, and storage temperature was 20ºC to 60ºC. Dust concentrations were immediately calculated and displayed on the LCD –SKC EPMA-5000. The Variables being studied are in accordance with Table 2. At the end of each sampling period, the measurement data were transferred to a computer for analysis. The effect of ventilation system factors, station depth, the geographical location of stations, and measurement season on the emission of suspended particles were analyzed with SPSS software version22. Paired-t-test was used to compare the concentrations of pollutants in the two seasons and in different modes of the ventilation system, separately for each station. Three-way variance has been used to investigate the effect of depth and geographical location on the concentration of particles in the platforms of metro stations during two seasons.

Table1. The specifications of the study stations are given in

#	Station name	geographical location	Depth of station (m)
	Tajrish	North	57
	Gholhak	North	16
	Mirdamad	North	22
	Beheshti	Center	20
	Mofteh	Center	17
	7 Tir	Center	12
	Darvazeh Dowlat	Center	21
	Saadi	Center	30
	Imam Khomeini	Center	20
	15 Khordad Square	Center	10
	Mohammadiyah Square	South	11
	Shrine of Imam Khomeini	South	8

There are two types of ventilation systems in metro stations; A) Air conditioners: V3 and V4 are the air conditioners at the end of the platforms. V5 is the air conditioner in the middle of the platforms and office rooms. B) Ventilators: there is a ventilation system along with each station along the tunnel. V1 and V2 are inter-tunnel fans. The V5 is used as both an air conditioner and a ventilator (in an emergency such as a fire). It emits twice as much air as air conditioners. The operation of the ventilation system in the subway is such that first, the imported air passes through the silencer 1#, and after a short distance, it passes through the normal damper #1. In the next step, the filtered air enters the air washer (In the metro ventilation system, the temperature is lowered to about 10-12 ºC. The water of the air washer in the Tehran metro system is drained once a month). The air then passes through the normal #2 damper and exits through the jet fans (Jet fans and motors are designed for temperatures of 250°C. The fan's speed in a subway line is constantly 1500 rpm. The amount of electric current used by jet fans is 120mAh). Finally, the air is discharged through the valves and distributed at the stations (before the air is distributed between the valves, there is silencer 2#).

Table2. Study variables

Variable type	Unit of measurement
Concentration of Suspended Particles on Station Platforms	($\mu g/m^3$)
Station Depth	Meter
Station Ventilation System	On/Off/ Inlet air
Geographical Location	North, Center, South
Season	during the two seasons of autumn and spring

RESULTS & DISCUSSION

Based on the results obtained from different modes of the ventilation system, the average concentration of TSP, PM_{10} and $PM_{2.5}$ in the on mode of the ventilation system is significantly different from the off mode of the ventilation system ($P < 0.001$). Also, the average concentration of TSP, PM10, and PM2.5 in the off mode of the ventilation system is significantly different from the inlet air ventilation system ($P < 0.001$), but the average concentration of TSP, PM10, and PM2.5 in the on mode of the ventilation system is not statistically different at the level of 0.05. According to the results, PM2.5-PM10 - TSP values in line one stations are higher in spring than in autumn. High passenger population at stations, traffic, and congestion of streets around stations, and unfavorable weather conditions (presence of winds that cause severe dust storms), important reasons are the increase in particle concentration in the spring. Another important factor is the lack of adequate humidity by subway ventilation systems in the spring due to a sharp drop in temperature on the platforms. This reduces the efficiency of the ventilation system in absorbing suspended particles and thus increases the concentration of suspended particles in the stations. Among the stations of Tehran metro line 1, "Saadi Station" had the highest particle concentration in all three sizes TSP-PM_{10}-$PM_{2.5}$ Saadi station due to its geographical location in the city center. Additionally, the existence of bag and shoe factories in this area and the high passenger density in this station as well as the high traffic of cars in the streets around the station are prone to high concentrations of particles. Based on the comparison of similar studies conducted with this study, we find that the concentration of suspended particles in the Tehran metro is higher than the metros studied in other parts of the world. Comparison of particle concentrations between Tehran Metro and Seoul and Shanghai Metro that the particle concentration is higher in Tehran Metro (Table 3). The existence of automatic doors on the platforms, high-efficiency ventilation system, new passenger trains is the main factors of low particle concentration in these cities, according to studies.

Table3. Comparison of particle concentrations in Tehran, Seoul and South Korea metro systems

Parameter	Iran	China	Korea
$PM_{2.5}$	Based on the results obtained from this study, the highest particle concentration was obtained in the autumn at **245 µg / m3.**	According to a 2016 study by Wang, J et al. In Shanghai, the particle concentration was reported being **39.7 µg / m3.**	#
PM_{10}	According to the results of this study, the highest particle concentration in the autumn is **416,667 µg / m3**.	A dose of **27.6 µg / m3** has been reported.	According to a study by Kim, G et al. In 2016, in South Korea, the particle concentration was reported to being120 µg / m3.

The results of Table 4. show the $PM_{2.5}$ particle concentrations during the two seasons of spring and autumn. In spring, the highest concentration is related to Shahid Mofteh station with 118.66 µg/m^3. Additionally, in the autumn, Saadi station has the highest concentration with 142 µg/m^3. The concentration of $PM_{2.5}$ particles in the two modes of on and off ventilation system in the autumn shows that the highest concentration is related to Saadi station with 142 µg/m^{3}in off ventilation mode and 245 µg/m^3 in the on-ventilation system(Table 6). The results of Table 6. show the concentration of $PM_{2.5}$ particles in both on-ventilation system and the air inlet in the autumn to the ventilation devices. In autumn, the highest concentration air inlet is related to Haft Tir and Beheshti stations with a concentration of 82.6 µg/m^3, and in mode of on ventilation is related to Saadi station with a concentration of 142 µg/m^3.

Table 4. Statistical results of measuring particle concentration ($PM_{2.5}$) in the condition of "on ventilation" system in the platforms of Tehran metro line 1 stations, during the two seasons of autumn and spring.

Station	Season	Average (µg/m^3)	P-value
Tajrish	$Pm_{2.5}$_ spring season $Pm_{2.5}$_ autumn	51.66 70	0.174
Gholhak	$Pm_{2.5}$_ spring season $Pm_{2.5}$_ autumn	45.666 15.666	0.01
Mirdamad	$Pm_{2.5}$_ spring season $Pm_{2.5}$_ autumn	23.333 45	0.025
Beheshti	$Pm_{2.5}$_ spring season $Pm_{2.5}$_ autumn	35.667 23	0.123
Mofteh	$Pm_{2.5}$_ spring season $Pm_{2.5}$_ autumn	118.667 53	0.002
7 Tir	$Pm_{2.5}$_ spring season $Pm_{2.5}$_ autumn	46.667 2.667	0.001
Darvazeh Dowlat	$Pm_{2.5}$_ spring season $Pm_{2.5}$_ autumn	53.667 2.667	0.002
Saadi	$Pm_{2.5}$_ spring season $Pm_{2.5}$_ autumn	53.667 142	0.009
Imam Khomeini	$Pm_{2.5}$_ spring season $Pm_{2.5}$_ autumn	47.667 38	0.697
15 Khordad Square	$Pm_{2.5}$_ spring season $Pm_{2.5}$_ autumn	73.667 6	0.001
Mohammadiyah Square	$Pm_{2.5}$_ spring season $Pm_{2.5}$_ autumn	44.667 63.333	0.001
Shrine of Imam Khomeini	$Pm_{2.5}$_ spring season $Pm_{2.5}$_ autumn	18.333 110.333	0.001

Table 5. Statistical results of measuring the concentration of particles ($PM_{2.5}$) in the platforms of Tehran metro line 1 stations during two modes of "on and off ventilation" system in autumn

Station	Ventilation system mode	Average (μg/m^3)	P-value
Tajrish	on Off	70 88	0.013
Gholhak	on Off	15.667 7.33	0.0001
Mirdamad	on Off	45 80.667	0.002
Beheshti	on Off	23 69	0.038
Mofteh	on Off	53 6.667	0.184
7 Tir	on Off	2.667 63	0.001
Darvazeh Dowlat	on Off	2.667 59.333	0.0001
Saadi	on Off	142 245	0.003
Imam Khomeini	on Off	38 89.667	0.0001
15 Khordad Square	on Off	6 127.667	0.001
Mohammadiyah Square	on Off	63.33 20.667	0.001
Shrine of Imam Khomeini	on Off	110.33 145.333	0.001

Table 6. Comparison of particle concentrations ($PM_{2.5}$) between "ventilator inlet" and "on ventilation" in the autumn.

Station	Ventilation system mode	Average (μg/m^3)	P-value
Tajrish	on Inlet air	70 76.333	0.558
Gholhak	on Inlet air	15.667 11	0.025
Mirdamad	on Inlet air	45 32.333	0.108
Beheshti	on Inlet air	23 82.667	0.0001
Mofteh	on Inlet air	53 6	0.0001
7 Tir	on Inlet air	2.667 82.667	0.0001
Darvazeh Dowlat	on Inlet air	2.667 61.333	0.0001
Saadi	on Inlet air	142 78	0.003
Imam Khomeini	on Inlet air	38 7	0.126
15 Khordad Square	on Inlet air	6 13.333	0.065
Mohammadiyah Square	on Inlet air	63.33 3	0.0001
Shrine of Imam Khomeini	on Inlet air	110.33 35	0.001

The results of Table 7 show that the probability value (P-value) for the station and system (ventilation) variables is less than 0.001, so the effect of these two variables on the $PM_{2.5}$ concentration is statistically significant at the level of 0.05.

Table 7. The result of three-way analysis of variance to investigate the effects of station, system (ventilation) and season variables on the concentration of $PM_{2.5}$

Variable	Average of squares(μg/m^3)	Degrees of freedom	Statistical value F	P-value
Station	9280.42	11	6.59	< 0.001
System (ventilation On/Off/ Inlet air)	50373.26	2	35.80	< 0.001
Season	1920.07	1	1.36	0.244
The amount of error	201	1407.23		

Table 8. Results of analysis of variance model after adding variables of depth(m) and geographical location

Variable	Statistical value F	Probability value
geographical location (North, Center, South)	2.50	P-value= 0.085
Depth(m)	4.05	P-value < 0.001

Table 9. The result of three-way analysis of variance to investigate the effects of station, system (ventilation) and season variables on PM_{10} concentration

Variable	average of squares(μg/m^3)	Degrees of freedom	Amount value F	P-value
Station	2205.67	11	6.45	< 0.001
System (ventilation On/Off/ Inlet air)	121901.13	2	35.65	< 0.001
Season	5211.67	1	1.52	0.218
The amount of error	3419.32	201		

The results of Table 9 show that the probability value (P-value) for the station and system (ventilation) variables is less than 0.001 .Therefore, the effect of these two variables on PM_{10} concentration is statistically significant at the level of 0.05. According to Table 9, the probability value for the season variable was calculated to be 0.218, which is greater than 0.05, i.e., it is not significant at the level. The effect of variables on TSP concentration using three-way analysis of variance is shown in Table10.

Table 10. The result of three-way analysis of variance to investigate the effects of station, system (ventilation) and season variables on TSP concentration.

Variable	average of squares(μg/m^3)	Degrees of freedom	Statistical value F	P-value
Station	21797.51	11	5/89	< 0.001
System (ventilation On/Off/ Inlet air)	120162.03	2	32/49	< 0.001
Season	20768.17	1	5/62	.019
The amount of error	3697.86	201		

The results of Table 10 show that the probability value (P-value) for the station and system variables (ventilation) is less than 0.001 and for the season is 0.0199. Therefore, the effect of these three variables on TSP concentration is statistically significant at the level of 0.05. The results of the analysis of variance model after adding the variables of depth and geographical location are shown in Table 11.

Table 11. The results of the analysis of variance model after adding the variables of depth and geographical location.

Variable	Statistical value F	Probability value
geographical location	4.72	P-value= 0.031
Depth(m)	2.60	P-value= 0.007

The results of Table 11 show that the variables of geographical location and depth are significant at the level of 0.05.

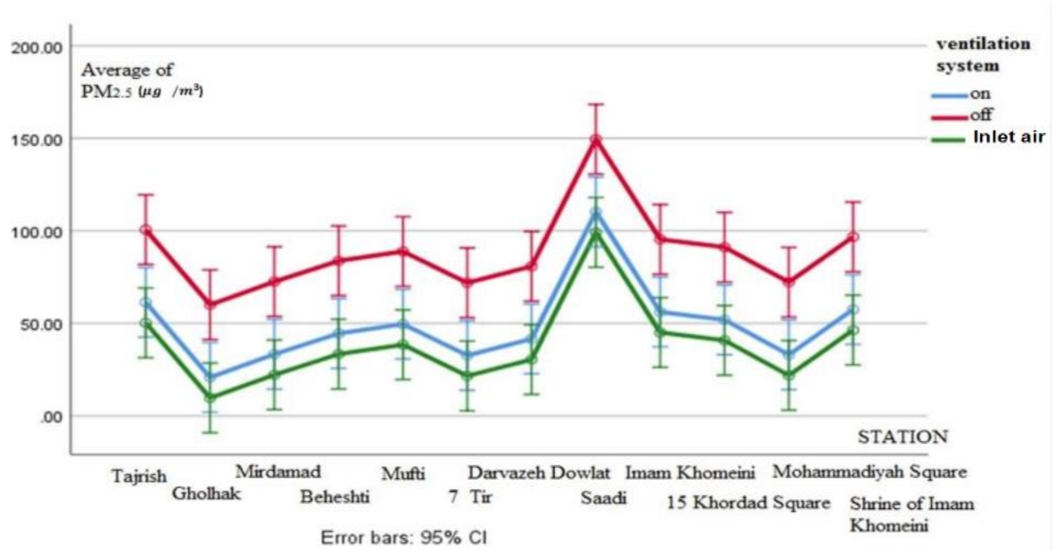

Fig. 1. $PM_{2.5}$ concentration for off, on and inlet air ventilation system by station (Tajrish, Gholhak, etc.) $PM_{2.5}$ µg/m^3

Figure 1 shows the concentration of $PM_{2.5}$ particles in different modes of the ventilation system in the stations of line one of the metro. In the inlet air the metro ventilator, the lowest particle concentration is close to the particle concentration in the on state, and in the off state, there is a higher particle concentration of $PM_{2.5}$. See the stations understudy Saadi station has the highest particle concentration of $PM_{2.5}$ in three modes of ventilation system (on, off, and ventilation inlet air). Saadi Station is located in the center of the city due to its geographical location. Additionally, the existence of bag and shoe factories in this area and the high passenger density in this station as well as the high traffic of cars in the streets around the station are prone to high concentrations of pm2.5 particles.

Figure 2 shows the concentration of $pm_{2.5}$ particles in different modes of the ventilation system in the two seasons of spring and autumn, the concentration of $PM_{2.5}$ particles in the inlet air the ventilation system in the two seasons of spring and autumn in the off state is the highest. Additionally, there is little difference between the concentrations of $PM_{2.5}$ particles in the air entering the ventilation system and its on state. This indicates that when fresh air enters the subway intake fans due to various factors such as (high number of passengers, high depth of stations, high frequency of trains, etc.) the concentration of $PM_{2.5}$ particles increases compared to the outside air. By turning on the ventilation system, some of these particles are captured.

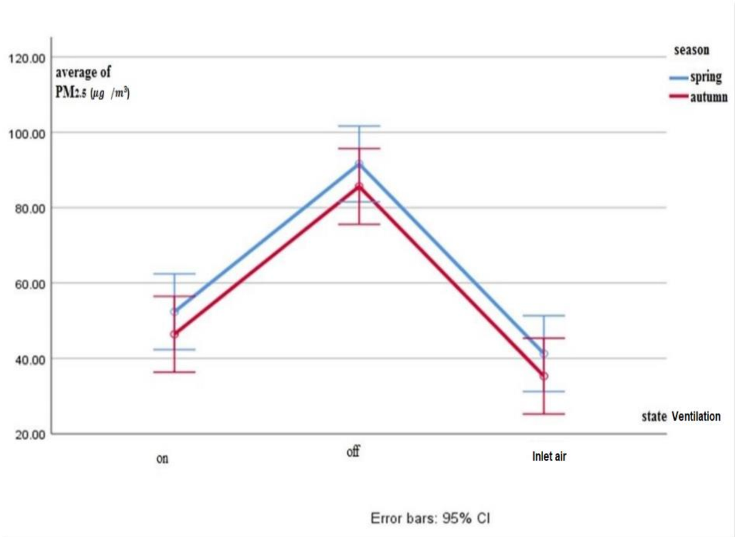

Fig. 2. $PM_{2.5}$ concentration for on, off and inlet air ventilation system by $PM_{2.5}$ ventilation system On/Off/ Inlet air in µg/m^3

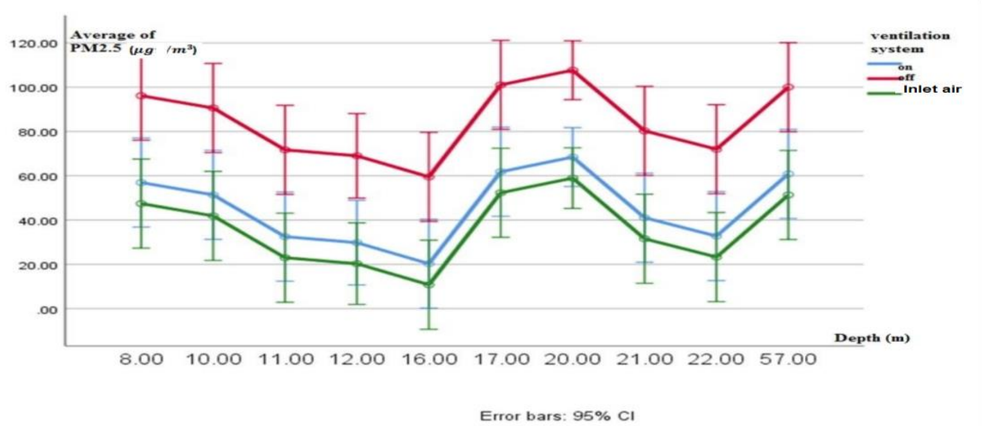

Fig. 3. The trend of changing the mean $PM_{2.5}$ concentration by changing the station depth.

Figure 3 shows the concentration of $PM_{2.5}$ particles in different modes of the ventilation system and at different depths of the stations. The concentration of $PM_{2.5}$ particles in the off state of the ventilation system has higher values than in the on state and the air entering the ventilators. Since depth alone is not an effective factor in increasing the concentration of particles in stations. The concentration of particles at different stations is not an absolute function of depth variable. However, as shown in Figure 3, at the Tajrish station at a depth of 57 meters, which is the highest depth between stations, the concentration of particulate matter $PM_{2.5}$ is relatively higher than other stations. Tajrish station is prone to high concentration of $PM_{2.5}$ particles due to its high depth compared to other stations as welled high passenger traffic.

CONCLUSION

According to the results, despite the increase in PM2.5-PM10 - TSP concentration in some stations in autumn, but by comparing all the stations in the three different modes of the ventilation system in both seasons, the particle concentration in spring is higher than in autumn.

Insufficient rainfall and strong winds in the spring are the main factors increasing the concentration of particles. In general, among the stations of Tehran Metro Line 1, Saadi Station had the highest particle concentration in all three sizes. Saadi station due to its geographical location in the city center. The existence of bag and shoe production workshops and shopping centers in the streets around this station as well as high traffic and car traffic in the streets around the station and high passenger density in it are prone to high concentration of particles. Based on the results between depth and geographical location Stations there is a strong correlation in that the deeper we go from south to north, the greater the depth of the stations as well as the pm2.5 particle concentration. The results showed that there was a small difference between the mean concentrations of TSP, PM_{10}, and $PM_{2.5}$ particles in the condition of the on-ventilation system with inlet air the stations. Based on the comparison of similar studies with the present study, we find that the concentration of suspended particles in the Tehran metro is higher than the concentration of suspended particles in the air of subways in other parts of the world. An important factor in the high concentration of particles in Tehran metro stations is the lack of highly efficient ventilation system. The subway ventilation system is a cold system and the required air is supplied from outside. Therefore, failure to install a particle collector filter will cause suspended particles to enter the station. Also, the inefficiency of air washbasins and the lack of regular cleaning of air washbasins (which is done once every few years) and should be washed at least twice a year, can be other effective factors in this regard. In the results of the present study, the ventilation system in metro stations has little effect on reducing the particle concentration. According to the studies, the main reason is the lack of filters in the ventilation system of a Tehran metro line since 2017.

Among the effective factors in reducing the concentration of particulate matter in Tehran metro stations, the following can be mentioned;

- Improving the efficiency of ventilation systems (equipping with a suitable filter) and fans in the station. Regular and periodic washing of the walls of subway tunnels (Which is washed once a year).
- Design and application of PSD (Platform screen DOORS) or platform separator systems in metro stations, which according to research, is effective and useful in reducing the concentration of pollutants and the absence of pollutants in the tunnel to the station platform.
- Do not use metallic brake pads with asbestos
- Do not use old and worn type trains
- Increase the frequency of cleaning and washing of stations and tunnels.

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This research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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