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Investigating the performance of urban air quality monitoring station in measuring PM2.5 and PM10: A case study in Tehran, Iran

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Abstract

Background: In recent years, new findings on the relationship between human health and air pollutants have emerged, underscoring the necessity for appropriate site selection of air monitoring stations.

Methods: This analytical-cross-sectional study aimed to compare the concentration levels of PM_{10} and $PM_{2.5}$, as measured by weight method, with data collected from an air quality monitoring station (AQMS) in Tehran. Initially, data were collected from the Tarbiat Modares AQMS. The accuracy of this data was then evaluated using a high-volume sampler and Grimm dust monitor situated approximately 200 meters away from the Tarbiat Modares station. The study period was between June 2017 and October 2017, and the frequency of sampling was every six days according to the instructions.

Results: The results revealed that the average concentration levels of PM_{10}, as measured during the sampling period by the high-volume sampler, the Grimm device, and the air quality measurement station, were 143.54±33.84, 70.95±7.06, and 110.06±27.08 μg.m^{-3}, respectively. The highest daily concentration of PM_{10} was recorded by the high-volume sampler device at 197.12 μg.m^{-3}.

Conclusion: This study found a weak correlation between the aerosol concentration data obtained from the monitoring station and those obtained from the Grimm device and the high-volume sampler. Therefore, it is crucial to ensure the quality control and assurance of data collected from monitoring stations for accurate decision-making and planning.

Keywords: Air pollution, Particulate matter, Validation study, Dust, Cross-sectional studies

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Introduction

Air pollution is the first leading environmental risk factor for health (1). The exposure to air pollutants imposes different health effects on humans, depending on the composition, exposure level, exposure duration, exposure frequency, and toxicity of the pollutant of interest (2,3). The International Agency on Cancer Research (IARC) has classified air pollution and particulate matter as a carcinogen for humans (Group I) (4). Numerous studies have estimated that the number of excess deaths attributed to ambient air pollution ranges from 7 to 8.9 million deaths per year (5).

Tehran, Iran's capital and most populous city, is dealing with high concentrations of air pollution, especially particulate matter with an aerodynamic diameter less than 10 and 2.5 μm (PM_{10} and $PM_{2.5}$). This is due to the rapid and unsustainable industrialization and urbanization, the mounting number of motorized transportation means, and dust episodes (6-9). Air pollution in Tehran has been one of the main challenges for the government, policymakers, and the public during the last decades. Several studies have been conducted on different aspects of particulate air pollution in Tehran, including chemical characteristics of PM (10-12), source apportionment of $PM_{2.5}$ (13,14), and estimating the health impacts attributed to the short- and long-term exposure to PM (7,15,16). However, there are still areas with insufficient or lack of knowledge.

Understanding the temporal and spatial variations of pollutants within the urban environment is of critical importance for any strategy and plan toward reducing air pollution levels, promoting air quality, and protecting public health (17). Continuous air quality monitoring is a primary tool for assessing air pollution patterns (18). This is performed by temporary and fixed air quality monitors (AQMs) located in residential, suburban, and industrial areas (17,19). However, a significant problem for AQMs is the lack of a complete dataset, i.e., the presence of missing values. This could be due to equipment malfunctions, calibration issues, operation and maintenance needs, computing errors, filter changes, or power outages (20,21).

Air pollution studies on improving air quality management actions, determining long-term trends, and locating possible sources of pollution could lead to more efficient regulations on air quality (18). Establishing a network of AQMs in each city is an infrastructural action in the management of air quality. The objectives for such a network include quantifying the effect of air pollution control strategies using monitoring and evaluating the trend of changes and fluctuations, identifying the hazards for human ecosystems, determining the population exposure and assessing the effect of air pollution on human health, providing public informing and warning systems, developing a reliable dataset for research in areas with no AQMs, source apportionment of air pollutants, and evaluating the compliance with national standards and international guidelines. Tehran's Air Quality Control Company (TAQCC), which operates a network of AQMs in Tehran, possesses similar objectives (7). Epidemiological studies consistently present cutting-edge findings on the association between air pollutants and health (22). These studies necessitate appropriate siting and planning of AQMs to secure precise and accurate pollutant measurements. Employing more precise, accurate, and reliable tools for assessing the effects of pollutants on health leads to estimates that more closely reflect actual conditions (23). The reliability of AQMs data depends primarily on the location of the AQMs site, followed by the efficient operation and maintenance of these facilities. A few organizations in Tehran are measuring air pollution levels for several years. However, their datasets have been questioned in terms of reliability, mainly due to the lack of on-time and proper calibration, insufficiently trained employees, and inadequate financial resources. This study aimed to measure PM_{10} and $PM_{2.5}$ concentrations in an area in Tehran and compare the obtained values with the reported concentrations in a nearby AQM.

Materials and Methods

Sampling location

The present study was conducted on one of the AQMs in Tehran. The sampling site for this study was located on the rooftop of one building in Shariati Hospital of Tehran. This building is located 200 m from the Tarbiat Modares (TB) AQM. The building's height was about 12 meters, and there was no obstacle for the sampler in a radius of 8 m (Table 1). In total, 21 samples were taken and compared to the TB monitor. During the study period, the average, maximum, and minimum air temperatures were 26.78, 38.00, and 17.00°C, respectively (Table 2). Figure 1 shows the sampling location for the present study.

Sampling strategy

PM_{10} and $PM_{2.5}$ concentrations were measured using a high-volume sampler and a portable PM monitor (GRIMM Aerosol Spectrometer, model 11E, Grimm Aerosol Technik GmbH, Ainring, Germany). Using the portable PM monitor, PM_{10}, $PM_{2.5}$, and PM1 concentrations were measured simultaneously. This device automatically stores the values in its memory, capable of calculating averages over several seconds, minutes, hours, and even days. Also, using temperature, pressure and humidity sensors, the standard conditions can be easily calculated and included in the measurements. Operating on the principle of laser measurement, this device counts particles and measures their diameters. The measurement rules in this device are in accordance with the USEPA and European Union rules and standards. This device uses light scattering technology to count particles (24). According to the environmental air standard method of the American Environmental Organization, it is used for sampling suspended particles in the ambient air. The engine of the device is designed for high-speed, continuous 24-hour sampling.

In addition, a high-volume air sampler was used to collect PM_{10} mass. The sampler ran using a glass fibre filter (fiberglass filter with dimensions of 203 × 254 mm) under an airflow of 1.3-1.7 m^3/min (1400 m^3/d). High-volume devices underwent calibration whenever the sampling device's location changed or any device repairs

Table 1. Characteristics of the sampling site

Parameter	Information/Value
Location site	Tarbiat Modares Monitor
Distance to the sampling site	200 m
Distance to highway	150 m
Longitude	51.3′ degree
Latitude	35.7′ degree
$PM_{2.5}$ instrument	Met One BAM-1020, USA
PM_{10} instrument	Environment SA, MP 101M, France

Table 2. Descriptive statistics of meteorological parameters during the study period

Parameter	Average	SD	Minimum	Maximum	Median
Daily temperature (°C)	26.7	5.5	17.0	38.0	28.5
Wind speed (m/s)	2.5	1.3	1.9	4.7	2.3
Visibility (m)	10.1	0.3	9.3	10.9	9.7

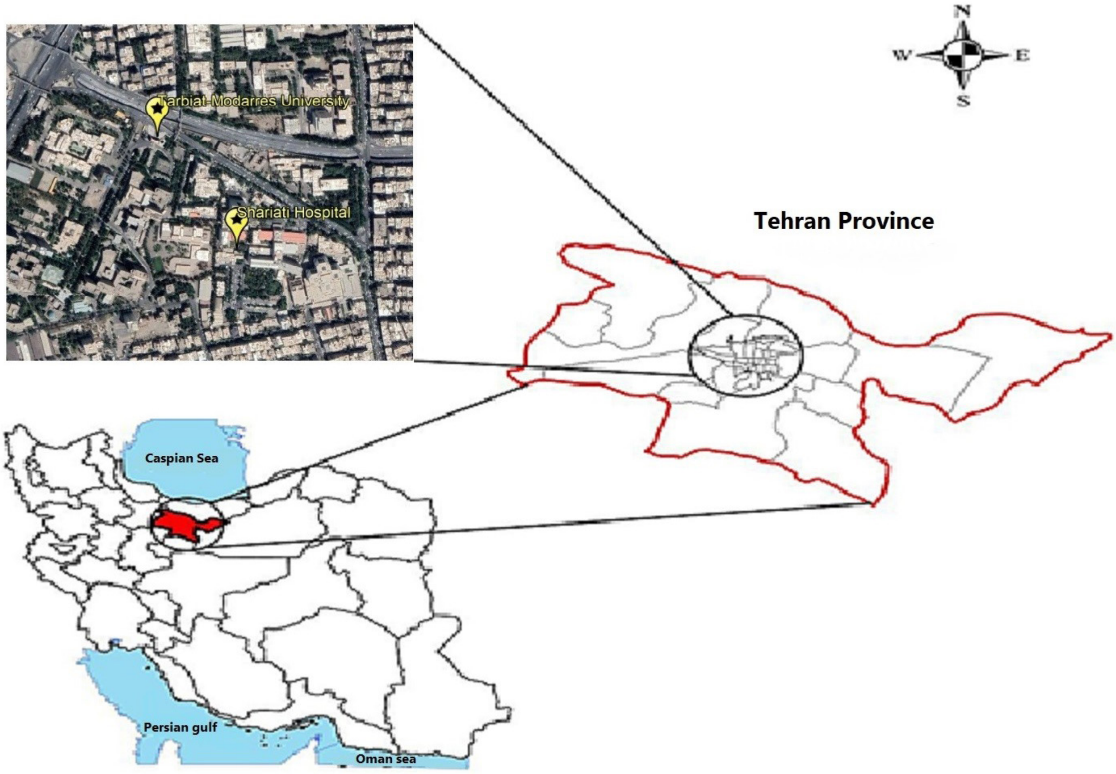

Figure 1. The sampling location for the present study

and servicing took place, especially when replacing the device's suction pump. Calibration was also done before initiating the measurement, with a separate calibration curve being prepared and drawn anew each time the device was calibrated. There is a relationship between the flow rate measured by the device's stability section (apparent flow rate) and the device's actual flow rate (25). Based on the EPA's instruction, the samples were collected every six days from June 2017 to October 2017 (five months). Each sampling session was initiated from morning until the next 24 hours.

The ambient air sample at the measurement station is directed through sampling probes into one or more analyzers situated within the air quality monitoring station (AQMS). Usually, the particle analyzer has an independent probe. For these analyzers, the sample air enters a section termed the "flow distributor" via the probe, then, it proceeds into the gas analyzers through distinct pipes. These analyzers immediately determine the concentration of pollutants following the sample's analysis, and the ensuing data are typically transferred to the section responsible for data maintenance and storage. Ultimately, the monitoring data can be accessed and utilized via the reporting software on the computer within the station (26). Since the objective of this study was to compare the measured concentrations of PM with those formally reported from an AQM, the PM_{10} and $PM_{2.5}$ concentrations reported by the Tarbiat Modares station were acquired from the TAQCC. The data for air temperature, wind speed, visibility, and precipitation were obtained from the Mehrabad Airport's meteorological station.

Mass analysis of PM_{10}

Before sampling, the glass fibre filters were kept at a temperature of 550 °C for 5 hours. For cooling, the filters were held at a temperature range of 22 to 24 °C and relative humidity of 50% (±5) for 48 hours. Then, the filters were weighed using a microbalance (Mettler-Toledo Inc).

After PM_{10} sampling, the filter was kept at a temperature of 22-24 °C and relative humidity of 50% (±5) for 48 hours. Afterward, the filters were weighed using the microbalance (Mettler-Toledo Inc). PM mass was calculated considering the primary and secondary mass of filters.

Statistical analysis

The concentrations reported from TB monitor were statistically compared to and validated by the concentrations obtained from the high-volume sampler (as the standard method) and portable PM monitor. Data handling and statistical analysis were performed using Excel (Microsoft Office 2013, Microsoft, US.) and R Programming Software (R v4.1.1 for Windows). In all analyses, a significance level of 0.05 was considered.

Results

PM concentrations

The present study was conducted on one of the AQMs in Tehran. In total, 21 samples were taken and compared to the TB monitor. During the study period, the average, maximum, and minimum air temperatures were 26.78, 38.00, and 17.00°C, respectively. The averages (±standard deviation) of the PM_{10} concentrations for the TB monitor, high-volume sampler, and portable PM monitor were 110.06±27.08, 70.96±7.06, and 143.54±33.80 μg/m³, respectively (Table 3). The maximum and minimum concentrations of PM were recorded by the high-volume sampler (197.12 μg/m³) and portable PM monitor (62.09 μg/m³), respectively (Table 3).

In addition, the average (±standard deviation) concentrations of $PM_{2.5}$ in TB monitor and high-volume sampler were 35.30±8.50 and 20.80±4.20 μg/m³, respectively. The highest concentration of $PM_{2.5}$ was observed in TB monitor (53.08 μg/m³) (Table 3).

The box plots in Figure 2 present the median, 25th percentile, 75th percentile, minimum, and maximum concentrations of PM_{10} and $PM_{2.5}$ in the TB monitor and sampling site. In this plot, the dotted horizontal lines, indicating the total concentrations of PM_{10} and $PM_{2.5}$, show the amount of PM data exceeding the relevant standard values.

Table 3. PM_{10} concentrations observed in TB monitor and high-volume sampler and $PM_{2.5}$ concentrations observed in TB monitor and portable PM monitor

Parameter	PM_{10}			$PM_{2.5}$	
	TB monitor	High-volume sampler	Portable PM monitor	TB monitor	Portable PM monitor
Average	110	143.5	70.9	35.3	20.8
Median	101.2	139.7	68.3	33.0	19.3
Standard deviation	27	33.8	7	8.5	4.2
Variance	733.5	1145.4	49.8	72.5	17.7
Minimum	70.7	98.7	62	19.1	16.3
Maximum	176.6	197.1	89	53	30.3

Monthly variations of PM

Fluctuations of monthly concentrations of PM_{10} and $PM_{2.5}$ during the study period were evaluated. For the high-volume sampler, the minimum and maximum monthly concentrations of PM_{10} were observed in July-August (134.32±17.32 μg/m³) and October-November (185.60±3.04 μg/m³), respectively. In the case of TB monitor (155.80 μg/m³) and the portable monitor (81.65 μg/m³), the maximum monthly PM_{10} concentrations were also observed in October-November. However, the minimum concentrations of TB monitor (93.22 μg/m³) and the portable monitor (62.09 μg/m³) occurred in June-July.

For $PM_{2.5}$ particles, the minimum monthly concentrations of TB monitor (25.44 μg/m³) and the portable monitor (18.60 μg/m³) were recorded from June to August.

Daily variations of PM

Figures 3 and 4 illustrate the variations of PM_{10} and $PM_{2.5}$ concentrations on different days of the week. The middle days of the week (Tuesday and Wednesday, based on the Persian calendar) showed higher concentrations of PM, possibly due to the more vehicle transportation and traffic within the city. Conversely, weekends (Thursday and Friday, according to the Persian calendar) recorded lower PM concentrations. This could be due to reduced transportation within the city, as most people typically choose to travel or remain at home during the weekends.

Comparing to the national standard and WHO guideline

The guideline values set by the World Health Organization (WHO) for PM_{10} and $PM_{2.5}$ (24 hours) are 25 and 15 μg/m³ (27), respectively. The National Standards of Iran for PM_{10} and $PM_{2.5}$ (24 hours) are 150 and 35 μg/m³, respectively. The daily average concentrations of PM_{10} in TB monitor (110.06 μg/m³), high-volume sampler (70.94 μg/m³), and portable monitor (70.94 μg/m³) were higher

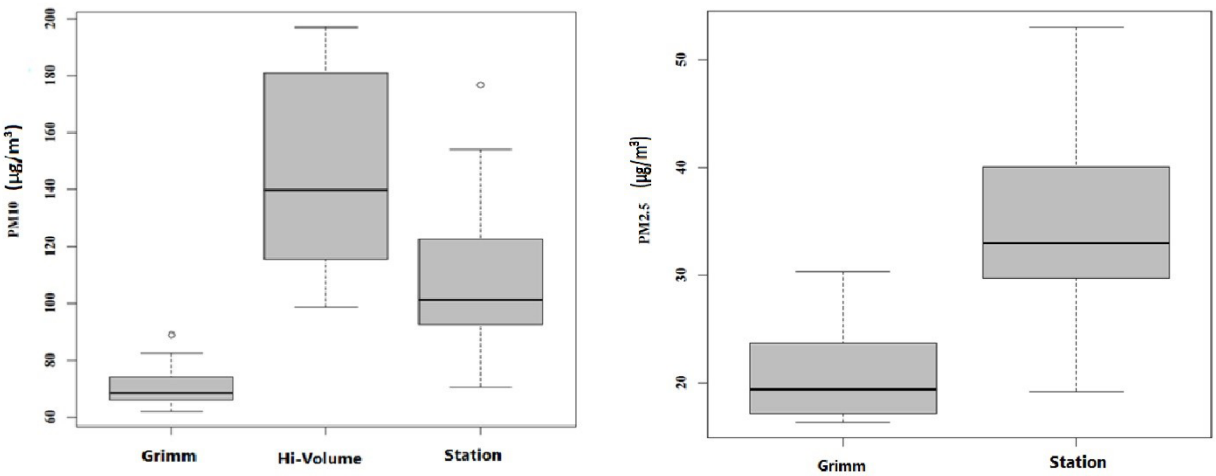

Figure 2. Box plot for comparing PM_{10} (left) concentrations in TB monitor, high-volume sampler, and portable PM monitor; Box plot for comparing $PM_{2.5}$ (right) concentrations in TB monitor and portable PM monitor

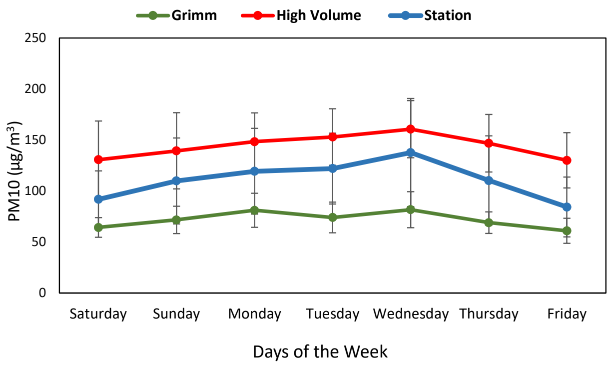

Figure 3. Daily variations of PM_{10} in TB monitor, high-volume sampler, and portable PM monitor

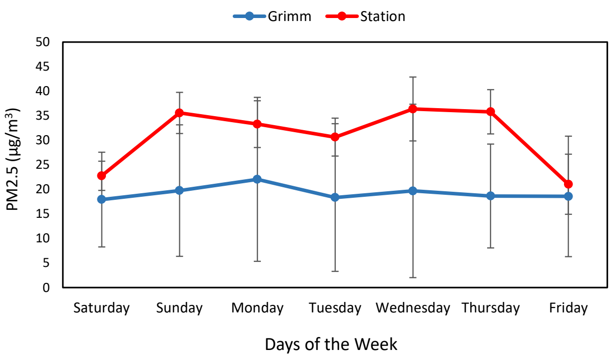

Figure 4. Daily variations of $PM_{2.5}$ in TB monitor and portable PM monitor

Table 4. Intra-class correlation (ICC) for the concentrations of PM_{10} and $PM_{2.5}$ between TB monitor, high-volume sampler, and portable monitor

PM/Station	TB monitor	High-volume sampler	Portable PM monitor
PM_{10}			
TB monitor	1	0.3	0.2
High-volume sampler	-	1	-
Portable PM monitor	-	0.1	1
$PM_{2.5}$			
Portable PM monitor	0.2	-	1

Table 5. The Lin's concordance correlation coefficient (CCC) between TB monitor, high-volume sampler, and portable monitor

	TB high-volume sampler	TB portable monitor	High-volume sampler – portable monitor
Confidence interval 95%	0.01 – 0.5	0.1 – 0.2	0.00 – 0.05
Error correction factor	0.6	0.1	0.06
Pearson's correlation coefficient	0.4	0.6	0.4
Concordance correlation coefficient	0.3	0.09	0.1

than the WHO's guideline and lower than that of Iran's National Standards. In addition, the daily $PM_{2.5}$ mean in TB monitor (34.14 µg/m^3) and portable monitor (20.59 µg/m^3) was higher than the WHO's guideline and still lower than Iran's National Standards.

Validation of TB monitor

Table 4 presents the intra-class correlation (ICC) between the concentrations of PM_{10} and $PM_{2.5}$ in various measurements. ICC coefficients show a weak correlation between TB monitor and the results of this study. The ICC coefficients for TB monitor-high volume sampler, TB monitor-portable monitor, and high volume sampler-portable monitor were 0.39, 0.21, and 0.13, respectively. These results indicate that TB measurements are inconsistent with those from the high-volume sampler, as the gold standard. Additionally, there was a weak correlation between the high-volume sampler and portable monitor measurements (0.13 for PM_{10} and 0.2 for $PM_{2.5}$). This might be attributable to their different measurement mechanisms (gravimetric in the high-volume sampler versus light scattering in the TB monitor and Grimm instrument). Another factor could be the significant discrepancy in the airflow of the devices (around 1 m^3/min in the high-volume sampler versus 1.2 L/min in the portable monitor).

Table 5 presents the Lin's concordance correlation coefficient (CCC) between measurements in TB monitor and the present study. The CCC indicated a weak correlation between TB monitor and the results of this study. The CCCs for TB monitor-high volume sampler, TB monitor-portable monitor, and high volume sampler-portable monitor were 0.28, 0.02, and 0.19, respectively.

According to Table 4, the ICC for $PM_{2.5}$ measurements in TB monitor and portable monitor was 0.23, indicating a weak correlation between the two datasets. This indicates that the $PM_{2.5}$ concentrations obtained from the TB monitor are inconsistent with those measured by the portable PM monitor.

Discussion

The results of this study showed that PM_{10} concentrations obtained from TB monitor are consistently lower than those measured by the high-volume sampler. There was a distance and height difference between the locations of two devices that can contribute somehow to the difference in the PM concentrations. Goudarzi et al conducted a study on the validation of PM measurements in Tehran and found that the PM_{10} concentrations reported by TAQCC may not be reliable due to the lack of instrument sensitivity, as similar concentrations were reported for several consecutive hours (28). In another study, PM_{10}, $PM_{2.5}$, and PM_1 concentrations were measured simultaneously using a high-volume sampler and Grimm portable PM monitor. The results indicated a significant difference between the measurements of the two devices since higher concentrations were observed by the high-volume sampler (29).

Fluctuations of monthly concentrations of PM_{10} and $PM_{2.5}$ during the study period were evaluated. For the high-volume sampler, the minimum and maximum monthly concentrations of PM_{10} were observed in July-August and October-November, respectively. In the case of TB monitor and the portable monitor, the maximum monthly PM_{10} concentrations were also observed in October-November. However, the minimum concentrations of TB monitor and the portable monitor occurred in June-July. The maximum monthly $PM_{2.5}$ concentrations were also observed in October-November. Fossil fuels are the major sources of ambient fine particles ($PM_{2.5}$ and PM_1). It can be posited that during the colder months (such as October and November), an increase in the burning of fossil fuels is experienced. This escalation in emissions, coupled with the phenomenon of atmospheric inversion, leads to the consequent accumulation of particulate matter in the atmosphere during these chillier seasons. The topography of Tehran, being surrounded by mountains, is further seen to exacerbate these unfavorable conditions.

The daily average concentrations of PM_{10} in TB monitor high-volume sampler and portable monitor were higher than the WHO's guideline and lower than that of Iran's National Standards. In addition, the daily $PM_{2.5}$ mean in TB monitor and portable monitor was higher than the WHO's guideline and still lower than Iran's National Standards. Between 2012 and 2017, the annual mean concentrations of PM_{10}, $PM_{2.5}$, and No_2 in Tehran were higher than the WHO or quality guideline values. The authors stated that the annual average concentrations of PM_{10} were between 78.9 and 89.9 μg/m^3 from 2012 to 2017. By contrast, the $PM_{2.5}$ concentration declined 14.3% from 2012 to 2017. The annual mean concentration of ambient No_2 was increased during six years (2012-2017) (23).

With regard to the PM_{10} validation data measured at the monitoring station, it was consistently observed that the station reported a lower concentration than the actual concentration indicated by the reference device, namely the high-volume sampler device. It is important, however, to take into account the differences in height and distance between the high-volume sampler and the monitoring station, as these variables are likely to contribute to the observed discrepancies between the results from the high-volume sampler and those from the monitoring station.

In the study by Goudarzi et al on the validation of PM measurement in Tehran, based on statistical analysis and the consistent readings taken by the Air Quality Control Company at different times, it has been concluded that the data published by this company regarding PM_{10} lacks the necessary credibility due to the absence of sensitivity in the device for recording and measuring fluctuations.

In the study of Goudarzi et al on the validation of PM concentrations in Tehran based on the statistical analyses and the stability of the readings taken by the air quality control company at different times on a specific duration, that indicates the lack of device sensitivity in recording and measuring fluctuations, the data published by this company lacks the necessary credibility regarding PM_{10} (28).

Limitations of this study

In terms of the data measured by the authors, the errors related to measurement and calibration and maintenance issues of the devices were observed. The authors have no information regarding the collocated data of the instruments, flow calibration, and quality assurance and quality control (QA/QC) at the network level. Furthermore, according to personal communication with the technical officer of the AQMSs, it was conveyed that QA/QC procedures adhered to are exactly as specified in the manual of monitoring instruments used at each AQMS.

Conclusion

The objective of this study was to evaluate the condition of the measuring stations. The findings have apprised the accountable entities in this field about the essentiality of placing increased emphasis on the crucial matter of QA/QC at these stations.

The results of this study showed that there is a weak correlation between the PM concentration reported by an urban monitoring station with the concentration measured by a high-volume sampler and a portable PM monitor. The urban monitor (TB monitor) recorded lower PM levels compared to the high-volume sampler as the standard method. It should be noted that parts of this difference can be due to the distance between the two devices, the small sample size, and the insufficient duration of the study. Future studies can focus on these limitations. Based on this study, it is necessary to control the quality and guarantee the quality of the measurements in the TB monitor and other monitors of the Tehran air quality monitoring network.

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Authors' contribution

Conceptualization: Zahra Aboosaedi, Kazem Naddafi, Ramin Nabizadeh Nodehi, Mohammad Sadegh Hassanvand.
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Resources Zahra Aboosaedi, Kazem Naddafi, Ramin Nabizadeh Nodehi, Mohammad Sadegh Hassanvand.
Software: Zahra Aboosaedi, Kazem Naddafi, Ramin Nabizadeh Nodehi, Mohammad Sadegh Hassanvand, Sasan Faridi.
Supervision: Kazem Naddafi, Ramin Nabizadeh Nodehi, Mohammad Sadegh Hassanvand.
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Writing–original draft: Zahra Aboosaedi, Kazem Naddafi, Mohammad Sadegh Hassanvand, Sasan Faridi.
Writing–review & editing: Zahra Aboosaedi, Kazem Naddafi, Mohammad Sadegh Hassanvand.

Competing interests
The authors declare that they have no conflict of interests.

Ethical issues
The authors certify that this manuscript is the original work of the authors and all data collected during the study are as presented in this manuscript, and no data from the study will be published elsewhere separately. Ethical code: IR.TUMS.SPH.REC.1396.2171.

References

1. GBD 2016 Risk Factors Collaborators. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet. 2017;390(10100):1345-422. doi: 10.1016/s0140-6736(17)32366-8.
2. Amini H, Yunesian M, Hosseini V, Schindler C, Henderson SB, Künzli N. A systematic review of land use regression models for volatile organic compounds. Atmos Environ. 2017;171:1-16. doi: 10.1016/j.atmosenv.2017.10.010.
3. Keshtgar L, Shahsavani S, Maghsoudi A, Anushiravani A, Zaravar F, Shamsedini N, et al. Investigating the relationship between the long-term exposure to air pollution and the frequency of depression in Shiraz during 2010-2017. Environ Health Eng Manag. 2021;8(1):9-14. doi: 10.34172/ehem.2021.02.
4. Taghizadeh F, Mokhtarani B, Rahmanian N. Air pollution in Iran: the current status and potential solutions. Environ Monit Assess. 2023;195(6):737. doi: 10.1007/s10661-023-11296-5.
5. Burnett R, Chen H, Szyszkowicz M, Fann N, Hubbell B, Pope CA 3rd, et al. Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. Proc Natl Acad Sci U S A. 2018;115(38):9592-7. doi: 10.1073/pnas.1803222115.
6. Amini H, Hosseini V, Schindler C, Hassankhany H, Yunesian M, Henderson SB, et al. Spatiotemporal description of BTEX volatile organic compounds in a Middle Eastern megacity: Tehran study of exposure prediction for environmental health research (Tehran SEPEHR). Environ Pollut. 2017;226:219-29. doi: 10.1016/j.envpol.2017.04.027.
7. Faridi S, Shamsipour M, Krzyzanowski M, Künzli N, Amini H, Azimi F, et al. Long-term trends and health impact of PM2.5 and O3 in Tehran, Iran, 2006-2015. Environ Int. 2018;114:37-49. doi: 10.1016/j.envint.2018.02.026.
8. Molina LT, Zhu T, Wan W, Gurjar BR. Impacts of Megacities on Air Quality: Challenges and Opportunities. Oxford University Press; 2020. doi: 10.1093/acrefore/9780199389414.013.5.
9. Shamsipour M, Hassanvand MS, Gohari K, Yunesian M, Fotouhi A, Naddafi K, et al. National and sub-national exposure to ambient fine particulate matter (PM2.5) and its attributable burden of disease in Iran from 1990 to 2016. Environ Pollut. 2019;255(Pt 1):113173. doi: 10.1016/j.envpol.2019.113173.
10. Motesaddi Zarandi S, Hashempour Y, Nowrouz P. Characterizing of air pollution in Tehran: comparison of two air quality indices. Civ Eng J. 2017;3(9):749-58. doi: 10.21859/cej-030911.
11. Parvizimehr A, Norouzian Baghani A, Hoseini M, Sorooshian A, Cuevas-Robles A, Fararouei M, et al. On the nature of heavy metals in PM10 for an urban desert city in the Middle East: Shiraz, Iran. Microchem J. 2020;154:104596. doi: 10.1016/j.microc.2020.104596.
12. Hassanvand MS, Naddafi K, Kashani H, Faridi S, Kunzli N, Nabizadeh R, et al. Short-term effects of particle size fractions on circulating biomarkers of inflammation in a panel of elderly subjects and healthy young adults. Environ Pollut. 2017;223:695-704. doi: 10.1016/j.envpol.2017.02.005.
13. Taghvaee S, Sowlat MH, Hassanvand MS, Yunesian M, Naddafi K, Sioutas C. Source-specific lung cancer risk assessment of ambient PM2.5-bound polycyclic aromatic hydrocarbons (PAHs) in central Tehran. Environ Int. 2018;120:321-32. doi: 10.1016/j.envint.2018.08.003.
14. Taghvaee S, Sowlat MH, Mousavi A, Hassanvand MS, Yunesian M, Naddafi K, et al. Source apportionment of ambient PM2.5 in two locations in central Tehran using the Positive Matrix Factorization (PMF) model. Sci Total Environ. 2018;628-629:672-86. doi: 10.1016/j.scitotenv.2018.02.096.
15. Li Z, Zhang X, Liu X, Yu B. PM2.5 pollution in six major Chinese urban agglomerations: spatiotemporal variations, health impacts, and the relationships with meteorological conditions. Atmosphere. 2022;13(10):1696. doi: 10.3390/atmos13101696.
16. Faridi S, Niazi S, Yousefian F, Azimi F, Pasalari H, Momeniha F, et al. Spatial homogeneity and heterogeneity of ambient air pollutants in Tehran. Sci Total Environ. 2019;697:134123. doi: 10.1016/j.scitotenv.2019.134123.
17. Hirabayashi S, Kroll CN. Single Imputation Method of Missing Air Quality Data for i-Tree Eco Analyses in the Conterminous United States. 2017. Available from: https://

www.itreetools.org/documents/51/Single_imputation_method_of_missing_air_quality_data_for_i-Tree_Eco_analyses_in_the_conterminous_United_States.pdf.
18. Taghizadeh F, Mokhtarani B, Rahmanian N. Air pollution in Iran: the current status and potential solutions. Environ Monit Assess. 2023;195(6):737. doi: 10.1007/s10661-023-11296-5.
19. Kim Y, Kelly S, Krishnan D, Falletta J, Wilmot K. Strategies for imputation of high-resolution environmental data in clinical randomized controlled trials. Int J Environ Res Public Health. 2022;19(3):1307. doi: 10.3390/ijerph19031307.
20. Huang Z, Yu Q, Liu Y, Ma W, Chen L. Optimal design of air quality monitoring network for pollution detection and source identification in industrial parks. Atmosphere. 2019;10(6):318. doi: 10.3390/atmos10060318.
21. Saeipourdizaj P, Sarbakhsh P, Gholampour A. Application of imputation methods for missing values of PM10 and O3 data: interpolation, moving average and K-nearest neighbor methods. Environ Health Eng Manag. 2021;8(3):215-26. doi: 10.34172/ehem.2021.25.
22. Ghorani-Azam A, Riahi-Zanjani B, Balali-Mood M. Effects of air pollution on human health and practical measures for prevention in Iran. J Res Med Sci. 2016;21:65. doi: 10.4103/1735-1995.189646.
23. Yousefian F, Faridi S, Azimi F, Aghaei M, Shamsipour M, Yaghmaeian K, et al. Temporal variations of ambient air pollutants and meteorological influences on their concentrations in Tehran during 2012-2017. Sci Rep. 2020;10(1):292. doi: 10.1038/s41598-019-56578-6.
24. Grimm aerosol. Spectrometer portable Environmental Dust monitor simultaneous measurement of PM10, PM2.5 and PM1, model #1.07. Available from: https://www.durag.com/en/grimm-aerosol-technik-4528.htm.
25. US EPA, Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air; Sampling of Ambient Air for Total Suspended Particulate Matter (SPM) and PM10 Using High Volume (HV) Sampler... 1999. Report No.: US.EPA-Method IO-2.1.EPA/625/R-96/010a.
26. Heard DE. Analytical Techniques for Atmospheric Measurement. Blackwell Publishing; 2006.
27. World Health Organization (WHO). WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide: Summary of Risk Assessment, Global Update 2005. WHO; 2005. Available from: http://www.euro.who.int/Document/E87950.pdf.
28. Goudarzi G, Geravandi S, Saeidimehr S, Mohammadi MJ, Vosoughi Niri M, Salmanzadeh S, et al. Estimation of health effects for PM10 exposure using of Air Q model in Ahvaz city during 2009. Iran J Health Environ. 2015;8(1):117-26. [Persian].
29. Zallaghi E, Goudarzi G, Sabzalipour S, Zarasvandi A. Estimation of PM2.5 pollutant and risk of chronic obstructive pulmonary disease (COPD) in Ahvaz, Iran. Jundishapur J Chronic Dis Care. 2020;9(4):e106131. doi: 10.5812/jjcdc.106131.