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Investigation of vertical distribution of ambient air particulate matter ($PM_{2.5}$ and PM_{10}) concentration at the respiratory heights of children and adults

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ABSTRACT

Introduction: Air pollution is one of the most important environmental risks to human health. The particulate matter tend to be carcinogenic for humans and can pose a greater hazard to children due to their immaturity and lack of development of the immune system. The current study is aimed to investigate the difference in the concentration of Particulate Matter ($PM_{2.5}$ and PM_{10}) in the ambient air in the breathing height of children and adults.

Materials and methods: Particulate matter were measured cross-sectionally in sidewalks, streets, alleys, squares, and parks of Tehran simultaneously at two heights of 160 cm and 70 cm from the ground. As well as, other variables such as vegetation, buildings and meteorological data were also measured in each location.

Results: There was a difference between the concentration of $PM_{2.5}$ at the breathing height of children, with the average concentration of 52.0 µg/m^3, and the concentration of $PM_{2.5}$ at the breathing height of adults with the average concentration of 51.6 µg/m^3, with p-value of 0.013. Even though the difference is significant, it does not seem to have a significant impact on health. No significant difference was observed between the PM_{10} concentration at the breathing height of children and adults; however, there was significant difference between the concentrations of $PM_{2.5}$ with the clean air standard of Iran and data from monitoring stations.

Conclusion: The amount of $PM_{2.5}$ and PM_{10} is almost the same in children and adults based on the difference in breathing height.

Introduction

Effects of air pollution on health

Known as the most important environmental risk factor for human health, air pollution is caused by man-made and natural activities, and [1]. exposure to it has many acute and chronic effects According to the World Health Organization (WHO) in 2019, about 7 million deaths were estimated to be caused by air pollution in the world every year [2].

Suspended particles and their effects on health

According to the Global Burden of Disease

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(GBD) in 2020, Particulate Matter ($PM_{2.5}$) is the 6th risk factor in terms of attributed deaths, with the highest percentage of deaths among all risk factors in the world [2]. World Health Organization surveys demonstrate the fact that for every 10 micrograms increase in the concentration of particulate matter, the mortality rate increases by 1-3% [3]. Particulate matter as a complex mixture of small solid particles and fine liquid droplets in the air, are created naturally through fires, dust phenomena and volcanoes, and through human activities such as the combustion of gas and petroleum compounds, industrial processes as well as cooking [4]. These particles may consist of chemical compounds (e.g. nitrates, sulfates, and organic carbon), organic compounds (e.g. polycyclic aromatic hydrocarbons), biological compounds (e.g. endotoxin), and metals (e.g. iron, copper, nickel, zinc, and vanadium) [5]. The size of particulate matter has a direct relation to their potential in causing health problems. The concerning particles include "large inhalable particles (PM_{10})" with a diameter of 2.5 to 10 μm and "fine particles ($PM_{2.5}$)" with a diameter of fewer than 2.5 μm. Since the particulate matter can be suspended for long periods of time and travel long distances in the atmosphere, it can also result in a wide range of diseases [6]. Based on several epidemiological studies, long-term exposure to particulate matter often leads to respiratory and cardiovascular diseases and creates a risk for the health of city residents [7].

Children's vulnerability to air pollution

Despite the fact all members of society are at risk of particles, heart and lung patients, the elderly and children are at greater risk; In fact, one percent of deaths due to acute respiratory infection in children under 5 years old is because of air pollution [8]. The breathing rate of babies and children is usually faster than those of adults, exposing them to more air pollutants. Since children and infants frequently breathe through their mouths without passing air through effective nasal filters, most of the pollutants are able to be swallowed without passing through any barrier. Because children's immune system and organs of development are not yet fully complete, exposure to toxic air pollutants during infancy and childhood can affect the growth and development of the respiratory system, nerves, glands and immune system, and can increase the risk of cancers later on. Particles are proven to aggravate asthma, cough, throat congestion and other respiratory diseases in children [9].

Vertical profile of PM

Due to the fact that air pollutants can change their concentration vertically as well as horizontally, several studies have investigated their concentration at different heights using balloons, drones, or meteorological towers [10]. According to most of the studies, the concentration of these particles decreases exponentially by increasing the altitude. Many researchers observed an exponential decrease in PM concentration in the vertical direction using a drone [11]. According to another study, experiments using an unnamed aircraft, in general, $PM_{2.5}$ concentration decreases with increasing altitude [12]. In contrast, other researchers found that in a study of three heights of building balconies, $PM_{2.5}$ concentration shows little variation in the vertical profile [13]. In another studyit was investigated the $PM_{2.5}$ concentration on the lower, middle and upper floors of two residential buildings; based on the findings of vertical distribution, the highest average concentration of $PM_{2.5}$ was on the middle floors of the building [14].

Aim of study

According to the literature, there is limited information regarding the vertical distribution of air pollutants, especially particulate matter. Considering the difference in breathing height in

children and adults, and the higher vulnerability of children to air pollutants in comparison to adults, the current study was conducted with the aim of investigating the vertical profile of the concentration of ambient air particulates ($PM_{2.5}$ and PM_{10}) at the breathing heights of children and adults.

Materials and methods

Study time and location

This experiment is a descriptive/analytical and cross-sectional study, conducted on the $PM_{2.5}$ and PM_{10} concentrations in the passing routes of Tehran citizens at the breathing height of children and adults. The current study was carried out on the pavements, alleys, parks, squares, highway bypasses and intersections in the area restricted by three air quality monitoring stations in Tehran (Piroozi station, Tarbiat Modares station, Setad Bohran station). The sampling has taken place in the months of October, November, December, January, February, and March (fall and winter) of 2019-2020, based on the Environmental Protection Agency (EPA) 2020, 2021 sampling program, every six days in the two shifts of morning and afternoon, and about six locations per every shift (2 locations close to the tree barrier, 2 locations close to the building barrier, and 2 locations in outdoors with no barriers). The geographical location of the understudy areas is shown in Fig. 1.

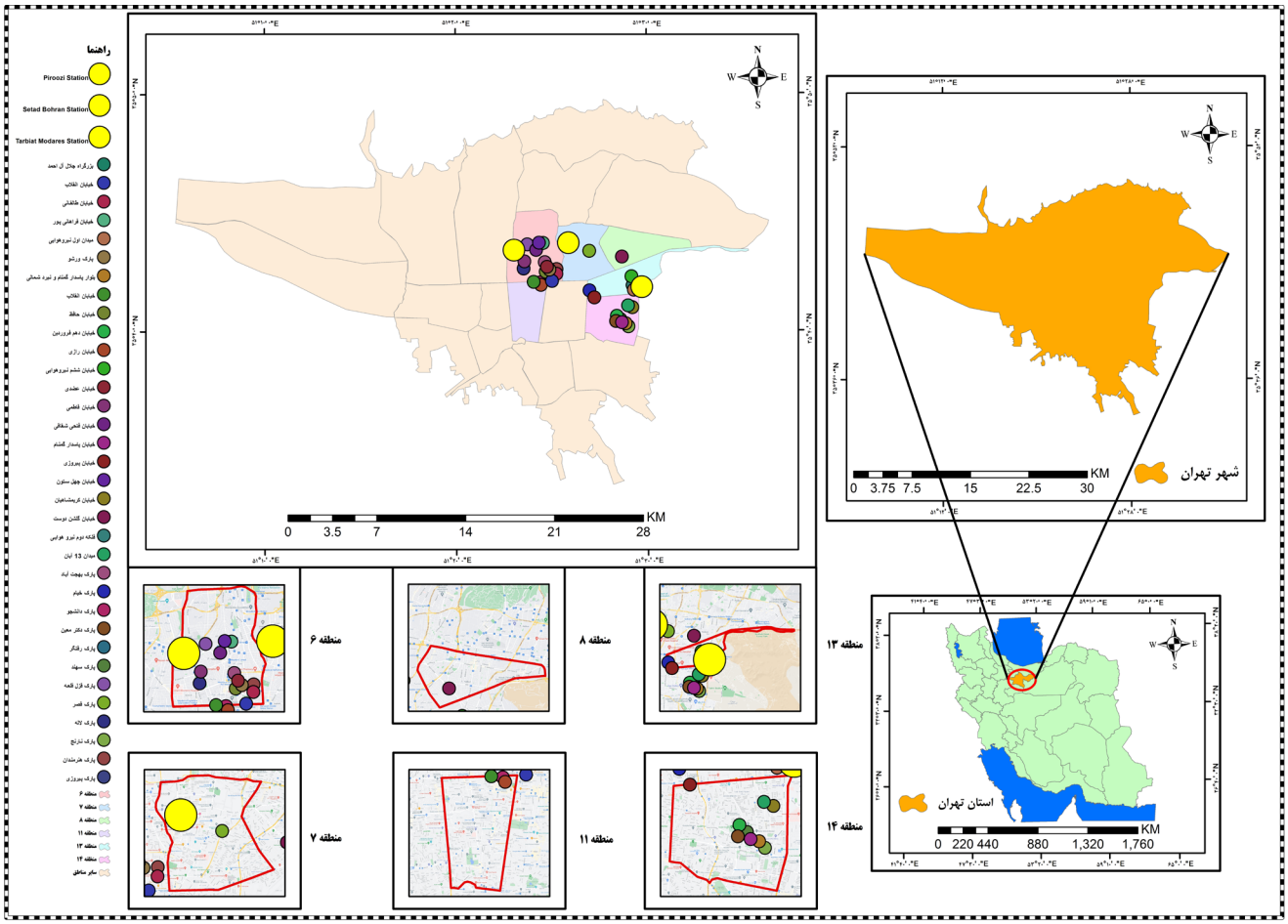

Fig. 1. The geographical location of the understudy areas

Study variables

The $PM_{2.5}$ and PM_{10} concentrations have been measured simultaneously in each location at two heights of 160 cm and 70 cm using Benetech and Xiaomi portable direct reading devices. Other variables include the temperature and humidity of the environment (using Benetech), the height of the surrounding barrier, the distance from the street, the traffic situation, the weather situation, the cloudiness index and the type of tree (by direct observation) and meteorological information such as wind speed, wind direction, and rainfall (obtained from national weather service) have been documented as well. The 24-h particulate matter concentration was also measured using air quality monitoring stations and was calculated by inverse distance weighting method for each study location.

Statistical analysis of data

Subsequently, the obtained raw data were categorized in Excel software. The categorized data were analyzed by SPSS and according to the descriptive statistics (central and dispersion indices), and then reported as tables and graphs. The data were then analyzed by paired t-test in order to compare the particulate matter concentrations ($PM_{2.5}$-PM_{10}) obtained from the measuring devices at two breathing heights as well as the overall comparison of the ($PM_{2.5}$-PM_{10}) concentrations obtained from the devices with the concentrations of particulate matter obtained from air quality monitoring Also, the concentrations of particulate matter were compared with Iran's clean air standard using the one sample t-tset. Eventually, the difference of the PM_{10} and $PM_{2.5}$ concentrations in ambient air at the breathing heights of children and adults was evaluated with the changes of individual variables of the study using paired t-test.

Results and discussion

In this study, there was a total of 4610 data obtained from each $PM_{2.5}$ and PM_{10} concentrations. The average concentration of 4610 samples obtained from $PM_{2.5}$ concentration at both breathing heights was 51.8 µg/m^3 and the average concentration of 4610 samples of PM_{10} at both breathing heights was 67.5 µg/m^3. Based on the breathing height of children and adults, the average concentration of 2305 samples of $PM_{2.5}$ for the breathing height of children was 52 µg/m^3 and the average concentration of 2305 samples of $PM_{2.5}$ in the breathing height of adults was equal to 51.6 µg/m^3. For the concentration of PM_{10}, the average concentration of 2305 samples in the breathing height of children was 67.6 µg/m^3 and the average concentration of 2305 samples in the breathing height of adults was 67.4 µg/m^3. Fig. 2 and 3 show the concentration of PM_{10} and $PM_{2.5}$ based on the breathing height of children and adults. According to the result of the paired t-test and the significant difference in the concentration of $PM_{2.5}$ in two breathing heights, and also in the significant difference in the concentration of PM_{10} in the two breathing heights, the p-value was calculated as 0.013 and 0.515, respectively.

According to the analysis, the average concentration of $PM_{2.5}$ and PM_{10} at the monitoring stations were 45.4 µg/m^3 and 84.1 µg/m^3, respectively. The p-value of 0.00 was obtained based on the paired t-test and the significant difference between the concentrations ($PM_{2.5}$-PM_{10}) at the monitoring stations and the concentrations measured at two breathing heights of children and adults.The average difference between the measured $PM_{2.5}$ concentration and the $PM_{2.5}$ of the monitoring station was equal to 6.8 µg/m^3. As well as the average difference between the measured PM_{10} concentration and the PM_{10} of the monitoring

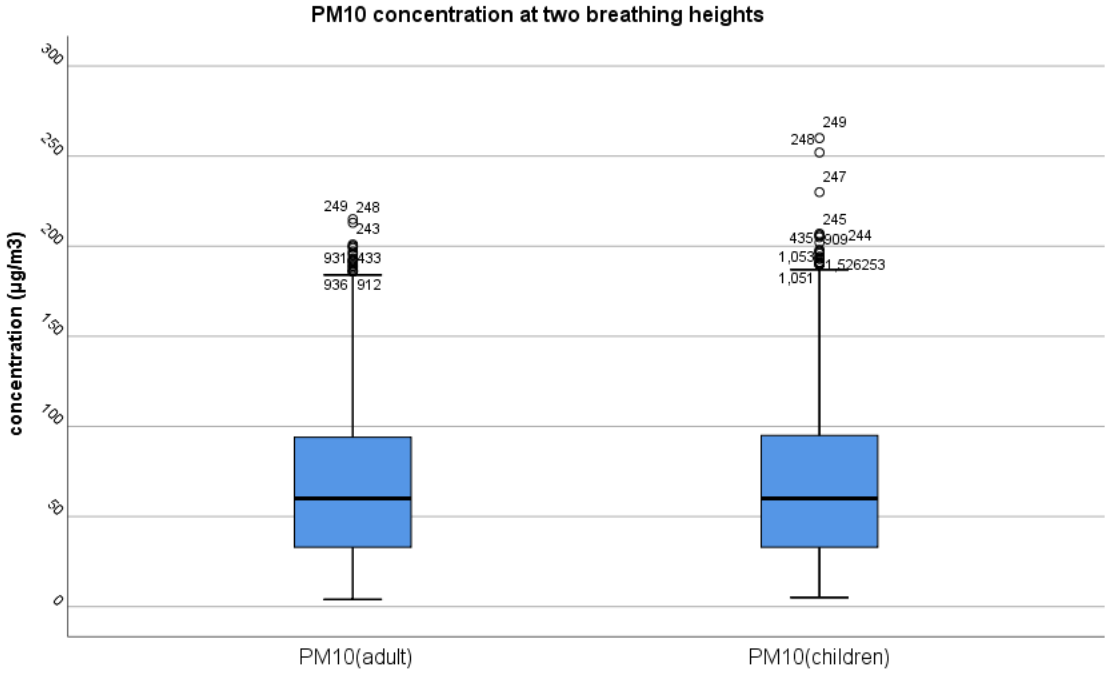

Fig. 2. Box plot of PM_{10} concentration based on the breathing height of children and adults

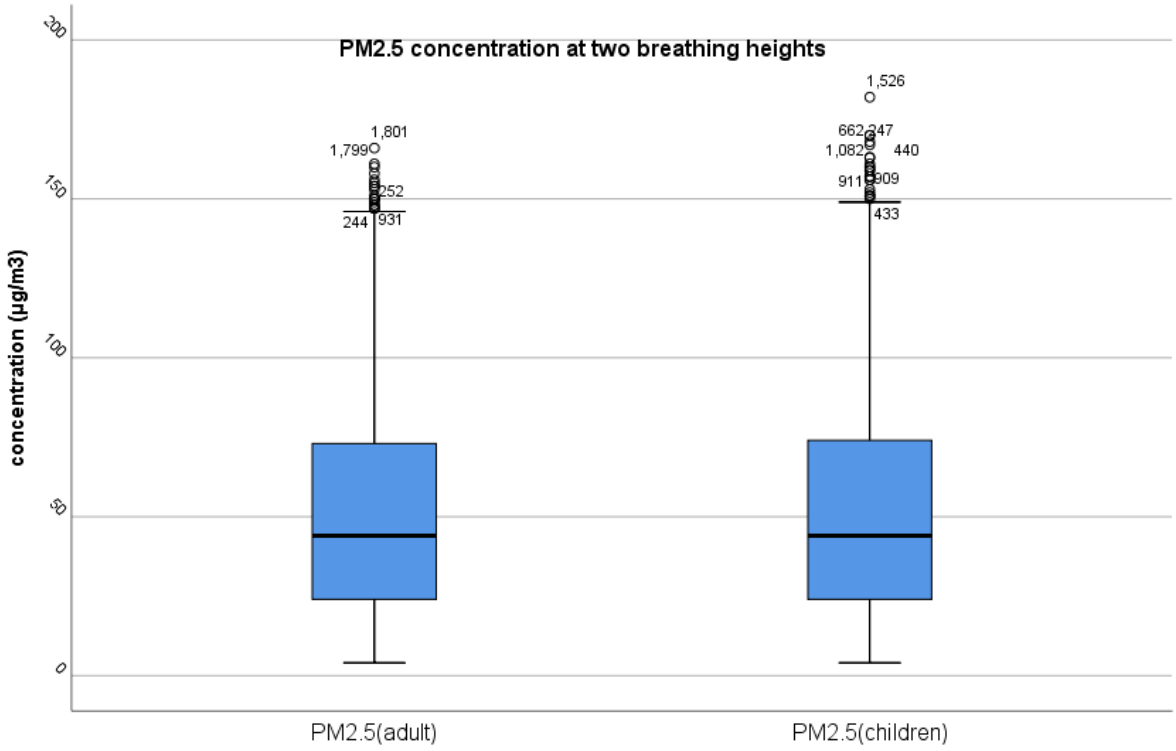

Fig. 3. Box plot of $PM_{2.5}$ concentration based on the breathing height of children and adults

station was equal to -14.7 µg/m.3 According to the clean air standard of Iran approved in 2015, the maximum 24-h standard for PM_{10} and $PM_{2.5}$ was calculated as 150 µg/m^3 and 35 µg/m^3, respectively. The p-value of 0.00 was calculated according to the one sample t-test and the significant difference between the clean air standard of Iran and the concentrations ($PM_{2.5}$-PM_{10}) measured at two breathing heights of children and adults. The average difference of $PM_{2.5}$ concentration measured with $PM_{2.5}$ of clean air standard was equal to 16.8 µg/m^3. As well as the average difference of PM_{10} concentration measured with PM_{10} of clean air standard was equal to -82.4 µg/m^3. Fig. 4 and 5 demonstrate the difference in concentrations measured according to the clean air standard of Iran. Other variables were recorded as follows during the study: the average temperature of 14˚C, the average relative humidity of 39.6, the average distance from the street of 28.9 m, the average precipitation of 0.4 mm, the average height of the barrier of 14.1 m, and the average wind speed of 3.1 m/s. The significant difference in the particulate matter' concentration at two breathing heights with changes in the study variables (p-value) is attached in the word file due to the high volume.

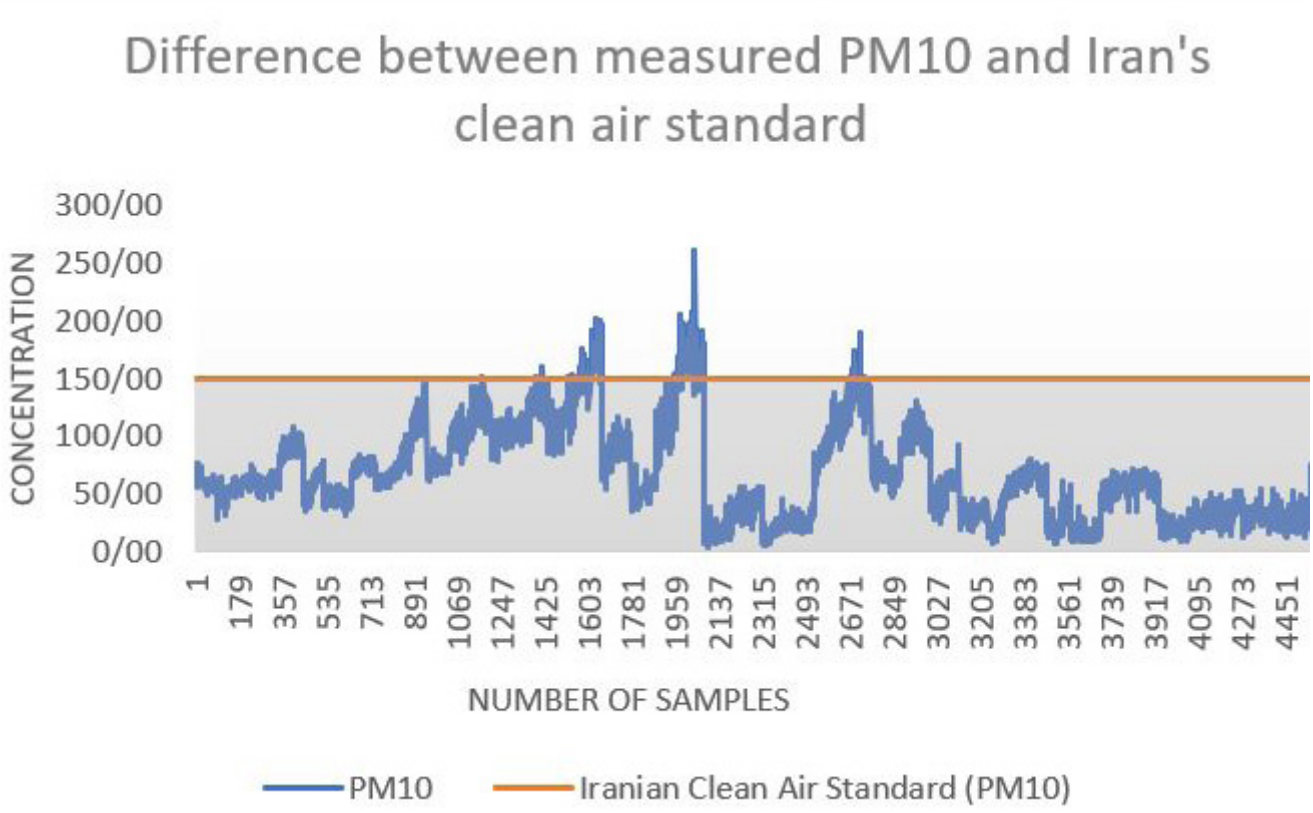

Fig. 4. Linear diagram of the PM_{10} concentration difference measured at two breathing heights and PM_{10} concentration of the clean air standard of Iran

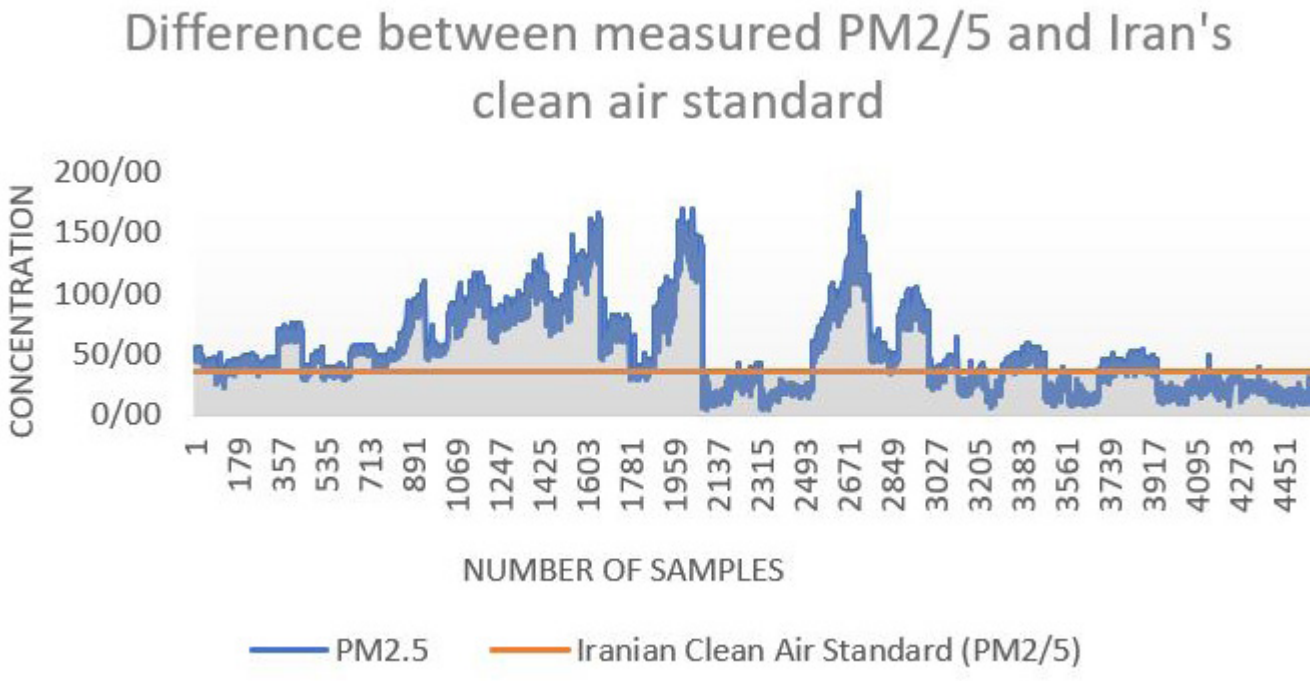

Fig. 5. Linear diagram of the $PM_{2.5}$ concentration difference measured at two breathing heights and $PM_{2.5}$ concentration of the clean air standard of Iran

Several scientific studies previously carried out at different heights and great distances above the ground demonstrate that the concentration of air pollutants, especially particulate matter, decreases with the increase in the height from the surface of the earth. Some researchers collected samples of PM_{10}, $PM_{2.5}$, and PM_1 on the first and fifth floors of a building; according to the results of their study, the concentration of particles decreased with the increase in height [15]. Other researchers found that $PM_{2.5}$ concentration generally decreases with increasing altitude [16]. In a study ot was measured the vertical profiles, horizontal profiles, and size distribution of airborne particles near major roads in Macao; according to the results, a significant decrease in the concentration of PM_{10}, $PM_{2.5}$ and PM_1 was reported with the increase in the height above the ground from 2 m to 79 m [17]. On the other hand, different results were obtained in few other studies; for an instant, according to a study, the concentrations of $PM_{2.5}$ and PM_{10} particles at different altitudes had a complex vertical distribution and formed distinct layers with an increase in altitude [18]. The findings in the current experiment show that there is a significant difference between the $PM_{2.5}$ concentration at the breathing height of children and the height of adults; however, it has no significant health value. No significant difference was observed between PM_{10} concentration at breathing height of children and the height of adults as well.

According to the paired t-test, a significant difference was observed between the concentrations $PM_{2.5}$ of the monitoring stations and the concentrations $PM_{2.5}$ measured at two breathing heights; meaning the measured concentrations at two breathing heights are higher than the concentrations recorded at the monitoring stations. In fact, it is because the sampling location of the monitoring stations is about 3 m above the ground and much higher

than the breathing height of people, while in our experiment, the sampling was done at the breathing height of children and adults. Moreover, there was a significant difference between the clean air standard of Iran $PM_{2.5}$ and the concentrations measured at two breathing heights according to the one sample t-test; this means that the measured concentrations of $PM_{2.5}$ are higher than the clean air standard of Iran. These findings are aligned with the previous studies. Researchers reported that the $PM_{2.5}$ concentrations in different heights were higher in comparison to the standards [18]. Other researchers examined the particulate matter in the air and showed that the concentration of particulate matter usually has a higher amount in comparison to the national standard [19]; in general, it may be due to the fact that in cold seasons, especially winter, the concentration of pollutants, especially particulate matter, is higher than the standard due to atmospheric stability factor.

According to the paired t-test, among the variables, regions 11 and 14 among the urban, Tarbiat Modares station among the monitoring stations, inside the parks among other sampling locations, among the barriers in no-barrier circumstances and next to trees with leaves, among the trees only next to the pine, white mulberry, and eucalyptus trees, in clear and rainy weather among other conditions, the condition of no-clouds, completely cloudy, among the cloudiness indicators, precipitation as well as low and moderate amount of precipitation from the state of precipitation, wind directions of east, southeast among all wind directions, condition of high wind speed, medium, and high temperature, low relative humidity, light traffic, a long distance from the street, the medium and high barrier height in $PM_{2.5}$ concentrations at the breathing height of children is higher than the concentration of $PM_{2.5}$ at the breathing height of adults. Additionally, according to the paired t-test, only in regions 6, 11, and 13 among the variables of urban areas, close to Tarbiat Modares and Pirouzi stations among other monitoring stations, inside parks and sidewalks among other sampling locations, among the barriers in buildings and trees with leaves, only next to the pine and eucalyptus trees among other trees, only in clear, cloudy, rainy and dusty state of weather among all weather conditions, among the cloudiness indices in the condition without clouds, completely cloudy, rainfall and absence of rain, low and medium rainfall conditions among the rainfall conditions, in south, west, southeast and northeast wind directions, high temperature conditions, light and heavy traffic, far distance from the street, medium and high barrier height, the concentration of PM_{10} in the breathing height of children is higher than the PM_{10} concentration in the breathing height of adults.

limitations

The measuring devices were disrupted on rainy days, due to high humidity; thus, sampling was stopped. The measuring stations used in this study were inactive on some days during the sampling. There were some complaints from guards and employees due to sampling next to tall buildings with administrative and organizational use. Sampling in some parks and gardens was disrupted due to low cooperation of the contractors and the dismissal of the researcher. In general, the unfamiliarity of the device and military organizations in understudy locations has created sensitivity in the attributed units.

Conclusion

Ambient particulate matter is a major environmental threat to human health, particularly sensitive groups such as children. In this study, we investigated children exposure to ambient

$PM_{2.5}$ and PM_{10} using real-time PM detectors (Benetech and Xiaomi). The $PM_{2.5}$ and PM_{10} concentrations at the breathing height of children had no significant difference in terms of health in comparison to the $PM_{2.5}$ and PM_{10} concentrations at the breathing height of adults; in other words the present study showed that both children and adults were exposed to ambient air PM at the same levels. However, the mean concentrations of $PM_{2.5}$ during the study period were exceeded the WHO air quality guideline and national standard.

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Competing interests

The Journal of Air Pollution and Health is under the supervision of Tehran University of Medical Sciences, which is the financial sponsor of the research and the place where the authors work and study

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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 ob-served by the authors. The ethics committee code is IR.TUMS.SPH. REC.1399.230.

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