Journal of Air Pollution and Health (Spring 2025); 10(2): 225-242

**Original Article**

Available online at http://japh.tums.ac.ir

# Time-Series analysis of $PM_{10}$ and $PM_{2.5}$ pollutants and estimation of its health effects in Khorramabad city during a period of 5 years

***Faramarz Azimi[1], Mansour Ghaderpoori[1], Fariba Hafezi[2,*]***

[1] Environmental Health Research Center, Lorestan University of Medical Sciences, Khorramabad, Iran
[2] Student Research Committee, Lorestan University of Medical Sciences, Khorramabad, Iran

**ARTICLE INFORMATION**

*Article Chronology:*
Received 25 January 2025
Revised 21 April 2025
Accepted 10 June 2025
Published 29 June 2025

*Keywords:*
Temporal trends; Health effects; AirQ model; Khorramabad; Particulate matter

**CORRESPONDING AUTHOR:**
fariba.hafezi20@gmail.com
Tel : (+98 66) 33300661
Fax : (+98 66) 33300661

**ABSTRACT**

**Introduction:** Air pollution, particularly Particulate Matter (PM), poses a significant global health threat due to its deep penetration into the respiratory system, leading to or exacerbating cardiovascular and respiratory morbidities and mortalities, increased hospital admissions, and premature death. This study aimed to analyze the temporal trends of $PM_{10}$ and $PM_{2.5}$ concentrations in Khorramabad city and to quantify their associated health impacts over a five-year period (2013-2017).

**Materials and methods:** In this descriptive-analytical study, hourly concentration data for $PM_{10}$ and $PM_{2.5}$ from 2013-2017 were obtained from the Khorramabad Environmental Protection Agency. Data underwent rigorous validation based on World Health Organization (WHO) criteria and Z-score method in SPSS to ensure reliability and remove outliers. Time-series analysis and visualization of pollutant variations performed using R software and the Openair package. Health effect quantification, including estimations of attributable mortality and morbidity, conducted using the $AirQ_{2.2.3}$ model, integrating air quality data with epidemiological parameters such as Relative Risk (RR) and Baseline Incidence (BI).

**Results:** The study revealed an overall decreasing trend in $PM_{10}$ and $PM_{2.5}$ concentrations from 2013 to 2016, with a notable increase in $PM_{10}$ concentration observed in 2017. The annual average concentrations of $PM_{10}$ and $PM_{2.5}$ for the entire study period were estimated at approximately 65 $\mu g/m^3$ and 35 $\mu g/m^3$, respectively, significantly exceeding WHO air quality guidelines. Quantification of health effects indicated a total of 1634 attributable deaths due to $PM_{10}$ exposure over the five years, comprising 530 cardiovascular deaths and 103 respiratory deaths. For $PM_{2.5}$, the total attributable deaths were estimated at 933 individuals. The highest health burden for $PM_{10}$ related to total respiratory visits (1341 cases) and cardiovascular deaths (530 cases). Both pollutants exhibited similar diurnal and weekly patterns, with peaks during morning and evening rush hours and mid-week days, and higher concentrations during warm seasons, influenced by dust storms and agricultural burning.

**Conclusion:** The study reveals consistently high levels of $PM_{10}$ and $PM_{2.5}$ in Khorramabad, especially during warmer seasons, leading to a substantial public health burden. These findings emphasize the critical need for effective interventions and long-term strategies to control air pollution and safeguard community health.

Please cite this article as: Azimi F, Ghaderpoori M, Hafezi F. Time-Series analysis of $PM_{10}$ and $PM_{2.5}$ pollutants and estimation of its health effects in Khorramabad city during a period of 5 years. Journal of Air Pollution and Health. 2025;10(2): 225-242. https://doi.org/10.18502/japh.v10i2.19078

## Introduction

According to the World Health Organization, air pollution is recognized as the largest environmental health threat globally [1]. Suspended particles are among the most important air pollutants, especially in urban areas. In 2013, IARC experts classified outdoor airborne particulate matter as Group 1 carcinogens for humans, regardless of the size or chemical composition of the particles [2]. The suspended particles in outdoor air include Total Suspended Particulate matter (TSP), Particulate Matter ($PM_{10}$, $PM_{2.5}$), metal compounds, mineral compounds, pollen grains, microorganisms, and particles resulting from industrial processes and soot, which are emitted by various sources [3, 4]. The size and chemical composition of suspended particles play a decisive role in their impact on human health [5]. $PM_{10}$ particles include those with an aerodynamic diameter of 10 µm or less and are known as thoracic particles because they can pass through the body's first line of defense (the nose and throat) and reach the lungs, where they can deposit [6]. Fine particles range from 0.1 to 2.5 µm and, along with ultrafine particles, referred to as $PM_{2.5}$ (with a diameter of 2.5 µm or less). Due to their ability to penetrate the alveoli, $PM_{2.5}$ particles considered inhalable [7-9]. According to World Health Organization (WHO) guidelines in 2021, the average concentration of $PM_{10}$ and $PM_{2.5}$ pollutants for healthy air over a 24- period is 45 µg/m³ and 15 µg/m³, respectively [10]. Short-term exposure to suspended particles can lead to the exacerbation of cardiovascular, pulmonary, and respiratory symptoms, increased medication needs, and hospital admissions. Long-term exposure is a factor in premature mortality and the exacerbation of cardiovascular and pulmonary diseases. All individuals, especially those with cardiovascular and pulmonary diseases, the elderly, and children, are at risk from fine suspended particles, particularly those with a diameter of less than 2.5 µm. Scientific research has shown that, from the perspective of public health risks, suspended particles are among the main pollutants [11, 12]. The primary sources of this pollutant include fuel combustion (such as burning coal and wood), vehicles and diesel machinery without soot filters, industrial processes, temperature inversions, dust storms, agricultural sources, and emissions from vehicles (exhaust, brakes, tires, etc.) [7]. The concentration of suspended particles in urban atmospheres can be influenced by regional transport and the extensive natural and artificial emissions [13]. Additionally, in urban environments, traffic or vehicles are the main source of suspended particle emissions [14]. Openair is an R software package that serves as a tool for analyzing air pollution data and assessing the Air Quality Index (AQI), available for free as an R package [15]. Time series analysis has been used to study air pollution in many cities, providing a useful tool for better understanding causal relationships in environmental pollution, with the primary goal of describing the history of changes in a specific variable [16]. The results of some time series studies have shown the role of air pollution in both the short and long term, indicating that the rate of hospital admissions for cardiovascular and respiratory diseases, asthma attacks, mortality, and reduced life expectancy increases [17]. One of the most important methods is quantifying the effects, which estimates the impact attributed to each pollutant at a specific time and place [18]. Quantifying the effects attributed to air pollution specifically elucidates the susceptibility of individuals in the community to air pollutants and better illustrates critical air quality conditions [19]. Quantification in the context of air pollution aims to measure the impact of air pollution on public health and is feasible using mathematical and statistical models [18, 20]. The $AirQ_{2.2.3}$ model, designed and provided by the World Health Organization, is a specialized software for quantifying the long-term and short-term health effects of atmospheric pollutants on human health in a specific period and location [21]. This model is one of the most reliable methods for quantifying the effects of air pollution based on the risk assessment approach, grounded in statistical-epidemiological principles. It enables users to assess the potential effects of exposure to a specific pollutant in a defined urban area over a specific time period [22, 23]. Given the significant public health implications of particulate matter and the unique environmental characteristics of Khorramabad city (a valley-surrounded urban area prone to dust storms), a comprehensive assessment of air quality and its health impacts is crucial. Therefore, the main objectives of this research were:(1) To analyze the temporal trends and variations of $PM_{10}$ and $PM_{2.5}$ pollutant concentrations in Khorramabad city from 2013 to 2017 using the Openair package in R software (2). To quantify the attributable short-term and long-term health effects (mortality and morbidity) of these particulate pollutants on the population of Khorramabad using the $AirQ_{2.2.3}$ model.

## Materials and methods

### *Study area*

The study area in the present research is the city of Khorramabad, which covers an approximate area of 35 square km. As the capital of Lorestan Province, it is one of the ancient cities in western Iran, situated at an elevation of 1147 m above sea level. This city is located between 32 degrees, 30 min, and 20 sec east longitude and 21 degrees, 48 min, and 16 seconds north latitude [24]. According to the latest census in 2016, the population of this city is approximately 0.506 million [25]. Fig. 1 shows the map of the study area.

The location of Khorramabad in a valley surrounded by mountains contributes to the accumulation of pollutants, while the rectangular shape of the city and the prevailing winds along this rectangle help disperse the pollutants throughout the urban area [26]. The city has a continuously operating air quality monitoring station, and data from this station utilized for this study. This single station, operated by the Environmental Protection Agency, served as the primary source of ambient air quality data for this study due to its continuous operation and representative location within the urban area.

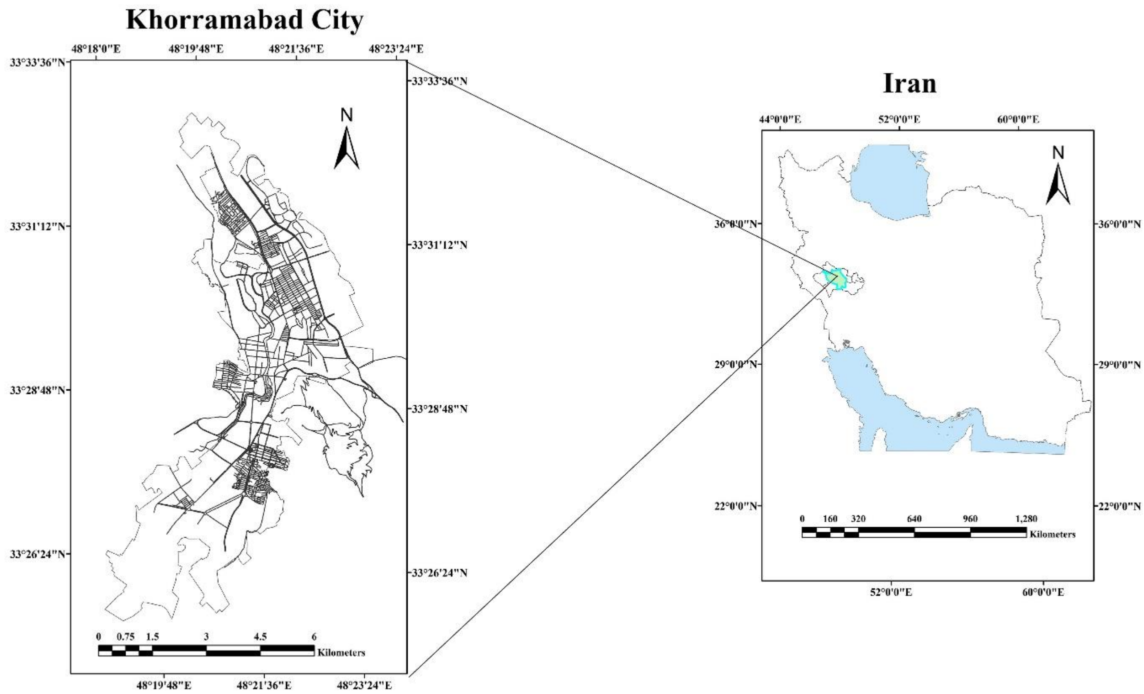


Fig. 1. Map of the study area

### *Data collection and analysis*

In this descriptive-analytical study, hourly data related to $PM_{10}$ and $PM_{2.5}$ pollutants from 2013 to 2017 collected by referring to the Environmental Protection Agency of Khorramabad.

### *Data validation and pre-processing*

To ensure the reliability and integrity of the collected air quality data, a rigorous data validation and pre-processing methodology employed. Initially, all hourly data for each pollutant from 2013 to 2017 compiled into separate Excel files. Given the inherent irregularities and unstructured nature of raw environmental monitoring data, a series of processing steps were undertaken. Zero and negative values, indicative of sensor malfunction or erroneous readings, systematically removed. Subsequently, invalid data sets (potentially arising from data entry errors, incorrect measurements, or anomalous extreme concentrations) were identified and excluded prior to any analytical procedures [27]. Data points with a Z-score greater than 3 or less than -3 were systematically identified as outliers and removed from the dataset [13, 14, 28]. This stringent quality control measure ensured that only statistically valid data retained for subsequent analysis. Eq. 1 illustrates the Z-score calculation:

$$\text{Z-score} = (X-\mu)/\sigma \quad (1)$$

Where X is the individual data point, μ is the population mean, and σ is the population standard deviation.

Following outlier removal, pollutant data standardized temporally to facilitate accurate average estimations. Adhering to World Health Organization (WHO) data validity criteria, the single continuously operating air quality monitoring station in Khorramabad deemed suitable for this study. According to these criteria, the ratio of valid data points for the warm and cold seasons should not be more than twice as many, and at least 50% of valid data should be available for the 24-h average from the available short-term data (No reference in your list for this specific criterion, but the concept is part of WHO guidelines for data validity.

### *Statistical analysis and time series modeling*

Secondary data processing conducted using programmed routines in Excel to calculate essential statistical indicators. These included annual mean concentrations, seasonal averages (summer and winter), and annual/seasonal maximum values for the pollutants of interest. Furthermore, Excel's filtering capabilities employed to determine the frequency of data points falling within the specific concentration ranges required as input for the $AirQ_{2.2.3}$ model for each pollutant at designated time intervals. To comprehensively examine the temporal trends and patterns of air pollutants, the R software and its powerful Openair package were utilized. Openair is an open-source tool renowned for its wide array of statistical techniques and visualization capabilities tailored for air quality data analysis [15]. Time series graphs for each pollutant were generated using this software, enabling a detailed analysis of hourly, daily, and seasonal variations over the study period [29].

### *Health impact quantification using $AirQ_{2.2.3}$ model*

The quantification of health effects attributed to air pollutants was performed using the $AirQ_{2.2.3}$ model, a specialized software developed by the World Health Organization (WHO) [21]. This model is recognized as one of the most reliable methodologies for assessing the health impacts of air pollution, grounded in robust epidemiological and statistical principles [30]. It enables users to estimate the potential health outcomes (both short-term and long-term) resulting from exposure to specific pollutants within a defined urban area over a specified time period [29]. For this study, the model integrated hourly air quality data with key epidemiological parameters. These parameters include: Relative Risk (RR), which quantifies the increased risk of an outcome (e.g., mortality) associated with a unit increase in pollutant concentration; Attributable Proportion (AP), representing the fraction of health outcomes in the exposed population that can be attributed to the exposure; and Baseline Incidence (BI), which is the background rate of a health outcome in the absence of the specific exposure. The model's output primarily focused on presenting results in terms of attributable mortality and morbidity cases. The default confidence interval for high relative risk in the model was set at 95%, while for low relative risk, it was set at 5% [9, 18]. Specific input parameters for the $AirQ_{2.2.3}$ model, including baseline incidence rates for Khorramabad's population, were derived from and the relative risk coefficients were sourced from the literature (e.g., WHO reports, meta-analyses of epidemiological studies) [31]. The model calculated the attributable cases of mortality and morbidity across predefined risk categories (low, medium, and high) for the study years.

## Results and discussion

The analysis of temporal and spatial trends for $PM_{10}$ and $PM_{2.5}$ pollutant concentrations in Khorramabad city over the five-year study period (2013-2017) utilized temporal and time variations by the Openair package. To illustrate the $PM_{10}$ concentration levels in Khorramabad, a time series Figs. 2 and 3 was used, and the current situation was compared with the WHO 2021 standard. The results of this comparison are presented in the form of Fig. 4. These guidelines suggest the use of interim targets for developing countries, allowing for a gradual progression towards the specified standard level over time.

### *Temporal and spatial trend analysis of $PM_{10}$ and $PM_{2.5}$*

Figures 2 and 3 illustrate the hourly, daily, and seasonal variations in $PM_{10}$ and $PM_{2.5}$ concentrations from 2013 to 2017. As well as throughout the week during the study period. According to Figs. 2 and 3, the hourly trend analysis shows that $PM_{10}$ and $PM_{2.5}$ follow a consistent pattern across all days, exhibiting two daily peaks. The first peak occurs at 7 AM, coinciding with the start of activities and vehicle traffic, and reaches its maximum at 11 AM. The second peak, which is relatively lower, appears in the afternoon at 7 PM and continues until 11 PM. At the start of the week, $PM_{10}$ and $PM_{2.5}$ concentration gradually increases, peaking significantly on mid-week days (Tuesday), which are the busiest days of the week, while it reaches its lowest levels on Fridays. Additionally, the highest concentrations of $PM_{10}$ were observed during the spring and summer seasons. Both pollutants exhibited two daily peaks: a prominent morning peak (around 7-11 AM) that directly correlates with the surge in anthropogenic activities and vehicular traffic after sunrise. A secondary, relatively attenuated evening peak (around 7-11 PM) was also observed, likely influenced by the evening rush hour coupled with evolving meteorological conditions, such as the formation of nocturnal inversions in the valley-surrounded topography of Khorramabad. These diurnal patterns underscore the dominant role of traffic emissions, including exhaust, road dust resuspension, and particulate matter from tire and brake wear, as significant urban sources. The contribution of heavy-duty vehicles within the traffic network further exacerbates suspended particulate concentrations. A study by Arvin [32] on $PM_{2.5}$ health effects in Isfahan corroborates that soot and suspended particles from fossil fuel combustion in diesel vehicles represent a substantial source of particulate matter emissions in urban environments. Weekly trends indicated a progressive increase in suspended particulate concentrations at the onset of the week, reaching a significant peak during mid-week days (specifically Tuesday), which are typically characterized by intensified urban activities and traffic volumes. Conversely, a discernible decline in particulate concentrations observed during the latter part of the week, with the lowest levels recorded on Fridays, coinciding with reduced vehicular activity as residents engage in weekend leisure or travel outside the city. Seasonal variations provided crucial insights, revealing consistently higher $PM_{10}$ and $PM_{2.5}$ concentrations during the warmer months (spring and summer) and considerably lower levels in colder months. This seasonality is primarily attributable to a confluence of meteorological and geographical factors, including reduced precipitation, elevated temperatures, and the frequent intrusion of regional dust storm phenomena originating from transboundary sources in Iraq [33]. These severe dust events profoundly impact air quality across western Iran, including Khorramabad. Furthermore, the specific topographical conditions of Khorramabad, alongside localized anthropogenic practices such as agricultural burning for post-harvest weed elimination, contribute significantly to the accumulation of suspended particulates during these warmer, drier periods. These observations are in strong agreement with findings from Mirhosseini and colleagues regarding average suspended particulate concentrations in Khorramabad [34]. The annual average concentrations of $PM_{10}$ and $PM_{2.5}$ pollutants during the study period were 65 µg/m³ and 35 µg/m³, respectively, with the highest values recorded in the years 2017 and 2014(Figs. 4 and 5).

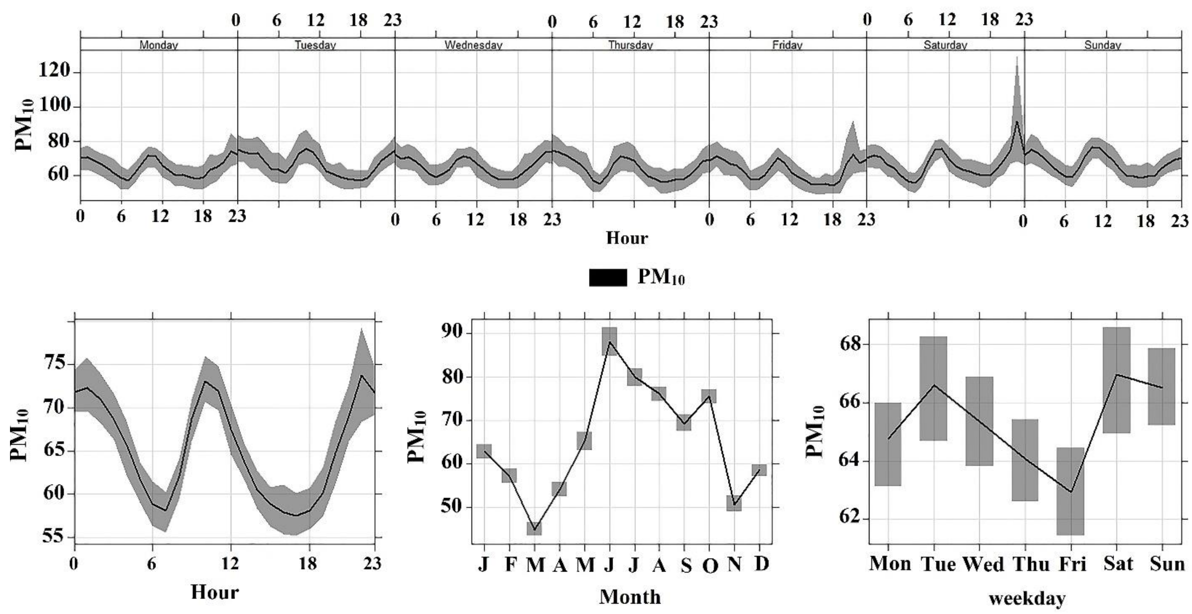


Fig. 2. Temporal variation based on different scales (hourly, daily, weekly, monthly) for $PM_{10}$ pollutant. from 2013 to 2017

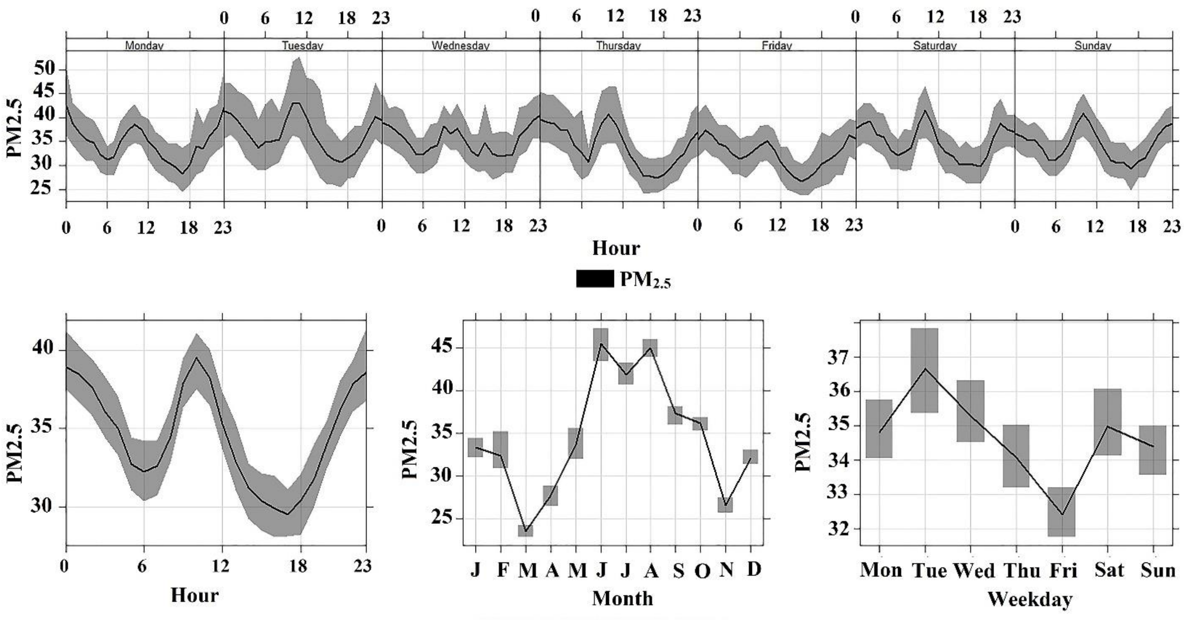


Fig. 3. Temporal variation based on different scales (hourly, daily, weekly, monthly) for $PM_{2.5}$ pollutant. from 2013 to 2017

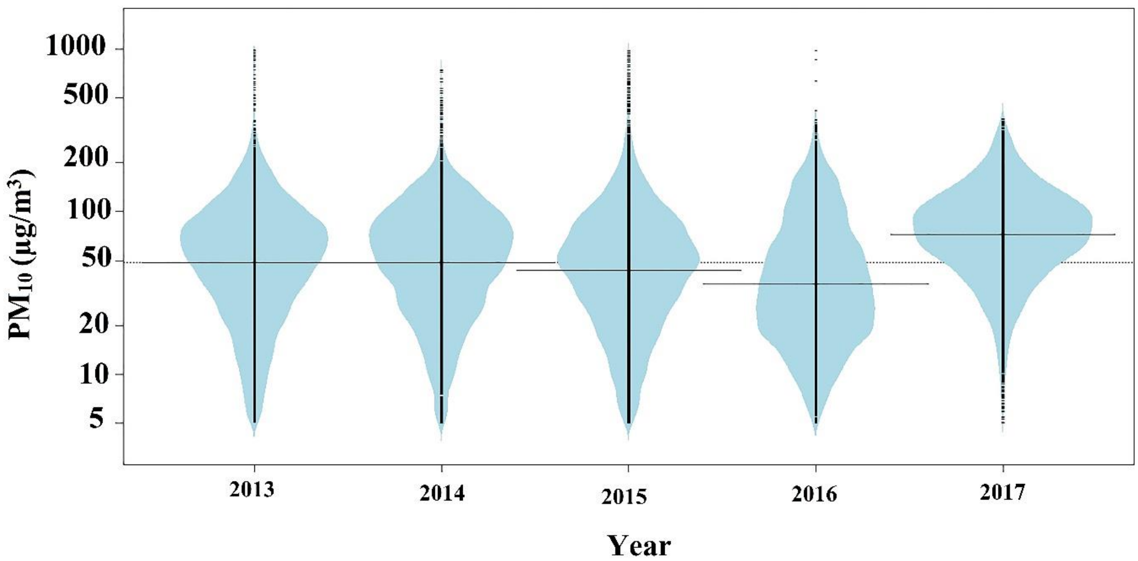


Fig. 4. Beanplot of annual variations in $PM_{10}$ concentrations.

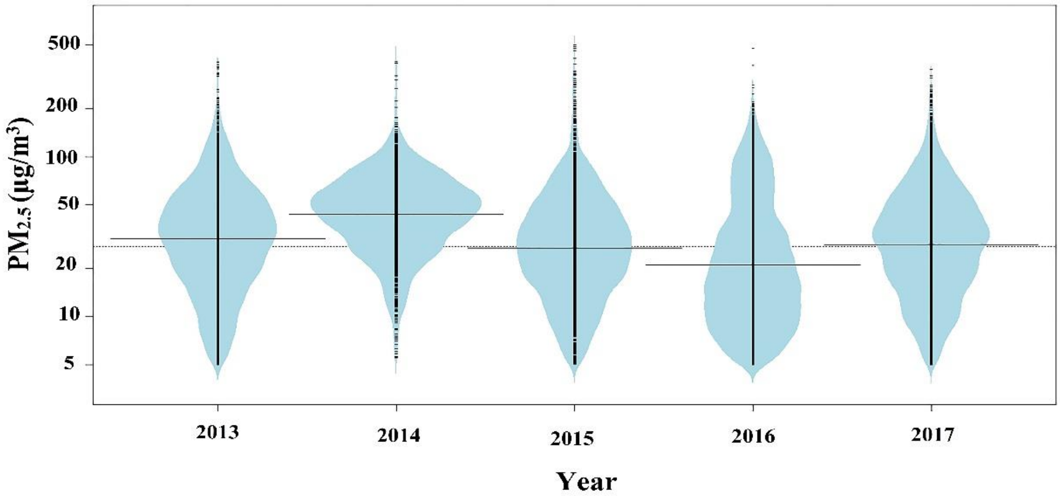


Fig. 5. Beanplot of annual variations in $PM_{2.5}$ concentrations

For $PM_{10}$ pollutant levels, the current status was compared across six different categories: values above target 1 (>150 µg/m³), target 1 (100-150 µg/m³), target 2 (75-100 µg/m³), target 3 (50-75 µg/m³), target 4 (45-50 µg/m³), and WHO standard (<45 µg/m³). It observed that on most days of 2017, the concentration of $PM_{10}$ exceeded target 3 compared to the WHO standard (Fig. 6).

For $PM_{10}$, the concentrations exceeded the WHO standard most days of the year 2017, predominantly occurring within the range of 50-75 µg/m³. The most significant source of suspended particles, beyond vehicular traffic, unequivocally attributed to natural sources such as soil erosion due to wind. Consequently, the highest recorded concentrations of suspended particles are consistently associated with the summer and spring seasons, with levels declining to their minimum during the winter and autumn [35, 36]. This pattern further supported by regional studies. For instance, researchers in Zahedan reported higher annual average $PM_{2.5}$ concentrations in summer than in winter [37], and other researchers demonstrated a positive correlation between dusty days and increased $PM_{2.5}$ concentrations [38]. A study on the spatial distribution of $PM_{2.5}$ aerosol column density across Iran also identifies maximum concentrations in the southwestern and western regions during the summer season, aligning with our findings for Khorramabad [39].

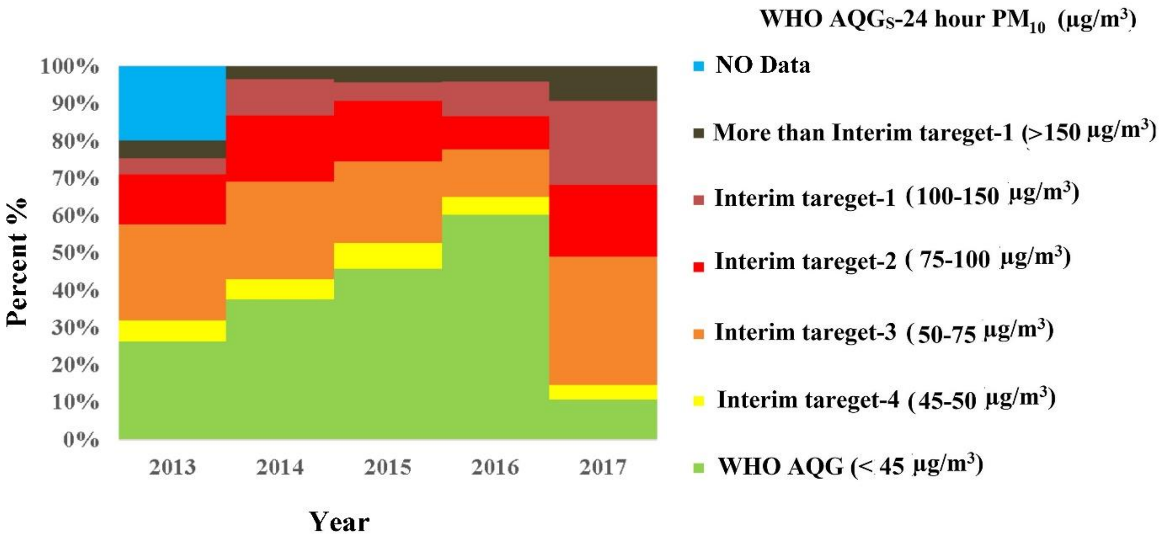


Fig. 6. The temporal distribution of average concentrations of $PM_{10}$ in various categories during the study period (2013–2017)

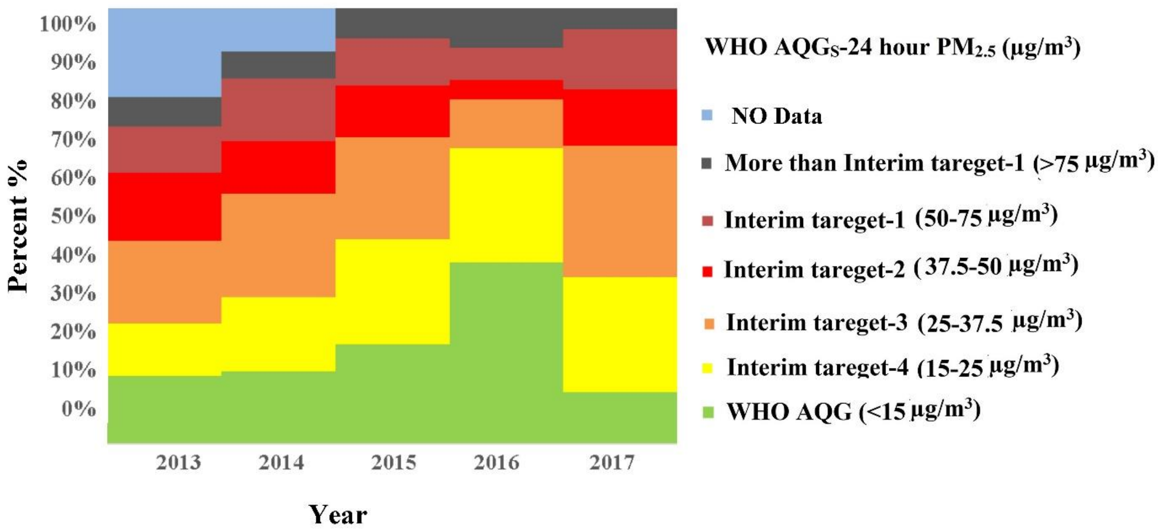


Fig.7. The temporal distribution of average concentrations of $PM_{2.5}$ in various categories during the study period (2013–2017)

For $PM_{2.5}$ pollutant levels, the current status was compared with six different scenarios: values above Target 1 (>75 µg/m³), Target 1 (50-75 µg/m³), Target 2 (37.5-50 µg/m³), Target 3 (25-37.5 µg/m³), Target 4 (15-25 µg/m³), and the WHO standard (<15 µg/m³). It observed that the highest number of days with $PM_{2.5}$ exposure occurred in the year 2013, particularly within the concentration range of 25-37.5 µg/m³ (Fig. 7).

### *Quantification of health effects*

This section details the findings derived from the quantification of health effects attributable to $PM_{10}$ and $PM_{2.5}$ using the $AirQ_{2.2.3}$ model. The model output, presented in tables and graphs, includes attributable cases of mortality and morbidity across low, medium, and high-risk categories, along with their respective Relative Risks (RR), Attributable Proportions (AP), and cumulative number of cases. As previously mentioned in the methodology, Relative Risk (RR) quantifies the increased risk of a health outcome (e.g., mortality) associated with a unit increase in pollutant concentration; Attributable Proportion (AP) represents the fraction of health outcomes in the exposed population that can be attributed to the exposure; and Baseline Incidence (BI) refers to the background rate of a health outcome in the absence of the specific exposure. The model's default confidence interval for high relative risk was set at 95%, while for low relative risk, it was set at 5% [40].

### *Quantification of health effects attributable to $PM_{10}$*

Based on the measurements obtained regarding the concentration of particulate matter less than or equal to 10 µm ($PM_{10}$), the annual average concentrations for the years 2013, 2014, 2015, 2016, and 2017 were 64.5 µg/m³, 62.3 µg/m³, 57.6 µg/m³, 51.9 µg/m³ and 87.5 µg/m³, respectively. The annual average concentration of $PM_{10}$ in 2017 was the highest compared to other years, while 2016 recorded the lowest concentration.

According to the World Health Organization's air quality guidelines, the recommended daily and annual concentrations for $PM_{10}$ are 45 µg/m³ and 15 µg/m³, respectively. Based on this, the concentrations of particulate matter were approximately 4.3, 4.1, 3.8, 3.4, and 5.8 times higher than the recommended standards. Table 1 shows the $PM_{10}$ concentrations (µg/m³) for the study years.

Table 1. $PM_{10}$ concentrations (µg/m³) for the study years

| Year / Parameter | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|
| Annual Average | 64.51 | 62.39 | 57.65 | 51.92 | 87.55 |
| Summer Average | 73.05 | 71.09 | 64.69 | 53.31 | 86.05 |
| Winter Average | 48.64 | 53.35 | 50.34 | 50.47 | 89.12 |
| 98th Percentile (Annual) | 198.96 | 159.14 | 208 | 171.23 | 219.41 |
| Maximum (Annual) | 550.1 | 348.59 | 459.7 | 243.51 | 317.48 |
| Maximum (Summer) | 550.1 | 348.59 | 459.7 | 243.51 | 273.04 |
| Maximum (Winter) | 125.13 | 164.84 | 240.84 | 174.81 | 317.48 |

The effects of the $PM_{10}$ pollutant on human health manifested as health outcomes including total mortality, cardiovascular mortality, respiratory mortality, total cardiovascular visits, and total respiratory visits. The baseline incidence for health effects expressed per 100000 individuals, and for $PM_{10}$, the model output utilized the baseline incidence figures corresponding to each health effect per 100000 individuals.

The results of the quantification of the $PM_{10}$ pollutant during the study years, considering the relative risk indices, attributable fractions, and health effect estimates from the central, lower, and upper perspectives, as well as the number of attributable cases, presented for the $PM_{10}$ pollutant in Khorramabad from 2013 to 2017 in Table 2.

Table 2. Health effect estimates of $PM_{10}$ pollutant in Khorramabad during the study years

| Attributable Cases | Baseline Incidence per 100000 | Year / Estimation | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| Total Mortality | 1013 | Low | 167 | 162 | 148 | 131 | 237 |
| | | Central | 198 | 192 | 176 | 155 | 280 |
| | | High | 228 | 222 | 204 | 179 | 323 |
| Cardiovascular Mortality | 497 | Low | 66 | 64 | 59 | 52 | 95 |
| | | Central | 105 | 102 | 93 | 82 | 148 |
| | | High | 224 | 217 | 200 | 177 | 310 |
| Respiratory Mortality | 66 | Low | 14 | 14 | 12 | 11 | 20 |
| | | Central | 20 | 20 | 18 | 16 | 29 |
| | | High | 56 | 54 | 51 | 45 | 75 |
| Total Cardiovascular Visits | 436 | Low | 70 | 67 | 62 | 54 | 99 |
| | | Central | 103 | 100 | 92 | 81 | 145 |
| | | High | 145 | 141 | 130 | 115 | 203 |
| Total Respiratory Visits | 1260 | Low | 162 | 157 | 144 | 126 | 230 |
| | | Central | 265 | 257 | 236 | 208 | 375 |
| | | High | 365 | 355 | 326 | 287 | 513 |

***Quantification of health effects attributable to $PM_{2.5}$***

Based on the measurements obtained regarding the concentration of particulate matter less than or equal to 2.5 µm ($PM_{2.5}$), the annual average concentrations for the years 2013, 2014, 2015, 2016, and 2017 were 38.2 µg/m³, 40.4 µg/m³, 35.9 µg/m³, 27.5 µg/m³ and 34.4 µg/m³, respectively. The annual average concentration of $PM_{2.5}$ in 2013 was the highest compared to other years, while 2016 recorded the lowest concentration.

According to the World Health Organization's air quality guidelines, the recommended daily and annual concentrations for $PM_{2.5}$ are 15 µg/m³ and 5 µg/m³, respectively. Based on this, the concentrations of particulate matter were approximately 7.6, 8.0, 7.1, 5.5, and 6.8 times higher than the recommended standards.

The effect of the $PM_{2.5}$ pollutant on human health manifested as health outcomes, specifically total mortality. According to the model output, a baseline incidence of 1013 per 100000 individuals used for $PM_{2.5}$.

The results of the quantification of the $PM_{2.5}$ pollutant during the study years, considering the relative risk indices, attributable fractions, and health effect estimates from the central, lower, and upper perspectives, as well as the number of attributable cases, presented for the $PM_{2.5}$ pollutant in Khorramabad from 2013 to 2017 in Table 4.

Table 3. $PM_{2.5}$ Concentrations (µg/m³) for the study years

| Year<br>Parameter | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|
| Annual Average | 38.27 | 40.49 | 35.9 | 27.5 | 34.46 |
| Summer Average | 43.67 | 41.09 | 40.8 | 30.57 | 30.76 |
| Winter Average | 28.23 | 31.84 | 30.8 | 24.3 | 38.33 |
| 98th Percentile (Annual) | 118.46 | 94.48 | 157/89 | 104.25 | 100.85 |
| Maximum (Annual) | 361.21 | 232.2 | 414.92 | 140.02 | 229.67 |
| Maximum (Summer) | 361.21 | 232.2 | 322.03 | 140.02 | 137 |
| Maximum (Winter) | 74.9 | 109.96 | 414.92 | 103.24 | 229.67 |

Table 4. Total mortality attributable to $PM_{2.5}$ in Khorramabad during the study years

| Attributable Cases | Baseline Incidence per 100000 | Year | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| | | Estimation | | | | | |
| Total Mortality | 1013 | Low | 160 | 147 | 146 | 102 | 136 |
| | | Central | 215 | 199 | 197 | 138 | 184 |
| | | High | 270 | 249 | 247 | 173 | 231 |

The total number of attributable deaths, cardiovascular deaths, respiratory deaths, total cardiovascular visits, and total respiratory visits due to $PM_{10}$ exposure exhibited a decreasing trend from 2013 to 2016, a pattern directly corresponding to the observed decrease in $PM_{10}$ concentrations during this period. However, a concerning increase in these health impacts observed in 2017, concomitant with a significant rise in $PM_{10}$ concentrations. These results unequivocally underscore the undeniable contribution of ambient particulate matter to mortality and morbidity. It is noteworthy that some researchers have documented adverse health effects of pollutants even at concentrations below commonly accepted air quality guidelines, suggesting that current standards may not offer sufficient public health protection [30, 41]. A study in Shiraz [42], investigating $PM_{10}$'s health impacts, similarly reported a direct correlation between elevated $PM_{10}$ concentrations (or increased exposure days) and higher rates of mortality and illness. Over the five-year study period, the most significant health effects attributed to $PM_{10}$ were total hospital visits due to respiratory diseases (estimated at 1341 individuals) and cardiovascular deaths (estimated at 530 individuals). Other attributable health effects of $PM_{10}$ included respiratory deaths (103 individuals), total cardiovascular visits (521 individuals), and total respiratory visits (1341 individuals). Findings by researchers [43] corroborate our observation that cardiovascular deaths often comprise a larger proportion compared to respiratory deaths due to air pollution. Furthermore, other studies [44, 45] consistently indicate a higher incidence of cardiovascular deaths and hospital visits for respiratory diseases when populations are exposed to suspended particulate concentrations exceeding standard limits. The health effect of the $PM_{2.5}$ pollutant quantified specifically in terms of total attributable deaths, estimated at 933 individuals based on the central estimate. The attributable ratio for $PM_{2.5}$ was highest in 2013 (4.2%), corresponding to the highest estimated total deaths for that year (215 individuals) at an annual average concentration of 38.27 µg/m³. A study by other vresearchers [46] on short-term health effects of air pollutants in Yazd found that the highest percentage of $PM_{2.5}$ exposure time occurred at concentrations between 40-70 µg/m³, with total cumulative deaths estimated at 212 individuals based on the average relative risk. From 2014 to 2016, a downward trend in the attributable ratio observed, correlating with a decrease in total attributable deaths. However, in 2017, the attributable ratio increased to 3.59%, leading to a rise in total deaths to 184 individuals for that year, despite an annual average concentration of 34.46 µg/m³. A study [47] in Semnan (2017) estimated total attributable deaths due to $PM_{2.5}$ at 91 individuals, with an annual average concentration of 22.52 µg/m³. Hopke and colleagues [48] reported that approximately 3.5% to 5% of natural mortality in Ahvaz is attributable to $PM_{2.5}$ exposure. Additionally, several studies [49] collectively indicate that $PM_{2.5}$ poses a discernible public health risk even at remarkably low levels, often significantly below established national standards.

## Conclusion

This comprehensive investigation unequivocally highlights the persistent and concerning exposure of Khorramabad's population to elevated concentrations of $PM_{10}$ and $PM_{2.5}$ particulate matter throughout the study period, particularly exacerbated during warmer months and peak anthropogenic activity times. The quantification of attributable health impacts reveals a substantial burden of disease, with thousands of premature deaths and considerable morbidity cases linked to particulate matter exposure. These findings underscore an urgent public health imperative for implementing robust and multifaceted interventions aimed at mitigating ambient air pollution in the region.

### *Recommendations for policy and practice*

Based on these findings, we propose the following key recommendations for policymakers and stakeholders in Khorramabad:

- Strengthen Emission Controls: Implement stricter vehicular emission standards and promote cleaner transportation alternatives.

- Implement Comprehensive Dust Management: Develop and execute plans for controlling both regional dust storms and local soil erosion.

- Promote Sustainable Agriculture: Encourage alternatives to agricultural burning to reduce seasonal particulate emissions.

- Enhance Public Health Communication: Disseminate real-time air quality data and protective guidelines for vulnerable populations.

- Integrate Green Infrastructure: Invest in urban green spaces and nature-based solutions for air quality improvement.

- Prioritize Source Apportionment Studies: Conduct detailed studies to identify specific local emission sources for targeted control measures.

## Financial supports

This research was a part of a Master's thesis at Lorestan University of Medical Sciences and has been approved by the university's Ethics Committee (IR.LUMS.REC.1400.236).

## Competing interests

The authors declare no competing interests.

## Author’s contributions

Faramarz Azimi: Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization, Formal analysis. Fariba Hafezi: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. Mansour Ghaderpoori:

Visualization, Supervision, Software, Project administration, Investigation.

**Acknowledgements**

We would like to thank the Meteorological Organization and the Environmental Protection Organization of Khorramabad for measuring and providing the data used in this study.

**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

**References**

1. Dargahi A, Dehghanzadeh R, Fahiminia V, Jabbari Y, Azizi F. Studying Air Quality Changes in Tabriz in Terms of $PM_{10}$ Pollutant Density Using AQI Index and its Relation with Drop of Water Level in Uremia Lake during 2008-2011. Journal of Environmental Science and Technology. 2016;18(3):55-62.

2. Loomis D, Grosse Y, Lauby-Secretan B, El Ghissassi F, Bouvard V, Benbrahim-Tallaa L, et al. The carcinogenicity of outdoor air pollution. The lancet oncology. 2013;14(13):1262-3.

3. Tertre AL, Quénel P, Eilstein D, Medina S, Prouvost H, Pascal L, et al. Short-term effects of air pollution on mortality in nine French cities: a quantitative summary. Archives of Environmental Health: An International Journal. 2002;57(4):311-9.

4. Finkelstein MM, Jerrett M, Sears MR. Traffic air pollution and mortality rate advancement periods. american Journal of epidemiology. 2004;160(2):173-7.

5. Oh SM, Kim HR, Park YJ, Lee SY, Chung KH. Organic extracts of urban air pollution particulate matter (PM2. 5)-induced genotoxicity and oxidative stress in human lung bronchial epithelial cells (BEAS-2B cells). Mutation Research/Genetic Toxicology and Environmental Mutagenesis. 2011;723(2):142-51.

6. Eskandari Z, Maleki H, Neisi A, Riahi A, Hamid V, Goudarzi G. Temporal fluctuations of PM 2.5 and PM 10, population exposure, and their health impacts in Dezful city, Iran. Journal of Environmental Health Science and Engineering. 2020;18:723-31.

7. Zolfaghari H, MASOUMPOUR SJ, SHAYGAN MS, Ahmadi M. A Synoptic Investigation of Dust Storms in Western Regions of Iran during 2005-2010 (A Case Study of Widespread Wave in July 2009). 2011.

8. Sanhueza PA, Reed GD, Davis WT, Miller TL. An environmental decision-making tool for evaluating ground-level ozone-related health effects. Journal of the Air & Waste Management Association. 2003;53(12):1448-59.

9. Tominz R, Mazzoleni B, Daris F. Estimate of potential health benefits of the reduction of air pollution with $PM_{10}$ in Trieste, Italy. Epidemiologia e prevenzione. 2005;29(3-4):149-55.

10. Carvalho H. New WHO global air quality guidelines: more pressure on nations to reduce air pollution levels. The Lancet Planetary Health. 2021;5(11):e760-e1.

11. Kelly FJ, Fussell JC. Size, source and chemical composition as determinants of toxicity attributable to ambient particulate matter. Atmospheric environment. 2012;60:504-26.

12. Gholampour A, Nabizadeh R, Hassanvand M, Taghipour H, Faridi S, Mahvi A. Investigation of the ambient particulate

matter concentration changes and assessing its health impacts in Tabriz. Iranian Journal of Health and Environment. 2015;7(4):541-56.

13. Curtis AE, Smith TA, Ziganshin BA, Elefteriades JA. The mystery of the Z-score. Aorta. 2016;4(04):124-30.

14. Mellenbergh GJ, Mellenbergh GJ. Outliers. Counteracting Methodological Errors in Behavioral Research. 2019:293-308.

15. Carslaw DC, Ropkins K. Openair—an R package for air quality data analysis. Environmental Modelling & Software. 2012;27:52-61.

16. López-Villarrubia E, Ballester F, Iñiguez C, Peral N. Air pollution and mortality in the Canary Islands: a time-series analysis. Environmental Health. 2010;9:1-11.

17. Goudarzi G, Daryanoosh S, Godini H, Hopke P, Sicard P, De Marco A, et al. Health risk assessment of exposure to the Middle-Eastern Dust storms in the Iranian megacity of Kermanshah. Public health. 2017;148:109-16.

18. Krzyzanowski M, Cohen A, Anderson R. Quantification of health effects of exposure to air pollution. BMJ Publishing Group Ltd; 2002. p. 791-3.

19. Afshe A, Farzadifar L, S S. Quantifying the health effects of air pollution in Dezful city in 2015. The Third National Conference on Environment and Natural Resources2015.

20. Kermani M, Bahrami Asl F, Aghaei M, Karimzadeh S, Arfaeinia H, Godarzi G, et al. Quantification of health effects attributed to ozone in five metropolises of Iran using AirQ model. Journal of Health. 2015;6(3):266-80.

21. 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. Environment international. 2018;114:37-49.

22. Khorsandi H, Karimzade S, Aghaei M, Kargar H, Mousavi Moghanjooghi S. estimation and quantification of health effects attributed to no2 pollutant in the air of urmia, Iran. Studies in Medical Sciences. 2016;26(12):1054-62.

23. Zallaghi E, Goudarzi G, Geravandi S, Mohammadi MJ. Epidemiological indexes attributed to particulates with less than 10 micrometers in the air of Ahvaz City during 2010 to 2013. Health Scope. 2014;3(4).

24. Sabzevari E, Sobhanardakani S. Analysis of selected heavy metals in indoor dust collected from city of Khorramabad, Iran: A case study. Jundishapur Journal of Health Sciences. 2018;10(3).

25. Iran S. Statistical Centre of Iran. Iran Population and Housing Census. 2016;2016.

26. Rashidi R, Almasian M. The measurement of volatile organic compounds in the ambient air of Khorramabad city and its comparison with current standards. Yafteh. 2015;16(4):54-61.

27. Melkonyan A, Kuttler W. Long-term analysis of NO, NO2 and O3 concentrations in North Rhine-Westphalia, Germany. Atmospheric Environment. 2012;60:316-26.

28. Habib U, Zucker G, Blochle M, Judex F, Haase J, editors. Outliers detection method using clustering in buildings data. IECON 2015-41st Annual Conference of the IEEE Industrial Electronics Society; 2015: IEEE.

29. Zalaghi E. Survey of health effects of air pollution Ahvaz, Bushehr and Kermanshah with use of AIRQ Model: MSc Thesis, Islamic Azad University, Science and Research Branch, Ahvaz; 2010.

30. Mamta P, Bassin J. Analysis of ambient air quality using air quality index-A case study. International Journal of Advanced Engineering Technology. 2010;1(2):106-14.

31. Organization WH. Ambient air pollution: A global assessment of exposure and burden of disease. Clean Air Journal.

2016;26(2):6-.

32. Arvin A. Investigation of the Effect of Less-Than-2.5-Microns Dust Particles on Human Health in Isfahan City. Spatial Planning. 2019;9(3):111-24.

33. Salmabadi H, Saeedi M, Roy A, Kaskaoutis DG. Quantifying the contribution of Middle Eastern dust sources to $PM_{10}$ levels in Ahvaz, Southwest Iran. Atmospheric Research. 2023;295:106993.

34. Mirhossieni SH, Birjandi M, Zare MR, Fatehizadeh A. Analysis of Particulate Matter ($PM_{10}$ and PM2. 5) Concentration in Khorramabad City, Iran. 2013.

35. Ganguly R, Sharma D, Kumar P. Trend analysis of observational $PM_{10}$ concentrations in Shimla city, India. Sustainable Cities and Society. 2019;51:101719.

36. Wang Y, Ying Q, Hu J, Zhang H. Spatial and temporal variations of six criteria air pollutants in 31 provincial capital cities in China during 2013–2014. Environment international. 2014;73:413-22.

37. Kamani H, Hassanvand MS, Khammari A, Haghighat S. Trend of ambient air particulate matter with aerodynamic diameter of 2.5 μm and smaller in Zahedan city in 2018-2019. Iranian Journal of Health and Environment. 2021;13(4):639-52.

38. Amarloei a, jonidi jafari a, asilian mohabadi h, asadollahi k. The Evaluation of $PM_{10}$, $PM_{2.5}$ and PM1 Concentration during Dust Storm Events in Ilam city, from Mar 2013 through Feb 2014. Journal of Ilam University of Medical Sciences. 2014;22(4):240-59.

39. Raispour K. Evaluation of spatiotemporal column particulate matter concentration (PM2. 5) due to dust events in Iran using data from NASAN/MERRA-2 reanalysis model. Journal of the Earth and Space Physics. 2021;47(2):333-54.

40. Krzyzanowski M, Cohen A, Anderson R. Quantification of health effects of exposure to air pollution. BMJ Publishing Group Ltd; 2002.

41. Jafari H, HassanPour S, Rahili KHorasanI L. selection and space-pla ce analyzes pollution and air pollution sources in the big city of Kermanshah. Journal of Environmental Studies. 2014;40(1):51-64.

42. Mohammadi A, Azhdarpoor A, Shahsavani A, Tabatabaee H. Health impacts of exposure to $PM_{10}$ on inhabitants of Shiraz, Iran. Health Scope. 2015;4(4).

43. Asl FB, Leili M, Vaziri Y, Arian SS, Cristaldi A, Conti GO, et al. Health impacts quantification of ambient air pollutants using AirQ model approach in Hamadan, Iran. Environmental research. 2018;161:114-21.

44. Geravandi S, Goudarzi G, Mohammadi MJ, Taghavirad SS, Salmanzadeh S. Sulfur and nitrogen dioxide exposure and the incidence of health endpoints in Ahvaz, Iran. Health Scope. 2015;4(2).

45. Noferesti AR, Atabi F, Nouri J, MiriLavasani MR, Jozi SA. Predicting the mortality rate due to particulate matters using AirQ software and health risk assessment in the city of Sanandaj. 2019.

46. Mokhtari M, Miri M, Mohammadi A, Khorsandi H, Hajizadeh Y, Abdolahnejad A. Assessment of air quality index and health impact of $PM_{10}$, PM2. 5 and SO2 in Yazd, Iran. Journal of Mazandaran University of Medical Sciences. 2015;25(131):14-23.

47. Yaghmaeian K, Ghobakhloo S, Mazloomi S. Evaluation of health effects of PM2. 5 air pollutant on Semnan air quality in 2017. Journal of health research in community. 2018;4(3):20-33.

48. Hopke PK, Nazari SSH, Hadei M, Yarahmadi M, Kermani M, Yarahmadi E, et al. Spatial and temporal trends of short-term health impacts of PM2. 5 in Iranian cities; a modelling approach (2013-2016). Aerosol and

air quality research. 2018;18(2):497-504.

49. Franklin M, Zeka A, Schwartz J. Association between PM2. 5 and all-cause and specific-cause mortality in 27 US communities. Journal of exposure science & environmental epidemiology. 2007;17(3):279-87.