Research Paper

Assessment of Health Impacts of $PM_{2.5}$ by AirQ+ Software in the City of Sanandaj, Iran (2018-2019)

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ABSTRACT

Background: Particulate or particle mattes in term of air pollution are particles with a diameter of 2.5 µm or less ($PM_{2.5}$). $PM_{2.5}$ is a natural source of air pollution and has harmful effects on citizens in Sanandaj City, located in the west of Iran.

Methods: In this study, the hourly data of concentration of $PM_{2.5}$ were taken from the Kurdistan Environmental Protection Agency. During the study period (2018-2019), the 24-hour concentration of $PM_{2.5}$ exceeded 339 times the average level. By AirQ+ software, the relationship between data and Relative Risk (RR), Baseline Incidence (BI), and Attributable Proportion (AP) were estimated. Then chronic obstructive pulmonary disease, lung cancer, ischemic heart disease, and brain stroke in the range of over 30 years were estimated.

Results: The main target of this study was to survey the relationship between $PM_{2.5}$ concentration and the death rate of citizens of this non-industrial city. The long-term health effect (more than 6 months) of $PM_{2.5}$ caused 326 deaths on average (except for accidents and poisoning).

Conclusion: Increase the concentration of $PM_{2.5}$ is one factor that affects a high percentage of mortality rate.

1. Introduction

In developed and developing countries, a major environmental risk factor is the air pollution that affects human health [1]. Based on the World Health Organization (WHO), air pollution is one of the main sources of environmental health risk factors. The relationship between morbidity and mortality due to respiratory and cardiovascular disorders is the most significant [2, 3].

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There are many air pollutants in the world. Fine particulate matter ($PM_{2.5}$, particles with an aerodynamic diameter less than 2.5 µm) is one of them that researchers have studied more than the other pollutants in ambient air [4]. Particulate Matter (PM) is an essential part of air pollutants and, its acute and chronic health problems, such as cardiovascular and respiratory mortality and hospitalizations, are generally mentioned as their two side effects [5].

Approximately 4.2 million deaths in long-term exposures to ambient $PM_{2.5}$ are among the statistical estimates of this pollutant. Therefore, $PM_{2.5}$ and health risk are the fifth-ranking mortality risk factor globally [6]. In 2013, the International Agency for Research on Cancer (IARC) categorized particulate matter in Group 1 (carcinogen group) when present in outdoor air pollution [7]. Adverse health effects of $PM_{2.5}$ may be different, as the main sources, regions area, and PMs' chemical characteristics are not the same [8]. Some toxicological and epidemiological studies have discovered that PM can cause oxidative stress and inflammation on the human respiratory system [9, 10].

Morbidity and mortality rates due to cardiovascular diseases and respiratory problems are strongly associated with $PM_{2.5}$ concentration [11]. In a cohort study, cardiovascular mortality increased by 8%-18% due to 10 µg/m^3 increase of $PM_{2.5}$ concentrations. However, a weak association was found between a similar amount of $PM_{2.5}$ and respiratory mortality [12].

In the course of PM classification, there are two well-known sources: natural (such as dust and sea salt) and anthropogenic (such as vehicles, coal burning in power plants, and industry) [13]. The components of PM are complex, from heavy metals, elemental carbon to inorganic salts. In the range of organic components, Polycyclic Aromatic Hydrocarbons (PAHs) and biological components like fungi and spores may be present in PM structure [13, 14]. In a study published in 2015, during the dust storm in Sanandaj, the observations showed that 56.2% of total bacteria were Bacillus spp. and 28.6% of total fungi was *Mycosporium* spp [15].

Dust storms occur in Iran seasonally [16]. They usually happen in the summer, when two powerful main winds (Shamal and Levar) blow [17]. In the other seasons of the year, such as winter, they may occur as well [18]. Iran has two main natural sources of dust, inside and outside. Sahara, Iraqi and Syrian deserts, and Mesopotamia are three main regions located outside of Iran [19]. The Dasht-e Kavir, the Dasht-e Lut, the Jaz murian depression, Sistan, and the Makran coast are inside main regional sources to generate dust particle matters [20]. Also, 15%-20% of the total global dust emissions are related to Middle Eastern Dust Storms (MEDS) or Arabic Dust Storm (ADS). The Arabian Peninsula, Iraqi plains, and southeast Iran are their origin [21].

Based on WHO guidelines, the average concentration of $PM_{2.5}$ is 38.02 µg/m^3 in 24 hours, and the Iranian standard is 10 µg/m^3 annual concentration [22, 23]. United States Environmental Protection Agency (USEPA) recommended $PM_{2.5}$ average concentration of 35 µg/m^3 for 24 hours [24].

Previous versions of the World Health Organization's (WHO's) was AirQ 2.2.3 tool that has been published to estimate the health effects of air pollution and health impact assessment [25]. The main sources used in these two software versions are based on concentration-response functions and methodology to estimate pollutants' effect on human beings [26]. Based on this or the last version of the software, several studies in Iran have estimated the side health effects of PM_{10} [27]. For example, in 2018, the increased hospital admission in Sanandaj was reported because of the short-term effects of PM_{10} [28]. It must be mentioned that a few studies have considered the health effects of $PM_{2.5}$ as a pollutant in Iran [29]. Determination strategies and plans of air pollution control devices, economic costs of deaths, hospitalizations, and other air pollution plans can help to make any decision for overcoming and control of air pollution in Iran and other countries [30].

This study aimed to estimate all mortality causes, including Chronic Obstructive Pulmonary Disease (COPD), Ischemic Heart Disease (IHD), Lung Cancer (LC), Brain Stroke (BS), and other deaths due to exposure to $PM_{2.5}$ in Sanandaj City from January 2018 to December 2019 using AirQ+ software.

2. Materials and Methods

Type of study

This research was a descriptive-analytic study (interpretation of historical data to understand better changes that have occurred) by using AirQ+ software. The software was used to evaluate the long-term mortality rate over the age of 25 and 30 years attributed to the concentration of $PM_{2.5}$ in Sanandaj City. As all the data were analyzed and collected daily, the study's duration and data collection was two years, from 2018 to 2019.

Location of study and $PM_{2.5}$ data collection

Sanandaj (the capital of Kurdistan Province) is located on the border of Iraq in the west of Iran with approximately 63688 km^2 area and an altitude of 1500 m above sea level. Its population was 414069 people, according to the report of the Statistical Center of Iran Inhabitants in 2018.

There is one station for air pollution analyses in this city. So, all the data about air pollution were taken from this station located approximately in the center of Sanandaj. Figure 1 is the map of Sandandaj.

Data collection

The hourly data of $PM_{2.5}$ concentration were taken from the Kurdistan Environmental Protection Agency (KEPA). The Beta attenuation method was used to detect the concentration of $PM_{2.5}$ from January 1, 2018, to December 31, 2019. The number of days that concentration of $PM_{2.5}$ and other pollutants, such as Co, SO_2, PM_{10}, O_3, and NO_2, were more than AQI>100 (Air Quality Index) are presented in Table 1.

Table 2 shows the number of days in each month when the index of $PM_{2.5}$ raised more than AQI. It must be mentioned that dust particles come from the ADS to Iran in all months of years, especially in warm seasons such as spring and summer.

AirQ+ software

AirQ+ software was presented by the WHO of Europe Branch (2016) to qualitatively analyzes data on air pollution. By using this software, long-term (>6 months) and short-term (≤6 months) effects of pollutants (PM10, $PM_{2.5}$, O_3, and NO_2) on human beings are calculated. Table 3 shows the health effects of each pollutant measured by AirQ+ [31].

Population data and estimated diseases and death

Whole data about mortality, COPD, IHD, LC, and BS were taken from the Kurdistan Center of Diseases Control (KCDC) between January 2018 and December 2019. This center collected data online and daily as death certificates must be approved by physicians present in health care centers, hospitals, and emergency centers. In this way, missing data in this part of the study were limited strictly. Data on population rate were collected from the Population and Family Center of Kurdistan University of Medical Sciences. The population data were separated into two groups, 30-60 and over 60 years old.

It must be mentioned that the background concentration had no health effect [32].

To simulate the short- and long-term health effects of air pollutants, like the previous version of AirQ2.2.3 software, AirQ+ employs epidemiological data, including Relative Risk (RR) values, Attributed Proportion (AP), and Baseline Incidence rate (BI) together with in-situ air pollution data (from monitoring station or modeling) of an exposed population data [33].

Simple definition of Relative Risk (RR) or rate ratio made it to used widely as a measure of association [32] and measured the probability of developing a disease relative to exposure (Equation 1):

1. $RR=exp.[\beta(X\text{-}X_0)]$

, where β is a factor that regulates the rate of RR increment, X (μg/m^3) is the estimated PM concentration, and X0 (μg/m^3) is the reference level concerning of PM (0 μg/m^3) [34].

The long-term exposure to $PM_{2.5}$ and quantification of mortality due to adult COPD and IHD in the AirQ+ software is based on integrated exposure-response functions from European cohort studies (Equation 2) [31].

2. $if\ z \geq z_{cf}$, $then\ RR(z)=1+\alpha\{1-exp\ [-\gamma(z-z_{cf})\delta]\}$

$if\ z < z_{cf}$, $then\ RR(z)=1$

, where z is the annual $PM_{2.5}$ concentration (μg/m^3), and z_{cf} is the trumped-up $PM_{2.5}$ concentration, below which there is no risk. The coefficients α, γ, and δ are pre-integrated AirQ+ factors [32]. The Attributed Proportion (AP) is the fraction of health endpoint in a population whose exposure to air pollutants [35]. Using the RR values for a specific health endpoint and $PM_{2.5}$ «c,» the AP is calculated. P(c) is the fraction of the population exposed to $PM_{2.5}$ (Equation 3):

3. $AP=\sum\{[RR_{(c)}-1]\times P_{(c)}\}\div\sum\{RR_{(c)}\times P_{(c)}\}$

The rate of health outcome attributable to $PM_{2.5}$ exposure (IE) is calculated as (Equation 4):

4. $IE=BI\times AP$

IE is the rate of the health impact attributable risk to the $PM_{2.5}$ exposure, and BI is the baseline incidence which is calculated per 100000 inhabitants [32].

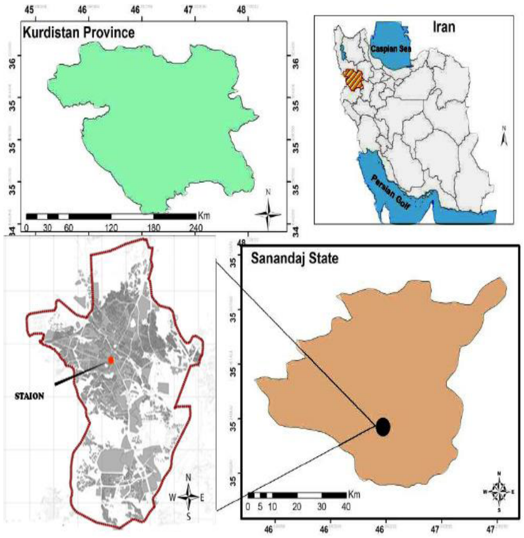

Figure 1. Location of monitoring site, Sanandaj (35°18′52″N, 46°59′32″E)

Remove the confounding variables

Missing data were omitted and considered confounding data. As the zero data were recorded by pollution measuring devices, failure to declare a pollutant concentration does not mean the absence of a pollutant, but the values in the range were not measured by the device.

3. Results and Discussion

In each city or region, the necessary information for the data analysis is the sources of $PM_{2.5}$. In all cities, traffic or transportation systems will be an essential source of emission of pollutants, but, in each city, local emission of $PM_{2.5}$ is different from other cities due to dust storms or industrial activities. In recent years, some of the cities located in the western and southern of Iran, such as Sanandaj and Ilam in the west, and Ahvaz in the Southwest, have been exposed to MEDS. An increase in the high death rate in these cities is attributable to PM emission or MEDS phenomenon [36].

AirQ+ is a software tool for quantifying the impact of air pollution, the attributable proportion of items, the number of attributable items singly and per 100000 at-risk populations, the fraction of cases in the range of pollutant concentration, and air pollutant concentration in the discussion of cumulative distribution. Due to the assessment's objectives, different estimates in various ways can be used [37].

Table 1. The number of days that concentration of pollutants was more than AQI>100 (Air Quality Index)

Month	Pollutants					
	$PM_{2.5}$	PM_{10}	CO	SO_2	O_3	NO_2
January	59	3	0	1	0	0
February	75	4	0	1	0	0
March	121	9	0	0	0	0
April	5	0	0	0	0	0
May	12	0	0	0	0	0
June	8	0	0	0	0	0
July	8	0	0	0	0	0
August	14	0	0	0	0	0
September	17	0	0	0	0	0
October	16	0	0	0	0	0
November	17	0	0	0	0	0
December	1	0	0	0	0	0
Total year	353	16	0	2	0	0

Table 2. $PM_{2.5}$ (μg/m³) concentration raised more than AQI (Air Quality Index) in each day of the months

Months	Good AQI (0-50)	Average AQI (50-100)	Unhealthy for sensitive persons AQI (101-150)	Unhealthy AQI (151-200)	Very unhealthy AQI (201-300)	Dangerous AQI (301-500)
January	10	16	3	0	0	1
February	7	18	4	1	0	0
March	6	13	7	2	0	0
April	12	14	4	1	0	0
May	0	19	11	1	0	0
June	1	22	8	0	0	0
July	0	23	8	0	0	0
August	0	17	14	0	0	0
September	0	14	17	0	0	0
October	2	11	16	0	0	0
November	0	11	16	0	2	1
December	9	20	1	0	0	0
Total	47	198	109	5	2	2

As mentioned before, the last version of AirQ+ was Air2.2.3 software. This software calculates PM_{10} instead of $PM_{2.5}$. The estimated relationship between PM_{10} and its short-term health effects using Air2,2,3 software showed 375 deaths (4.13% of total death) in Sanandaj citizens in 2015. Also, the percentage of respiratory mortality (0.2%), hospital admission respiratory (4.45%), cardiovascular mortality (4.45%), and hospital admission cardiovascular (4.98%) were estimated by AirQ 2.2.3 [38]. Table 4 presents the Baseline Incidence (BI) for these groups estimated for total mortality, COPD, LC, IHD, and BS. Based on the data from Table 1, $PM_{2.5}$ is the main source (95.14% of all six pollutants) of air pollution in Sanandaj.

$PM_{2.5}$ raised 353 times more than the standard of the Air Quality Index. On the other hand, the concentration of $PM_{2.5}$ in March and December had the highest and lowest level, respectively. NO_2, O_3, and CO are pollutants whose concentration in the ambient air of Sanandaj did not make a problem as major pollutants in the list of Air Quality Index. Thus, there is no day that the concentration of them increases above the index.

Table 3. Health effects of each pollutant measured by AirQ+

Pollutant	$PM_{2.5}$	PM_{10}	NO_2	O_3
Health effects	Mortality in adults (over 30 years old)	Chronic bronchitis in adults	Mortality due to all cases	Mortality due to respiratory system diseases
	Mortality due to COPD in adults (over 30 years old)	Bronchitis in infant	-	-
	Mortality due to lung cancer in adults (over 30 years old)	-	-	-
	Mortality due to IHD in adults (over 25 years old)	-	-	-
	Mortality due to brain stroke (over 25 years old)	-	-	-

Table 4. The estimated rate of death, diseases, and baseline incidence

Parameter	Rate of the Population Between 30-60 Years	Rate of the Population over 60 Years	Number of Death Between 30-60 Years	Number of Death over 60 Years	Baseline Incidence (BI) in 100000 Persons
Total mortality			326	1078	649
Mortality due to LC			10	25	16.176
Mortality due to COPD	179433	36902	2	36	18.95
Mortality due to IHD			2	39	18.95
Mortality due to BS			2	14	6.09

LC, Lung Cancer; IHD, Ischemic Heart Disease; BS, Brain Stroke; COPD, Chronic Obstructive Pulmonary Disease.

According to the air quality standards, the concentration of $PM_{2.5}$ is 15 µg/m³ for the annual average and 35 µg/m³ for the daily average (the WHO guideline and European Union guideline). The annual average of $PM_{2.5}$ in this study was 5.79 times more than the standard, and the average daily concentration was 356 times more than the standard.

Long-term exposure to $PM_{2.5}$ and health effects

The results of our study are illustrated in four categories as follows:

1- The estimated mortality rate related to $PM_{2.5}$ concentration

The association of long-term exposure to $PM_{2.5}$ and its side effects and mortality is an interesting subject that many researchers have studied [38]. $PM_{2.5}$ is one of the main ambient air pollutants that can increase mortality and morbidity risks, as a report of the Committee on the Medical Effects of Air Pollutants mentioned in 2018 [28]. Figure 2 displays the estimated relationships of low, average, and high range of $PM_{2.5}$ to mortality and four main diseases.

Apparently, $PM_{2.5}$ could increase mortality, COPD, LC, IHD, and BS. In this category, the portion of IHD is the most (66.6), and COPD is the lowest (25.3) on average. In Figure 3, the estimated attributable cases of mortality and four main diseases have been shown. As shown in Figure 3, an increase in the concentration of $PM_{2.5}$ is the main source of the increased rate of mortality. Total mortality (without accidents and poisoning) that happened in Sanandaj in 2018, according to KCDC reports, were 240.29 cases per 100000 deaths on average (Figure 4). The results of data analyses of AirQ+ software to estimate the number of death cases related to $PM_{2.5}$ was 520 cases as an average level.

Based on the results of another article (the relationship between PM_{10} and mortality rate by using AirQ2.2.3 software in Sanandaj during 2015) which was produced by the authors of this article, the estimated cases is 375 per 100000 deaths [39]. Therefore, the rate of mortality based on $PM_{2.5}$ is more than PM_{10}. Of course, it must be

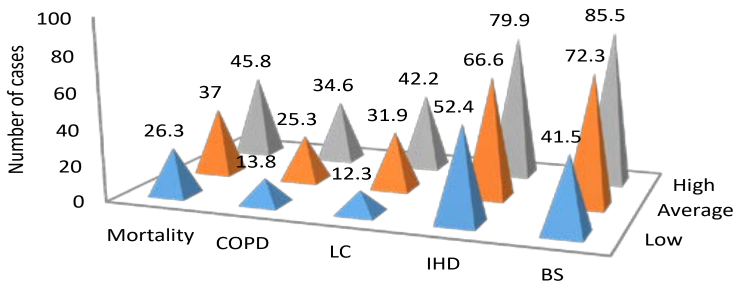

Figure 2. Estimated attributale proportion of $PM_{2.5}$ to mortality and diseases

LC, Lung Cancer; IHD, Ischemic Heart Disease; BS, Brain Stroke; COPD, Chronic Obstructive Pulmonary Disease.

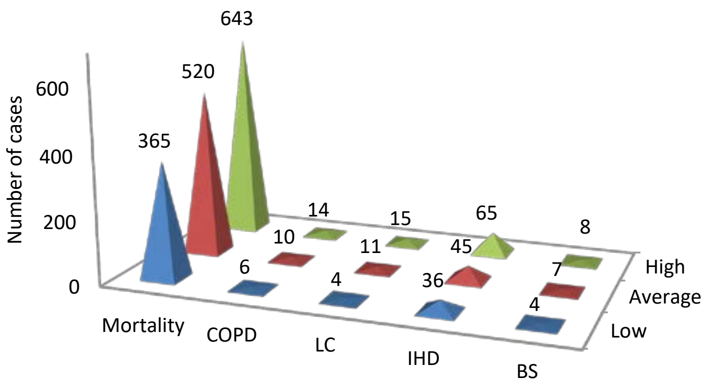

Figure. 3. Estimated attributable cases of mortality and diseases

Abbreviations: LC, Lung Cancer; IHD, Ischemic Heart Disease; BS, Brain Stroke; COPD, Chronic Obstructive Pulmonary Disease

acknowledged that some part of PM_{10} is $PM_{2.5}$. On the other hand, an essential reason for the greater impact of smaller particles on the lungs and other side effects is the possibility of their easier and deeper entry into the lungs compared to larger particles.

The estimate of the COPD incidence related to $PM_{2.5}$ concentration

COPD is a group of conditions that affect the lungs' structures in many ways; the most important of these effects are emphysema, asthma, and chronic bronchitis [40]. In a long-term follow-up prospective cohort study by Cui Guo et al. performed in Taiwan, it was found that increased incidence of COPD and lower lung function is associated with an increase in ambient $PM_{2.5}$ [41].

By increasing 10 μg/m³ of $PM_{2.5}$, 2.5% (95% CI, 1.5%-3.5%) increase in COPD mortality and 3.1% (95% CI, 1.6%-4.6%) increase in COPD hospitalizations was observed [42]. Also, a case-crossover study in Shanghai was shown that a 10 μg/m³ increase in PM_{10}, SO_2, and NO_2 could increase COPD mortality by 0.6%, 3.3%, and 4.2%, respectively [43]. In our study, the estimated attributable average cases of COPD were 10. Low and high levels of COPD were 6 and 14, respectively.

The estimate of the lung cancer incidence related to $PM_{2.5}$ concentration

A statistically significant positive correlation was seen between LC mortality and $PM_{2.5}$ concentration [44]. Long-term (between 3 and 4 years) exposure to $PM_{2.5}$ can increase the rate of LC fatalities estimated by the WHO reported in a range from 531036 to 532004, but the prevalence of this disease estimated by the American Cancer Society (ACS) was reported as 614860 cases [45]. It must be admitted that $PM_{2.5}$ from vehicle emissions is one of the main sources of increasing the LC risk rate significantly [46]. Besides, the risk of LC in males is more than

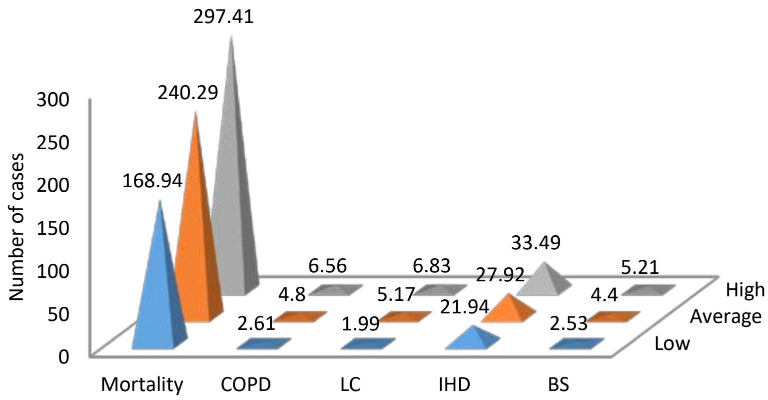

Figure. 4. Estimated attributable cases per100000 population at risk

LC, Lung Cancer; IHD, Ischemic Heart Disease; BS, Brain Stroke; COPD, Chronic Obstructive Pulmonary Disease in females, according to the mortality and incidence. One of the reasons for these differences is more exposure of men to tobacco smoke [47]. In this study, 5.17 LC cases in 100000 populations were calculated totally.

The estimate of the IHD incidence related to $PM_{2.5}$ concentration

An increase in IHD rate, in the range of 1.7% (95% CI, 1.5%-1.9%) is related to $PM_{2.5}$ and 2.0% (95% CI, 1.7%-2.3%) because PM_{10} has the strongest effect of this pollutant on IHD daily rate [48]. Based on epidemiological studies, there is a statistical relationship between IHD and PM concentrations. In other words, long-term exposure to $PM_{2.5}$ increases IHD mortality (Hazard Ratios or HRs=1.36; 95% Confidence Intervals or CIs = 1.28-1.44) per 10 $\mu g/m^3$ [49].

One of the risk factors for cardiovascular disease is air pollution, and the size of fine particulate has main effects [50]. Few new studies have focused on the function of particulate matter on men. Based on these research studies, autophagy, necrosis, apoptosis, pyroptosis, and ferroptosis are the most well-known side effects of $PM_{2.5}$ [51]. In our study, the average number of IHD was 27.92 cases. After the number of deaths, particles' effect on IHD was greater than the other diseases, such as COPD, LC, and BS. In this paper, the average number of IHD was 27.92 cases, as shown in Figure 4.

The estimate of the BS incidence related to $PM_{2.5}$ concentration

Cerebrovascular events and short-term exposure to PM have a relationship. PM size fraction ($PM_{2.5}$, PM_{10}, $PM_{2.5-10}$) and their effects on cerebrovascular diseases in meta-analyses have been evaluated. The evidence of this study showed an association between PM size and mortality and hospital admission [52]. About 10 $\mu g/m^3$ increase of $PM_{2.5}$ is associated with 1.130 rise of risk ratio in stroke incidence [53]. The main mechanism of the $PM_{2.5}$ effect on causing a stroke is not clear; inflammation and thrombosis are proposed for this relationship [54, 55]. BS has the lower level of the leading group of diseases classified as $PM_{2.5}$ in this AirQ+ software (Figure 4).

4. Conclusion

In natural pollutants, $PM_{2.5}$ has primary side effects on human respiratory and cardiovascular systems. In this study, the estimated relationship between $PM_{2.5}$ as the main natural pollutant and four main diseases and mortality rate using software was considered for a long time. AirQ+ software model has an opportunity to evaluate the health impact assessment of ambient $PM_{2.5}$ on human health. Natural sources of $PM_{2.5}$ are a major environmental pollutant in the city of Sanandaj.

There is a statistical relationship between $PM_{2.5}$, heart, and lung diseases. Thus, an increase in $PM_{2.5}$ concentration could increase the rate of mortality, COPD, LC, IHD, and BS estimated with the AirQ+ software.

Ethical Considerations

Compliance with ethical guidelines

Institutional Review Board and Ethics Committee of Kurdistan University of Medical Sciences (Ethics Code: IR.MUK.REC.1399.207) approved the study.

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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References

[1] Münzel T, Herzog J, Schmidt FP, Sørensen M. Environmental stressors and cardiovascular disease: The evidence is growing. Eur Heart J. 2017; 38(29):2297-9. [DOI:10.1093/eurheartj/ehx306] [PMID]

[2] GBD 2017 Risk Factor Collaborators. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990-2017: A systematic analysis for the Global Burden of Disease Study

2017. Lancet. 2018; 392(10159):1923-94. [DOI:10.1016/S0140-6736(18)32225-6] [PMID] [PMCID]

[3] Lefler JS, Higbee JD, Burnett RT, Ezzati M, Coleman NC, Mann DD, et al. Air pollution and mortality in a large, representative U.S. Cohort: Multiple-pollutant analyses and spatial and temporal decompositions. Environ Health. 2019; 18(1):101. [DOI:10.1186/s12940-019-0544-9] [PMID] [PMCID]

[4] Broome RA, Fann N, Navin Cristina TJ, Fulcher Ch, Duc H, Morgan GG. The health benefits of reducing air pollution in Sydney, Australia. Environ Res. 2015; 143(Pt A):19-25. [DOI:10.1016/j.envres.2015.09.007] [PMID]

[5] Mohseni Bandpi A, Eslami A, Shahsavani A, Khodagholi F, Alinejad A. Physicochemical characterization of ambient PM2.5 in Tehran air and its potential cytotoxicity in human lung epithelial cells (A549). Sci Total Environ. 2017; 593-594:182-90. [DOI:10.1016/j.scitotenv.2017.03.150] [PMID]

[6] Cohen AJ, Brauer M, Burnett R, Anderson HR, Frostad J, Estep K, et al. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: An analysis of data from the Global Burden of Diseases Study 2015. Lancet. 2017; 389(10082):1907-18. [DOI:10.1016/S0140-6736(17)30505-6]

[7] Loomis D, Grosse Y, Lauby-Secretan B, El Ghissassi F, Bouvard V, Benbrahim-Tallaa L, et al. The carcinogenicity of outdoor air pollution. Lancet Oncol. 2013; 14(13):1262-3. [DOI:10.1016/s1470-2045(13)70487-x] [PMID]

[8] Cavalli F, Alastuey A, Areskoug H, Ceburnis D, Čech J, Genberg J, et al. A European aerosol phenomenology-4: Harmonized concentrations of carbonaceous aerosol at 10 regional background sites across Europe. Atmos Environ. 2016; 144:133-45. [DOI:10.1016/j.atmosenv.2016.07.050]

[9] Kloog I, Ridgway B, Koutrakis P, Coull BA, Schwartz JD. Long-and short-term exposure to PM2.5 and mortality: Using novel exposure models. Epidemiology. 2013; 24(4):555-61. [DOI:10.1097/EDE.0b013e318294beaa] [PMID] [PMCID]

[10] Xing YF, Xu YH, Shi MH, Lian YX. The impact of PM2.5 on the human respiratory system. J Thorac Dis. 2016; 8(1):E69-74. [DOI:10.3978/j.issn.2072-1439.2016.01.19] [PMID] [PMCID]

[11] Avino P, Protano C, Vitali M, Manigrasso M. Benchmark study on fine-mode aerosol in a big urban area and relevant doses deposited in the human respiratory tract. Environ Pollut. 2016; 216:530-7. [DOI:10.1016/j.envpol.2016.06.005] [PMID]

[12] Crouse DL, Peters PA, Hystad P, Brook JR, van Donkelaar A, Martin RV, et al. Ambient PM2.5, O3, and NO2 exposures and associations with mortality over 16 years of follow-up in the Canadian Census Health and Environment Cohort (CanCHEC). Environ Health Perspect. 2015; 123(11):1180-6. [DOI:10.1289/ehp.1409276] [PMID] [PMCID]

[13] Cho CC, Hsieh WY, Tsai CH, Chen CY, Chang HF, Lin CS. In vitro and in vivo experimental studies of PM2.5 on disease progression. Int J Environ Res Public Health. 2018; 15(7):1380. [DOI:10.3390/ijerph15071380] [PMID] [PMCID]

[14] Zhang R, Wang G, Guo S, Zamora ML, Ying Q, Lin Y, et al. Formation of urban fine particulate matter. Chem Rev. 2015; 115(10):3803-55. [DOI:10.1021/acs.chemrev.5b00067] [PMID]

[15] Nourmoradi H, Moradnejadi K, Mohammadi Moghadam F, Khosravi B, Hemati L, Khoshniyat R, et al. The effect of dust storm on the microbial quality of ambient air in Sanandaj: A city located in the West of Iran. Glob J Health Sci. 2015; 7(7):114-9. [DOI:10.5539/gjhs.v7n7p114]

[16] Mesbahzadeh T, Salajeghe A, Soleimani Sardoo F, Zehtabian GR, Ranjbar A, Krakauer NY, et al. Climatology of dust days in the Central Plateau of Iran. Nat Hazards. 2020; 104(2):1801-17. [DOI:10.1007/s11069-020-04248-6]

[17] Rashki A, Kaskaoutis DG, Francois P, Kosmopoulos PG, Legrand M. Dust-storm dynamics over Sistan region, Iran: Seasonality, transport characteristics and affected areas. Aeolian Res. 2015; 16:35-48. [DOI:10.1016/j.aeolia.2014.10.003]

[18] Abdi Vishkaee F, Flamant C, Cuesta J, Oolman L, Flamant P, Khalesifard HR. Dust transport over Iraq and Northwest Iran associated with winter Shamal: A case study. J Geophys Res. 2012; 117(D3):D03201. [DOI:10.1029/2011JD016339]

[19] Ziyaee A, Karimi AR, Hirmas DR, Kehl M, Lakzian A, Khademi H, et al. Spatial and temporal variations of airborne dust fallout in Khorasan Razavi Province, Northeastern Iran. Geoderma. 2018; 326:42-55. [DOI:10.1016/j.geoderma.2018.04.010]

[20] Rashki A, Middleton NJ, Goudie AS. Dust storms in Iran - Distribution, causes, frequencies and impacts. Aeolian Res. 2021; 48:100655. [DOI:10.1016/j.aeolia.2020.100655]

[21] Mohammadpour K, Sciortino M, Saligheh M, Raziei T, Darvishi Boloorani A. Spatiotemporal regionalization of atmospheric dust based on multivariate analysis of MACC model over Iran. Atmos Res. 2021; 249:105322. [DOI:10.1016/j.atmosres.2020.105322]

[22] World Health Organization. Ambient air pollution: A global assessment of exposure and burden of disease. 2016: https://www.who.int/phe/publications/air-pollution-global-assessment/en/

[23] Shahsavani A, Naddafi K, Jafarzade Haghighifard N, Mesdaghinia A, Yunesian M, Nabizadeh R, et al. The evaluation of PM10, PM2.5, and PM1 concentrations during the Middle Eastern Dust (MED) events in Ahvaz, Iran, from April through September 2010. J Arid Environ. 2012; 77:72-83. [DOI:10.1016/j.jaridenv.2011.09.007]

[24] Congressional Research Service. Air Quality: EPA's 2013 Changes to the Particulate Matter (PM) Standard [Internet]. 2015 [Updated 2015 January 7]. Available from: https://www.everycrsreport.com/files/20150107_R42934_1ff9cb6b83e567019f30f3f101475a68264fddbd.pdf

[25] Oliveri Conti G, Heibati B, Kloog I, Fiore M, Ferrante M. A review of AirQ Models and their applications for forecasting the air pollution health outcomes. Environ Sci Pollut Res Int. 2017; 24(7):6426-45. [DOI:10.1007/s11356-016-8180-1] [PMID]

[26] Versporten A, Bolokhovets G, Ghazaryan L, Abilova V, Pyshnik G, Spasojevic T, et al. Antibiotic use in Eastern Europe: A cross-national database study in coordination with the WHO Regional Office for Europe. Lancet Infect Dis. 2014; 14(5):381-7. [DOI:10.1016/S1473-3099(14)70071-4]

[27] Nourmoradi H, Omidi Khaniabadi Y, Goudarzi GR, Daryanoosh SM, Khoshgoftar M, Omidi F, et al. Air quality and health risks associated with exposure to particulate matter: A cross-sectional study in Khorramabad, Iran. Health Scope. 2016; 5(2):e31766. [DOI:10.17795/jhealthscope-31766]

[28] Ghanizadeh Gh, Khoshniyat R, Karimi F, Haghshenas MR, Abdollahi M, Hamidi E, et al. Short-term effects of PM10 to increase rate of hospital admission cardiovascular and respiratory of Sanandaj, Iran during 2015. Iran J Health Saf Environ. 2018; 5(2):957-65. http://www.ijhse.ir/index.php/IJHSE/article/view/291

[29] Omidi Khaniabadi Y, Goudarzi GR, Daryanoosh SM, Borgini A, Tittarelli A, De Marco A. Exposure to PM10, NO2, and O3 and impacts on human health. Environ Sci Pollut Res Int. 2017; 24(3):2781-9. [DOI:10.1007/s11356-016-8038-6] [PMID]

[30] Bahrami Asl F, Kermani M, Aghaei M, Karimzadeh S, Salahshour Arian S, Shahsavani A, et al. [Estimation of diseases and mortality attributed to NO2 pollutant in five metropolises of Iran using AirQ model in 2011-2012 (Persian)]. J Mazandaran Univ Med Sci. 2015; 24(121):239-49. http://jmums.mazums.ac.ir/article-1-4965-fa.html

[31] World Health Organization. The top 10 causes of death [Internet]. 2020 [Updated 2020 December 9]. Available from: https://www.who.int/news-room/fact-sheets/detail/the-top-10-causes-of-death

[32] Burnett RT, Pope III CA, Ezzati M, Olives C, Lim SS, Mehta S, et al. An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. Environ Health Perspect. 2014; 122(4):397-403. [DOI:10.1289/ehp.1307049] [PMID] [PMCID]

[33] Sicard P, Lesne O, Alexandre N, Mangin A, Collomp R. Air quality trends and potential health effects - Development of an aggregate risk index. Atmos Environ. 2011; 45(5):1145-53. [DOI:10.1016/j.atmosenv.2010.12.052]

[34] Milner A, Page A, LaMontagne AD. Long-term unemployment and suicide: A systematic review and meta-analysis. PLoS One. 2013; 8(1):e51333. [DOI:10.1371/journal.pone.0051333] [PMID] [PMCID]

[35] Bonyadi Z, Ehrampoush MH, Ghaneian MT, Mokhtari M, Sadeghi A. Cardiovascular, respiratory, and total mortality attributed to PM2.5 in Mashhad, Iran. Environ Monit Assess. 2016; 188(10):570. [DOI:10.1007/s10661-016-5574-y] [PMID]

[36] Hopke PK, Hashemi Nazari SS, 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 Air Qual Res. 2018; 18:497-504. [DOI:10.4209/aaqr.2017.09.0325]

[37] Mudu P, Gapp Ch, Dunbar M. AirQ+ 1.0 example of calculations [Internet]. 2016 [Updated 2016 April]. Available from: https://www.euro.who.int/__data/assets/pdf_file/0008/309995/AirQ1-0-Examples-calculations.pdf

[38] Rich DQ. Accountability studies of air pollution and health effects: Lessons learned and recommendations for future natural experiment opportunities. Environ Int. 2017; 100:62-78. [DOI:10.1016/j.envint.2016.12.019] [PMID] [PMCID]

[39] Sanyal Sh, Rochereau T, Maesano CN, Com-Ruelle L, Annesi-Maesano I. Long-term effect of outdoor air pollution on mortality and morbidity: A 12-year follow-up study for metropolitan France. Int J Environ Res Public Health. 2018; 15(11):2487. [DOI:10.3390/ijerph15112487] [PMID] [PMCID]

[40] Rennard SI. COPD: Overview of definitions, epidemiology, and factors influencing its development. Chest. 1998; 113(4):235S-41. [DOI:10.1378/chest.113.4_Supplement.235S] [PMID]

[41] Guo C, Zhang Z, Lau AKH, Lin CQ, Chuang YC, Chan J, et al. Effect of long-term exposure to fine particulate matter on lung function decline and risk of chronic obstructive pulmonary disease in Taiwan: A longitudinal, cohort study. Lancet Planet Health. 2018; 2(3):E114-25. [DOI:10.1016/S2542-5196(18)30028-7]

[42] Li MH, Fan LC, Mao B, Yang JW, Choi AMK, Cao WJ, et al. Short-term exposure to ambient fine particulate matter increases hospitalizations and mortality in COPD: A systematic review and meta-analysis. Chest. 2016; 149(2):447-58. [DOI:10.1378/chest.15-0513] [PMID]

[43] Kan H, Chen B. A case-crossover analysis of air pollution and daily mortality in Shanghai. J Occup Health. 2003; 45(2):119-24. [DOI:10.1539/joh.45.119] [PMID]

[44] Cao Q, Rui G, Liang Y. Study on PM2.5 pollution and the mortality due to lung cancer in China based on geographic weighted regression model. BMC Public Health. 2018; 18(1):925. [DOI:10.1186/s12889-018-5844-4] [PMID] [PMCID]

[45] Fu J, Jiang D, Lin G, Liu K, Wang Q. An ecological analysis of PM2.5 concentrations and lung cancer mortality rates in China. BMJ Open. 2015; 5(11):e009452. [DOI:10.1136/bmjopen-2015-009452] [PMID] [PMCID]

[46] Kurt OK, Zhang J, Pinkerton KE. Pulmonary health effects of air pollution. Curr Opin Pulm Med. 2016; 22(2):138-43. [DOI:10.1097/MCP.0000000000000248] [PMID] [PMCID]

[47] Mousavi SM, Sundquist J, Hemminki K. Cancer incidence among Turkish, Chilean, and North African first-generation immigrants in Sweden compared with residents in the countries of origin and native Swedes. Eur J Cancer Prev. 2013; 22(1):1-7. [DOI:10.1097/CEJ.0b013e3283552e4d] [PMID]

[48] Dai X, Liu H, Chen D, Zhang J. Association between ambient particulate matter concentrations and hospitalization for ischemic heart disease (I20-I25, ICD-10) in China: A multicity case-crossover study. Atmos Environ. 2018; 186:129-35. [DOI:10.1016/j.atmosenv.2018.05.033]

[49] Pinault LL, Weichenthal S, Crouse DL, Brauer M, Erickson A, van Donkelaar A, et al. Associations between fine particulate matter and mortality in the 2001 Canadian Census Health and Environment Cohort. Environ Res. 2017; 159:406-15. [DOI:10.1016/j.envres.2017.08.037] [PMID]

[50] Hayes RB, Lim Ch, Zhang Y, Cromar K, Shao Y, Reynolds HR, et al. PM2.5 air pollution and cause-specific cardiovascular disease mortality. Int J Epidemiol. 2020; 49(1):25-35. [DOI:10.1093/ije/dyz114] [PMID] [PMCID]

[51] Wang Y, Zhong Y, Liao J, Wang G. PM2.5-related cell death patterns. Int J Med Sci. 2021; 18(4):1024-9. [DOI:10.7150/ijms.46421] [PMID] [PMCID]

[52] Wang Y, Eliot MN, Wellenius GA. Short-term changes in ambient particulate matter and risk of stroke: A systematic review and meta-analysis. J Am Heart Assoc. 2014; 3(4):e000983. [DOI:10.1161/JAHA.114.000983] [PMID] [PMCID]

[53] Huang K, Liang F, Yang X, Liu F, Li J, Xiao Q, et al. Long term exposure to ambient fine particulate matter and incidence of stroke: Prospective cohort study from the China-PAR project. BMJ. 2019; 367:l6720. [DOI:10.1136/bmj.l6720] [PMID] [PMCID]

[54] Dong H, Yu Y, Yao Sh, Lu Y, Chen Zh, Li G, et al. Acute effects of air pollution on ischaemic stroke onset and deaths: A time-series study in Changzhou, China. BMJ Open. 2018; 8(7):e020425. [DOI:10.1136/bmjopen-2017-020425] [PMID] [PMCID]

[55] Yang WS, Wang X, Deng Q, Fan WY, Wang WY. An evidence-based appraisal of global association between air pollution and risk of stroke. Int J Cardiol. 2014; 175(2):307-13. [DOI:10.1016/j.ijcard.2014.05.044] [PMID]

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