Original Article

Investigation Variations of Particulate Matter and Volatile Organic Compounds Concentration in Gorgan City and the Effect of Atmospheric Factors in Emission These Pollutants: Estimation of Spatial Distribution of Air Quality Index by GIS

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Abstract

Aims: In this study, the concentration of particulate matter (PM) $_{2.5}$ and PM_{10} particles and volatile organic compounds (VOCs) was measured from July of 2016 to June of 2017 in Gorgan City and the values of the air quality index (AQI) for particles were calculated and investigated. **Materials and Methods:** The concentrations of $PM_{2.5}$, PM_{10}, and VOCs were measured at eight stations in the city, and the relationship between different atmospheric conditions and the concentration of pollutants was assessed by statistical tests of variance analysis. Furthermore, the AQI values for the particles were measured, and based on the values of this index, using ArcGIS 10.3 software (ESRI Compony, USA), the zoning maps were prepared. **Results:** The average concentrations of $PM_{2.5}$, PM_{10}, and VOCs in the eight stations were 30.6 µg/m^3, 41.3 µg/m^3, and 0.82 ppm, respectively. The average concentration of $PM_{2.5}$ and VOCs is higher than Environmental Protection Agency and clean air standards. Analysis of variance test was showed that the concentration difference of particles in different stations was not significant ($P > 0.05$), but for VOCs concentration, there was a statistically significant difference between the station of Seyed Masoud restaurant and Terminal square ($P < 0.05$). Furthermore, the results were showed that the temperature has an inverse relationship with the concentration of pollutants. AQI values for $PM_{2.5}$ in the cold months of the year and in the central parts of the city were in the range of 101–150. The maximum AQI for PM_{10} was equivalent to 55, which was in December 2016. **Conclusion:** The air quality of Gorgan City was not in desirable conditions due to the high concentration of pollutants, especially $PM_{2.5}$ and VOCs, and should be taken control proceedings.

Keywords: Air pollution, air quality index, atmospheric factors, GIS, particles, volatile organic compounds

Introduction

With the industrialization of societies, air pollution has become a major issue in developed and developing countries.[1,2] In many developing countries, public health concerns about air pollution are increasing because the population and industry are growing rapidly. On the other hand, many of recent studies have clearly shown that air pollution can be have adverse effects on human health.[3-5] Among the pollutants in the air today, suspended particles and volatile organic compounds (VOCs), especially in large cities, are of great importance. The total suspended particles, the particles smaller than 2.5 µ and smaller than 10 µ, are called

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TSP, particulate matter (PM) $_{2.5}$ and PM_{10}, respectively.[6,7] $PM_{2.5}$ and PM_{10} are important in terms of health. Infection of the upper respiratory tract, pneumonia, pulmonary inflammation, cancer, bronchitis, dyspnea, and heart disorders are the major side effects of suspended particulates on humans.[8,9] The VOC compounds are carbon contaminants that have high vapor pressure at room temperature. These compounds have a natural and artificial origin. The forest and volcano are natural resources and combustion, industrial, and pharmaceutical processes, and petroleum and gas industries are artificial sources. The benzene, toluene, ethylbenzene, and xylene (BTEX) compounds are from of the most hazardous VOCs, which come out of the car's exhaust. This compound contains BTEX hydrocarbons.[10,11] Cancer, genetic mutation, eye irritation, dizziness, and headaches and even loss of short-term memory are the effects of prolonged exposure to VOCs.[12] According to the Environmental Protection Agency (EPA) standard, the maximum annual permissible concentrations of $PM_{2.5}$ and PM_{10} are 12 and 50 $\mu g/m^3$, respectively. Furthermore, based on clean air standards, the maximum permissible concentration for 3-hexposure to VOCs is 0.24 ppm.[13,14] EPA, in spite of the lack of uniformity and diversity of pollutants, in addition to determination of different standards, has set indexes for the expression of air quality and for public information purposes. One of these indicators is the air quality index (AQI), which used widely throughout the world over the last three decades.[15] The level of AQI is determined with the measurement of six pollutants includes concentration SO_2, NO_2, O_3, $PM_{2.5}$, PM_{10}, and CO.[16,17]

Given that the importance of air pollution issues, the aim of this study was to measure the concentrations of $PM_{2.5}$, PM_{10}, and VOCs in Gorgan City air and to investigate the effect of atmospheric factor on the concentration of these pollutants in 1 year (2016–2017). Furthermore, to determine the air quality of Gorgan, AQI, which is one of the conventional air quality indices, was calculated for the PM, and the results were presented as zoning maps.

Materials and Methods

Specifications of the area studied

Golestan Province with an area of 20437.77 km² constitutes for 1.3% of the total area of the country. The climate condition in different regions of this province is variable so that in the Southern regions of the province, the climate is mild and humid, and in its middle and northern regions, the climate is dry and semi-arid. Gorgan is located in the Southern part of the province and has a moderate climate. The area of this city is 1615.8 km² (7.91% of the province's area), and its longitude is 54°, 12.9′ to 54°, 44.9′ East and 36° 30.46′ to 36°, 58.8′ North latitude. The average temperature is in the range of 6°C–28.7°C, and the average annual precipitation is about 39.25 mm.[18-20]

Research methodology and sampling method

To survey the variation of $PM_{2.5}$, PM_{10}, and VOC concentrations in the air of Gorgan, the eight measurement stations were considered in the study area, which are shown in Figure 1.

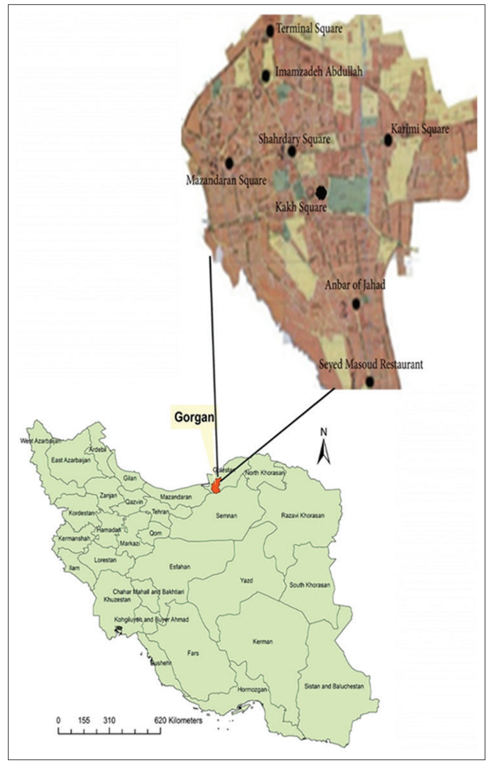

Figure 1: Location of Gorgan City relative to the whole country and sampling stations in Gorgan City

This study was a descriptive cross-sectional wherein $PM_{2.5}$, PM_{10}, and VOCs concentrations were measured from July 2016 to June 2017. Sampling was performed momentary, which for each contaminant monthly three samples per station and a total of 288 samples were taken. It should be noted that the sampling time was 10 AM on the 10th, 20th, and last days of each month. According to the standard 1/1/2, the samples were taken at a distance of 1 m from the ground and at a distance of 1 m from environmental barriers for 2 h.[21]

The samples of PM were taken in different atmospheric conditions using the HAZ-Dust Portable Device (EPAM-5000, SKC manufactured in the United States [USA]). This device has capable of sampling ambient dust at sizes of 1, 2, 5, and 10 mg/m^3, and for this purpose, it has three fraternity sample filters in said sizes. First, we turn on the device with a button on the right side of the home screen. The home screen appears, and we select the Special Function option. The next page has four options that choose the system option. On the third page, we select an extended option. In the next step, we select size, and depending on the size of the sampling, we choose one of the sizes 1, 2, 5, and 10 mg/m^3. Then, go to the next page and select Run and start sampling. By pressing the Enter key on the keyboard, the results are stored in memory by specifying the sample number. The VOCs were also the same way measured using a PhoCheck portable device (Made in Ireland).

Data analysis and statistical tests

The statistical population was the same samples taken from the air, which have been taken at different times and conditions. After doing the experiments and obtaining the results from the Excel, SPSS software was used to analyze the hypotheses and draw charts and data categorization. In this research, the significance level of the difference in concentrations of pollutants in different stations was determined using one-way analysis of variance (ANOVA test) and analyzed. Also, for determined correlation between of pollutants and some of the atmospheric condition was used from the ANOVA test. In this case, there is an independent qualitative variable (multilevel) and a dependent variable.

Furthermore, based on the normality of the data, the correlation between the groups of pollutants and their relationship with other meteorological factor, means temperature, was calculated with the Pearson Correlation test. This correlation coefficient, which is the most common type of correlation, indicates the linear relationship between the quantities.

Based on the results of the measurements for two particles $PM_{2.5}$ and PM_{10} in the whole city of Gorgan, the urban AQI for these two particles was calculated using the AQI formula.[16]

Preparation of zoning maps

Finally, due to the local specification of sampling stations, using GPS, the geographic coordinates of the sampling points were determined, and using the Arc GIS ver 10.3 software, contamination distribution according to the AQI, mapping was prepared. Furthermore, VOC annual concentrations were zoned at different stations in Gorgan. Due to station dispersal and sampling-restricted points, the inverse distance weighted model was selected.[22,23]

Results

$PM_{2.5}$, PM_{10}, and VOC concentrations at eight stations over a period of 1 year from July 2016 to June 2017 were measured, and the effects of various weather parameters such as sunny weather, wind speed, and air temperature on the concentration of these pollutants were studied. The results are shown in Table 1, which were described in the following.

Concentration of particulate matter$_{2.5}$, particulate matter$_{10}$, and volatile organic compounds in different station

The average particle concentration and VOC concentration at each station during a year are explained in Figure 2, respectively. The average concentrations of $PM_{2.5}$, PM_{10}, and VOC contaminants have fluctuated at different stations. However, by doing the ANOVA test, it can be found that the concentration of $PM_{2.5}$ and PM_{10} between different stations did not differ significantly (*P* value: 0.58 and 0.28 and degree of freedom [df]: 88). Totally, according to the results, the highest concentrations of $PM_{2.5}$ were measured at the Shahrdary Square station in the city center, equivalent to 36 $\mu g/m^3$, and the lowest in the Terminal Square in the North of the city, equivalent to 26 $\mu g/m^3$, which is more than the amount of permissible determination by the EPA. Meanwhile, the highest concentration of PM_{10} was observed at Seyed Masoud restaurant station, equivalent to 52 $\mu g/m^3$, and the lowest was at the Imamzadeh Abdullah station in the North of the city and equivalent to 32 $\mu g/m^3$.

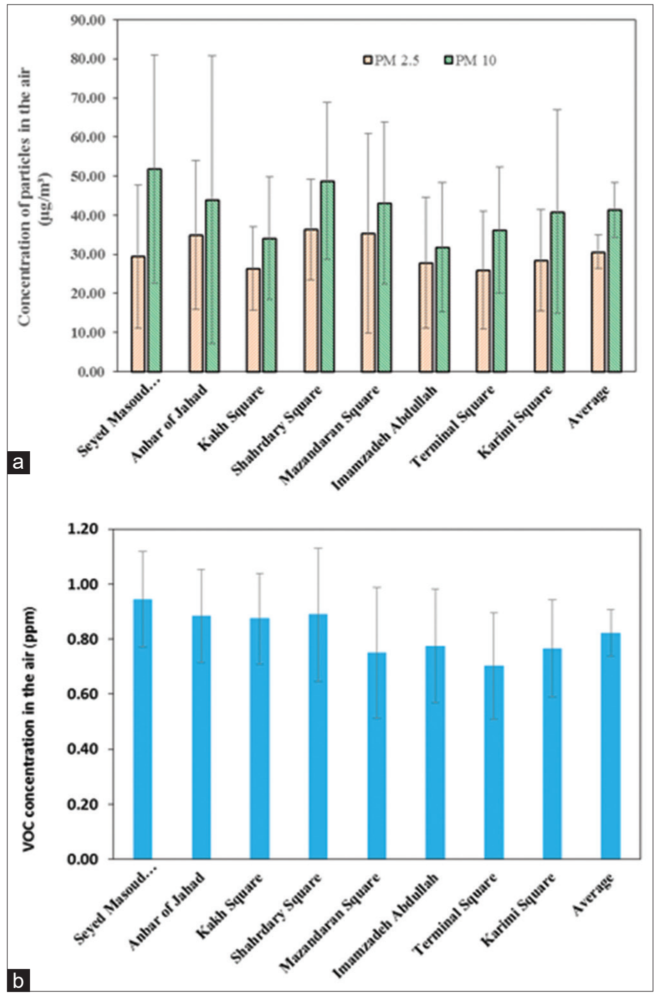

Figure 2: (a) The average $PM_{2.5}$ and PM_{10} (as $\mu g/m^3$) concentrations in sampling station, (b) The average volatile organic compounds (as mg/L) concentration in sampling station. PM: Particulate matter

In the case of VOC concentration, the results were showed that the maximum concentration of these compounds was measured at Seyed Masoud restaurant station, about 0.94 ppm. The result of the ANOVA test for determination of VOCs concentrations difference at the eight stations was showed that there was a significant difference in the amount of VOC in different stations. By doing the Tukey test for various stations, this difference was Between to the Seyed Masoud restaurant station and terminal square ($P < 0.05$).

Figure 3 shows the zoning of different stations in the city by GIS according to the average annual concentration of VOCs. Regarding Figure 3, it can be finding that the Seyed Masoud restaurant station had the maximum and Terminal Square station had the minimum concentration of VOC.

The effect of meteorological parameters on the concentration of pollutants

In this section, using statistical analyzes, the relationship between atmospheric conditions with concentrations of $PM_{2.5}$, PM_{10}, and VOCs has been investigated, which the following is discussed in each case.

Table 1: Average monthly concentration of PM2.5, PM10, and volatile organic compounds at different stations in Gorgan City

Station name	Pollutant	Months											
		July 2016	August 16	September 2016	October 2016	November 2016	December 2016	January 2017	February 2017	March 2017	April 2017	May 2017	June 2017
Seyed Masoud Restaurant	$PM_{2.5}$ (μg/m^3)	39	42	40.5	46.75	53	23	34	2	6	39	39	2
	PM_{10} (μg/m^3)	41	45	43	49	55	50	124	3	32	46	67	60
	VOCs (ppm)	0.68	0.8	0.74	0.87	1	1.1	1.1	1.1	1.1	1	0.9	0.7
Anbar of Jahad	$PM_{2.5}$	20	21	20.5	28.75	28	75	46	45	12	6	33	17
	PM_{10}	28	31	29.5	33.75	47	144	65	32	42	16	42	59
	VOCs	0.78	0.8	0.79	0.945	1.1	1	1.1	1.1	0.7	0.7	0.8	0.7
Kakh Square	$PM_{2.5}$	12	15	13.5	24.75	36	49	23	25	32	17	25	33
	PM_{10}	25	26	25.5	30.75	36	76	25	27	36	18	43	34
	VOCs	0.75	0.8	0.775	0.8875	1	1.2	1	1	0.8	0.8	0.8	0.6
Shahrdary Square	$PM_{2.5}$	32	34	33	31.5	30	49	52	20	32	12	55	34
	PM_{10}	50	54	52	46	40	85	56	30	33	42	84	38
	VOCs	0.67	0.8	0.735	0.8675	1	1.1	1.4	1	0.9	0.8	0.5	0.7
Mazandaran Square	$PM_{2.5}$	12	14	13	40	62	90	21	38	14	21	15	39
	PM_{10}	20	20	20	41	67	91	46	43	50	27	41	52
	VOCs	0.45	0.5	0.475	0.7375	1	1.1	1	0.9	0.7	0.7	0.8	0.4
Imamzadeh Abdullah	$PM_{2.5}$	14	15	14.5	22.25	30	47	34	60	23	6	17	11
	PM_{10}	15	19	17	26.5	36	57	42	64	38	18	29	35
	VOCs	0.7	0.7	0.7	0.75	0.8	0.8	0.9	1.27	0.8	0.8	0.5	0.5
Terminal Square	$PM_{2.5}$	5	4	4.5	18.75	33	47	45	27	30	24	35	9
	PM_{10}	15	7	11	25.5	40	65	53	34	36	36	48	42
	VOCs	0.65	0.7	0.675	0.6875	0.7	1	0.9	0.9	0.7	0.7	0.5	0.3
Karimi Square	$PM_{2.5}$	25	34	29.5	34.75	40	58	28	9	16	11	25	11
	PM_{10}	52	62	57	48	39	103	38	17	29	21	43	29
	VOCs	0.6	0.7	0.65	0.675	0.7	1	1	0.9	0.9	0.8	0.5	0.6

Sunny, warm (20°C-33.3°C), no wind

Cloudy and partly cloudy, no wind

Cloudy, a little wind (8-15 km/h)

Cloudy, a little wind, cold (1.7°C-6.5°C)

Cloudy, high wind (16-24 km/h)

Sunny, warm, a little wind

VOCs: Volatile organic compounds

Effect of atmospheric conditions

The atmospheric conditions studied include sunny, cloudy, and semi-cloudy weather conditions. The ANOVA analysis with df 95 was showed that the atmospheric conditions do not affect statistically the concentration of particulate pollutants and VOCs ($P > 0.05$).

Effect of intensity of wind

The effect of wind intensity (no wind, a little wind 8–11 km/h, and high wind) on the concentration of $PM_{2.5}$, PM_{10}, and VOCs pollutants was evaluated using ANOVA test, which by performing this test, the amount of P value whit df 95 was obtained as 0.48, 0.84, and 0.82, respectively. These results have indicated that the intensity of the wind does not correlate with the concentration of pollutants. Furthermore, the annual wind roses of Gorgan City were prepared during this time period, which is visible in Figure 4.[24] According to Figure 4, the prevailing wind direction was from the West and Southwest, in which 31.3% of the wind was calm.

Effect of air temperature

Since temperature is a quantitative parameter, Pearson correlation test was used to determine its effect on the concentration of $PM_{2.5}$, PM_{10}, and VOCs. Furthermore, the correlation between pollutants was investigated by this analysis. The results were shown that the temperature has an inverse effect on the concentration of the three pollutants ($P < 0.01$). That's mean, by decreasing the temperature, the concentration of PM pollutant and VOCs was increased. Due to the values of the correlation coefficient for $PM_{2.5}$, PM_{10}, and VOC pollutants which are 0.3, 0.26, and 0.7, respectively, the intensity of temperature effect on VOCs was higher.

Another result that can be found from the Pearson correlation analysis was that the concentrations of $PM_{2.5}$, PM_{10}, and VOC pollutants are statistically related ($P < 0.01$).

The air quality index values for particulate matter$_{2.5}$ and particulate matter$_{10}$

The AQI index for $PM_{2.5}$ and PM_{10} particles was calculated in different and the results are presented in Figure 5. According to the standard, to calculate the values of AQI, these two particle concentration is measured in μg/m^3/day. As the results have shown, the highest AQI is for $PM_{2.5}$ particles, which occurred in the months of November, December, and January. The AQI for these months was 117, 148, and 102, respectively, and according to Table 2, these values are in the unhealthy range for sensitive groups.

In this study, also the average annual concentration of $PM_{2.5}$ and PM_{10} was measured at different stations in Gorgan City, then the AQI index for these two particles was calculated. Finally, by using the Arc GIS, zoning maps were prepared which is visible in Figure 6.

Discussion

Concentration of particulate matter$_{2.5}$, particulate matter$_{10}$, and volatile organic compounds in different stations

Recently, air pollution is a serious threat to humans and the environment. PM and VOCs are significant air pollutants that any creature is exposed to serious damage by breathing air containing these pollutants in amounts of more than permissible limit and long term.[7,25]

Based on the results, the maximum concentration of $PM_{2.5}$ and PM_{10} was measured in the Center and Southern region of city, which are the busiest areas of the city. Since the transportation, fossil fuel motors, and traffic are from the main factors to create of PM, the results obtained were acceptable.[26]

In this regard, Shahbazi *et al*., by monitoring the particle concentration in the Tehran air, reported increased concentrations of PM in the high-traffic areas of the city.[27] Furthermore, according to the research of Hoek *et al*., the density of buildings and the type of land use have affected

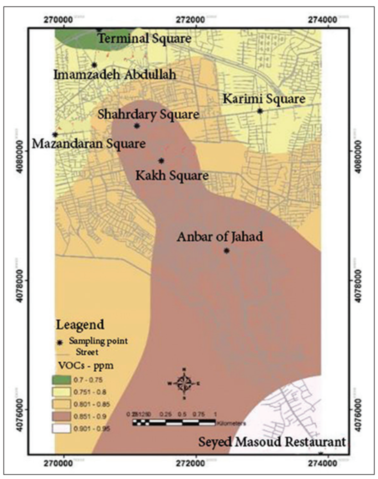

Figure 3: The zoning of different stations in *Gorgan* based on the annual concentration of volatile organic compounds with GIS

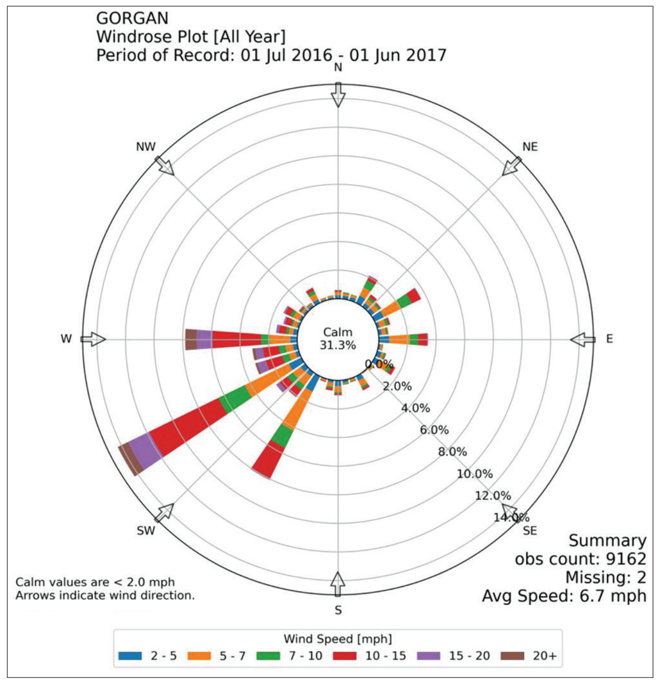

Figure 4: The wind rose of Gorgan city

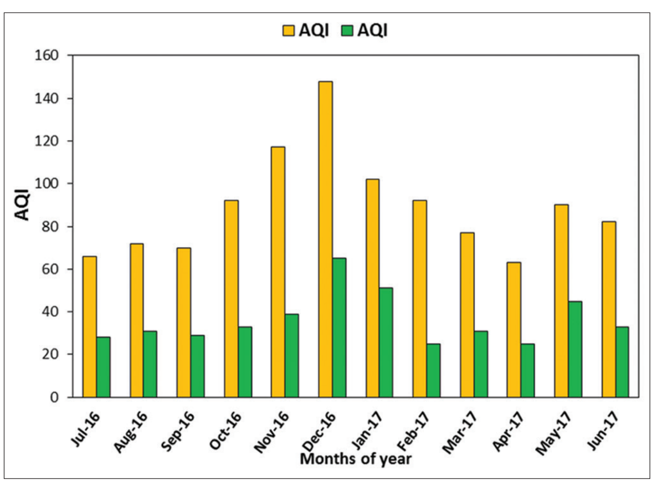

Figure 5: The city air quality index for $PM_{2.5}$ and PM_{10} particles in different months in Gorgan city. PM: Particulate matter

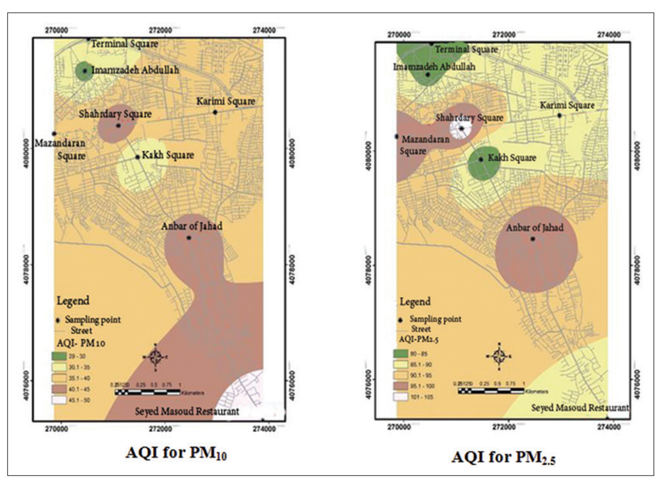

Figure 6: Zoning different stations based on air quality index values using GIS

Table 2: Air quality index breakdown points for $PM_{2.5}$ and PM_{10}

Level of health concern	AQI values	$PM_{2.5}$ (μg/m³/day)	PM_{10} (μg/m³/day)	Colors
Good	0-50	0-15.4	0-54	
Moderate	51-100	15.5-35	55-154	
Unhealthy for sensitive groups	101-150	35.1-65.4	155-254	
Unhealthy	151-200	65.5-150.4	255-354	
Very unhealthy	201-300	150.5-250.4	355-424	
Hazardous	301-400	250.5-350.4	425-504	
	401-500	350.5-500.4	505-604	

AQI: Air quality index

the amount of these pollutants.[28] In addition to these reasons, the higher humidity in the Southern areas of the Gorgan City leads to in the formation of secondary aerosols, which may be the reason for the increase of PM_{10} in these areas.[29] However, in cities with hot and dry climates such as Zahedan City, the adverse effect of humidity on air particle concentration has been reported.[30]

As mentioned, the concentration of $PM_{2.5}$, from the acceptable values, was exceeded. Due to the fact that the major particles that Precipitate in the alveolus and pass through the lung wall into the bloodstream is $PM_{2.5}$, the concentration control of this pollutant in the air is essential. Therefore, concentration control of these particles is essential.[7]

The reason for the increased concentration in *Seyed Masoud* restaurant VOCs can be attributed to forest density and fire in these areas that are natural sources of VOC production.[31,32] However, in the city center, artificial resources such as transportation and traffic can be the main reasons for the increase in VOC concentration.

The effect of meteorological parameters on the concentration of pollutants

The results of the effects of atmospheric on the concentrations parameters such as sunny or cloudy weather, wind speed, and air temperature variations of $PM_{2.5}$, PM_{10}, and VOC were different.

The literature in different cities shows that variations in the concentration of pollutants are strongly dependent on the geographical location of the city, its topography, and the climate conditions.[32] Gorgan is one of the Northern cities of Iran, which have temperate climate and sunny weather has no effect on the pollutant of PM and VOC concentration. However, increases in concentrations of PM_{10}, VOC, and ozone on summer sunny days have been reported in some warm/dry cities such as Tehran by Golhosseini *et al*. and Hosseinibalam *et al*.[33,34]

Furthermore, the weather condition of Gorgan City has caused that the wind speed has no significant effect on the concentration of target pollutants. According to the wind roses of Gorgan, the amount of calm winds was considerable, which probably was the reason for no influence of wind speed on PM and VOCs concentration.

But Rashki *et al*., as a result of a study conducted in Zahedan city, reported that monsoon winds could increase the concentration of particles in this city's air.[30] Therefore, the geographical location of the city can be an important factor in the effect of wind on pollutant concentrations.

Based on the results, the temperature was the parameter affecting the concentrations of $PM_{2.5}$, PM_{10}, and VOC pollutants, which its effect was inverse. Reducing of temperatures in cold seasons was increasing the use of automobiles as well as the use of fossil fuels for heating purposes which are sources of target pollutants. On the other hand, the reason for this increase in concentrations of pollutants in cold days can be attributed to the air temperature inversion that causes particle and hydrocarbons traps in the lower layer, which may be the reason of increased concentrations of these pollutants.[35,36] The results of this study were similar to report of Gholampour *et al*. in Tabriz.[37] However, according to other studies, in desert areas such as Zahedan city, which in the summer the monsoon winds are dominated, the increase in particle concentration is noticeable in these seasons.[30]

Furthermore, the Pearson correlation test showed that the concentrations of $PM_{2.5}$, PM_{10}, and VOCs pollutants were statistically correlated so that the concentration of these three pollutants was increased or decreased simultaneously, this means that the cause of the increase in these pollutants has been a common factor, which seems this factor is urban vehicles. Other studies have obtained similar results.[38]

The air quality index values for particulate $matter_{2.5}$ and particulate $matter_{10}$

According to the results, the best air quality is related to particles PM_{10}, which in the months of February and April, AQI is the least for this pollutant and is equal to 25, this means that the air of the city of Gorgan has less problems with PM_{10} than of $PM_{2.5}$. In Europe for decades, the concentration of $PM_{2.5}$ has risen in urban areas. Cohort studies on this continent was Indicates the direct relationship between long-term exposure to $PM_{2.5}$ with increased mortality rates and referral the people to hospitals due to heart and respiratory problems.[39] According to studies carried out in Barcelona of Spain, Stockholm of Sweden, and Madrid of Spain, the total deaths per 10 μg/m³ concentration of $PM_{2.5}$ particles increased by 1.4%, 1.5%, and 2.7%, respectively.[40-42] Furthermore, studies have shown that exposure to $PM_{2.5}$, on average reduces the collective life expectancy of 8.6 months.[43] In a study conducted in 545 cities in the USA to reduce the concentration of suspended particles and increase the life expectancy of people in these cities between in the years 2000 and 2007, the results showed that for reducing of each 10 μg/m³ concentrations of $PM_{2.5}$ particles, the average life expectancy increases to 0.35 years.[44] In general, in this study, the average particle concentration, especially $PM_{2.5}$, in the cold season was obtained more than in the other months due to the thermal inversion and increased fuel consumption for heating purposes. Therefore, control measures to reduce emissions of pollutants can significantly reduce mortality rates. The results from this study are similar to the results announced by other researchers such as Gu *et al*., which the reason of the increase in particle concentration in autumn and winter in the Tianjin city has explained thermal inversion.[29]

By observing the zoning maps in Figure 6, also it can be found that the highest AQI of $PM_{2.5}$ was in the central regions of the city, namely the Shahrdary Square and Mazandaran Square. Furthermore, maximum AQI by PM_{10} particles was measured in the central part and as well as in the Southern part of the city. The cause of this event can be the congestion of cars in these areas, which is the most important factor in the production of particles in cities.

In this study, due to limited equipment, taking more samples and examining the concentrations of different types of pollutants were also limited. Due to the importance of the subject, it is recommended to concentrate other pollutants such as NO, NO_2, NOx, SO_2, and CO to be measured and check the air quality of Gorgan City in the level of existing standards in the country and the world.

Conclusion

The aim of this study was to determine the air quality of Gorgan City in terms of $PM_{2.5}$, PM_{10}, and VOCs concentrations. Measurement results of $PM_{2.5}$, PM_{10}, and VOCs concentrations in 1 year from July 2016 to June 2017 showed that the average concentration of $PM_{2.5}$ was higher than the EPA and WHO standard values. Furthermore, the concentration of PM_{10} is high in the cold months of the year. About of VOCs, according to the clean air standard, the average annual concentration of VOCs in Gorgan City, which is about 0.81 ppm, is much higher than the declared permissible value. Statistical tests were showed that among the atmospheric parameters, only the air temperature was correlated with the concentration of pollutants, which was reverse. In general, the effect of temperature inversion in the cold months of the year can be led to the durability of air around the city and increase concentrations of these pollutants. AQI values for $PM_{2.5}$ and PM_{10} also indicate unhealthy weather conditions for sensitive individuals, with a high concentration of $PM_{2.5}$. Furthermore, the zoning of AQI values in the city using GIS software showed that in the central areas of the city where traffic was high, this index was also higher. The ban on the use of cars over 15 years of age in urban areas from 6:30 to 19:30 during 72 h in emergencies, prohibition of public and private buses with more than 8 years of age in the city within 72 h, preventing the burning of forest woods on the floor of Alang darreh and Naharkhoran areas and installing NO FIRE, and the use of personal protective equipment and masks in unhealthy days are the solutions for reducing air pollution and protecting people from polluted air.

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Conflicts of interest

There are no conflicts of interest.

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