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The effect of climatic parameters on air pollution in Sanandaj, Iran

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Original Article

Abstract

Air pollution is one of the emerging environmental issues of the western cities of Iran. Daily data (2009-2012) on air pollutants in Sanandaj, Iran, were collected from the Department of Environmental Protection, Kurdistan Province, Iran. Climatic parameters were collected from the Kurdistan Meteorological Bureau. The quality of air was assessed based on the air quality index (AQI). The relationship between climatic parameters was analyzed using the Pearson correlation coefficient and multiple regression analysis. AQI indicated that the air quality in Sanandaj is under normal conditions. However, Particulate Matter (PM_{10}) was at medium and critical level, requiring precautionary measures for the health of the elderly and children. The concentration of PM_{10} has increased in recent years during the months of April to June (reached an unhealthy level in the warm days of the year). The highest pollutant concentration (CO and SO_2) was observed during cold days of the year (December to February). The highest concentration of NO_2, NO, O_3, and PM_{10} were observed in summer and spring, whereas the lowest concentrations were observed in cold seasons. The Pearson correlation analysis revealed a significant correlation between air pollutants and climatic parameters. The multiple regression analysis and R^2 analysis showed the influence of climatic factors on pollutant concentration. ANOVA indicated Factors which cause the most significant variability in pollutant concentration are air temperature, relative humidity, and wind speed.

KEYWORDS: Air Pollution, Analysis of Variance, Humidity, Iran, Regression Analysis, Temperature

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Introduction

Air quality is strongly dependent on weather and is, therefore, sensitive to climate change.[1] Air pollution in urban areas is often the result of exhaust gases from vehicles, and combustion in industries and for domestic purposes.[2] Anthropogenic air pollutants caused by technological progress, industrialization, and urban overpopulation have led to the deterioration of environmental air quality.[3] Air quality has become an important environmental problem throughout the world because of the dramatic increase in emission of pollutants resulted from the economic and industrial growth in the last century.[4] Today, vehicles are the main cause of air pollution in developing countries such as Iran.[5] Urban air pollution has different characteristics because of the variability of meteorological factors depending on the geographical and topographical peculiarities of the urban area.[6] To understand the influence of the climate on pollution,

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regional and local climatic parameters must be taken into account. Atmospheric visibility degradation is a key issue in climatology and air pollution studies. It exerts adverse effects on human lives, such as on highway crowding and restricted aircraft movements.[7] The concentration of air pollutants varies depending on meteorological factors, the source of pollutants, and the local topography.[8] The air quality index (AQI) is one of the main indices used to show the overall quality of the environment. With the variation in weather, from day to day, the air quality also changes. Urbanization is a spreading phenomenon throughout the world. Urban environments are often characterized by higher mean temperature, concentration of greenhouse gases, and atmospheric pollutants compared with surrounding rural areas.[9] In such areas, human health is affected by air pollution. The most significant air pollutants are nitrogen dioxide, sulfur dioxide, polycyclic aromatic hydrocarbons (PAHs), and particulate matter (PM) including dust, soot, and smoke.[10] The most abundant components of air pollution in urban areas are nitrogen dioxide (NO_2), ozone (O_3), and PM. SO_2 is particularly abundant in industrial areas.[11] Urban air pollution issues are of increasing concern to urban planners and policymakers. Air quality in most urban areas can reach levels high enough to have some health impacts. Initially, urban air pollution was considered as a problem mainly associated with domestic heating and industrial emissions.[12] However, the concentration of air pollutants is not only affected by sources of emission, but also by meteorological variables. Meteorological variables play an important role in the dispersion, transportation, and photochemical reactions of air pollutants, and secondary pollutant formation including O_3 and NO_2.[13]

Venegas and Mazzeo estimated horizontal distributions of CO and NOx background concentrations in Buenos Aires City, Argentina.[12] Alkasassbeh et al. assessed Particulate Matter (PM_{10}) concentration prediction, and total suspended particles (TSP) using autoregressive artificial neural networks and external input models. They used climatic parameters (temperature, relative humidity, and wind) for model input and developed two autoregressive artificial neural networks with external input models (ANNARX) to provide high performance modeling for PM_{10} and TSP parameters.[10] Stamatelos analyzed data from ambient PM_{10} concentration monitoring in Volos during 2005-2010. The results showed that PM_{10} concentration had a negative correlation with temperature and a positive correlation with relative humidity.[14] Marcazzan et al. considered the characterization of PM_{10} and $PM_{2.5}$ in the ambient air of Milan (Italy). They simulated $PM_{2.5}$ and PM_{10} in September 1997 and 1998 in the city center of Milan. The multivariate analysis of elements, gaseous pollutants, and concentration data led to the identification of four main sources contributing to PM_{10} and $PM_{2.5}$ composition; vehicle exhaust emissions, suspended crustal dust, secondary sulfates, and industrial emissions.[15] Akpinar et al. performed statistical analysis of meteorological factors and air pollution during winter months in Elazig, Turkey.[6] They observed a relationship between pollutant concentrations (SO_2 and TSP) and climatic factors from October to March 2003 to 2005. They found a medium and weak relationship between pollutant concentrations and meteorological factors in Elazig.[6]

Iran is one of the top ten disastrous countries in the world and it will soon become one of the most polluted countries in the world. According to the World Health Organization (WHO) report in 2013, Sanandaj, Iran, was the most polluted city regarding PM_{10} concentration. Hence, this research was performed with the aim to identify and evaluate Sanandaj City air pollution for six major pollutants (SO_2, CO, NO_2, NO, O_3, and PM_{10}) and establish its relationship with climatic parameters (temperature, precipitation, relative humidity, frost days, and wind speed).

Materials and Methods

Sanandaj City, Kurdistan Province, Iran, is located on the geographic coordinates of 35°20' north latitude and 47°18' east longitude of the prime meridian (Figure 1). Height average of Sanandaj is 1535 m above sea level (the lowest and highest points are 600 and 2550 m, respectively). The city has a semi-arid Mediterranean climate.

This was a statistical-analytical research. Daily, monthly, and annual (from 2009 to 2012) data on climatic parameters (minimum temperature, maximum temperature, daily temperature (T °C), precipitation (mm), relative humidity (RH%), wind speed (Knot), and frost days of Sanandaj) were collected from the Kurdistan Meteorological Bureau. Then, the air quality data on pollutants (SO_2, CO, NO, NO_2, O_3, and PM_{10}) collected from the Kurdistan Environmental Protection Agency were adjusted for the same period. The Pearson correlation and multiple regression analysis were used to find and interpret the relationship between pollutants and meteorological parameters. Moreover, AQI was used to assess the air quality.

Results and Discussion

Climatic conditions

Sanandaj has a Mediterranean climate (Figure 2). Most of the total precipitation occurs between November and May, and the dry period is from June to October. The maximum, minimum, and daily mean temperature recorded for Sanandaj City is shown in figure 3. As figure 3 indicates, the coldest (-4.6 °C) and warmest (38 °C) months are January and June, respectively. Climatic parameters, such as relative humidity, wind speed, and frost days, are crucial factors in dispersing air pollutants. Figure 4 shows that the highest amount of relative humidity and frost days are observed in the winter (late December to late February), whereas the highest wind speed of the area occurs in spring to late summer. In fact, from late winter, wind speed increases due to the change of season and gradual increase in heat.

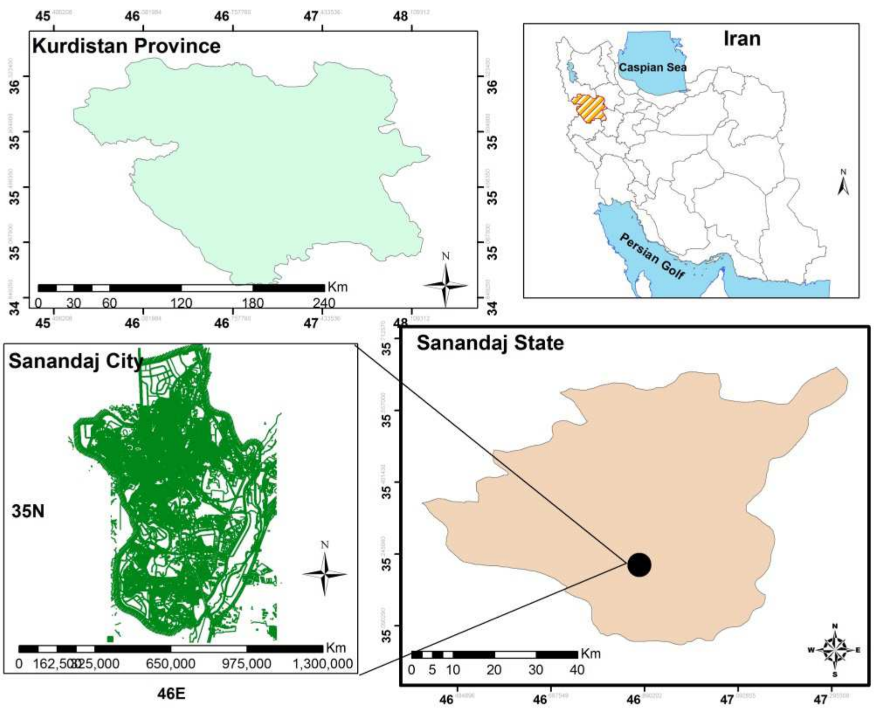

Figure 1. Geographical location of Sanandaj City

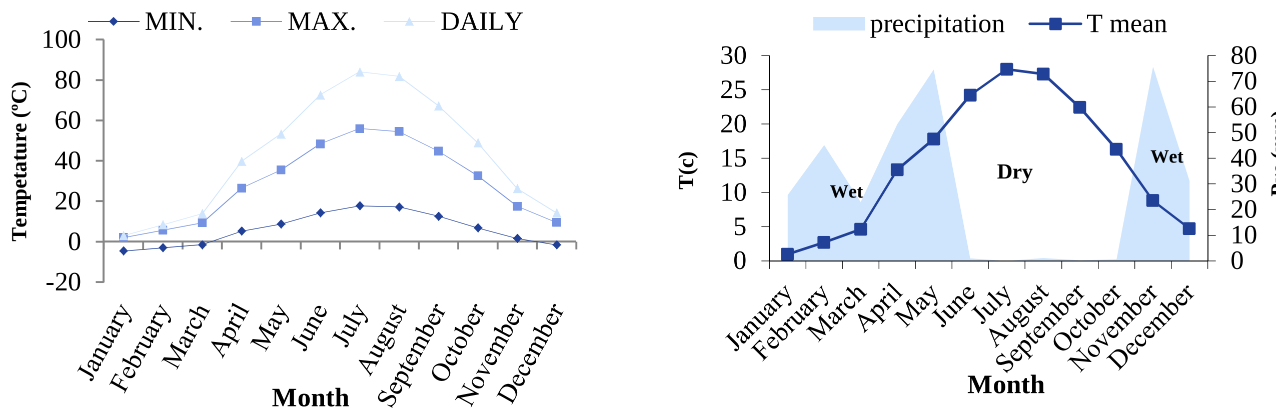

Figure 2. Climatic diagram of Sanandaj for 2009-2012

T mean: mean daily air temperature; pre: monthly total precipitation

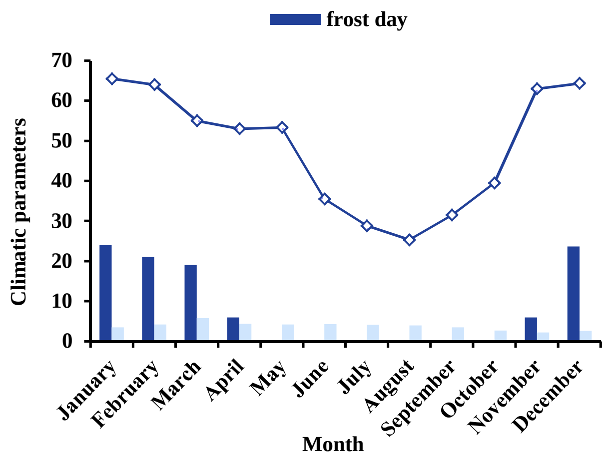

Figure 3. The mean frost days, humidity (%), and wind speed (m/s) in Sanandaj City from 2009 to 2012

Pollutant concentration

The monthly and seasonal, and diurnal concentrations of SO_2, NO, NO_2, CO, O_3, and PM_{10} during the period of the study are represented graphically in figure 4 and figure 5, respectively. The monthly variation of pollutants shows that CO and SO_2 have reached their maximum amount during December to February and NO, NO_2, and O_3 during June to August. The two main maximum concentrations of PM_{10} were observed during April to May and in July. The seasonal variation of pollutants shows that CO and SO_2 reached their maximum amount in winter, NO, NO_2, and O_3 in summer, and PM_{10} in spring.

Akpinar et al. reported that the highest concentration of SO_2 was observed during January-February, which are the coldest months of the year in Elaziğ City, Turkey.[6] Al-Awadhi observed that Kuwait experienced higher concentration of NO and SO_2 during winter, while higher O_3 values were recorded in summer.[16] In another study conducted in Daegu, Korea, Jo and Park reported that the maximum levels of CO and SO_2 were obtained in cold seasons, while NO_2 and O_3 had the highest level during warm seasons.[17] Moreover, AL-Jeelani showed that low values of O_3 and NO_2 appear in late autumn and winter (colder periods), while the high values appeared in late spring, summer, and early autumn (warmer periods).[3]

The high level of some pollutants during cold seasons can be attributed to the increased consumption of fuels caused by heat sources and vehicles along with meteorological conditions such as increased atmospheric pressure, air stability, and temperature inversion. Moreover, the seasonal maximum heat season could be contributed to the gradually increasing ground surface temperature, and decreasing precipitation and relative humidity. One of the main factors of an increase in ozone during spring and summer is the increase of photochemical reactions, and thus, ozone production. Factors effective on the high level of PM_{10} during summer might be air dryness, and increase in temperature and wind speed during this season.[18]

There is no heavy industry in Sanandaj or its neighboring areas. However, these high concentrations of pollutants could be attributed to the high number of old model vehicles, low quality petrol, and tendency to use private cars instead of public transportation.

Because of the importance of PM_{10} in the study area, the AQI was calculated for this pollutant based on daily data from 2012. Although mathematical equations could be used to convert air pollutant concentration into AQI values, many websites are available online which convert pollutant concentrations into AQI values.[19,20] As table 1 indicates, citizens of Sanandaj City and its surrounding areas experienced different concentrations of PM_{10} for 240 days, 38 days of which, the concentration exceeded 950 µg/m³ (very dangerous class).

It was found that the frequency and occurrence of sand and dust storms has continuously and drastically increased in the last decade in Iraq. Hence, the high concentration of PM_{10} could be attributed to the uncontrolled formation and occurrence of dust phenomenon in neighborhood countries like Iraq (Figure 6).[21]

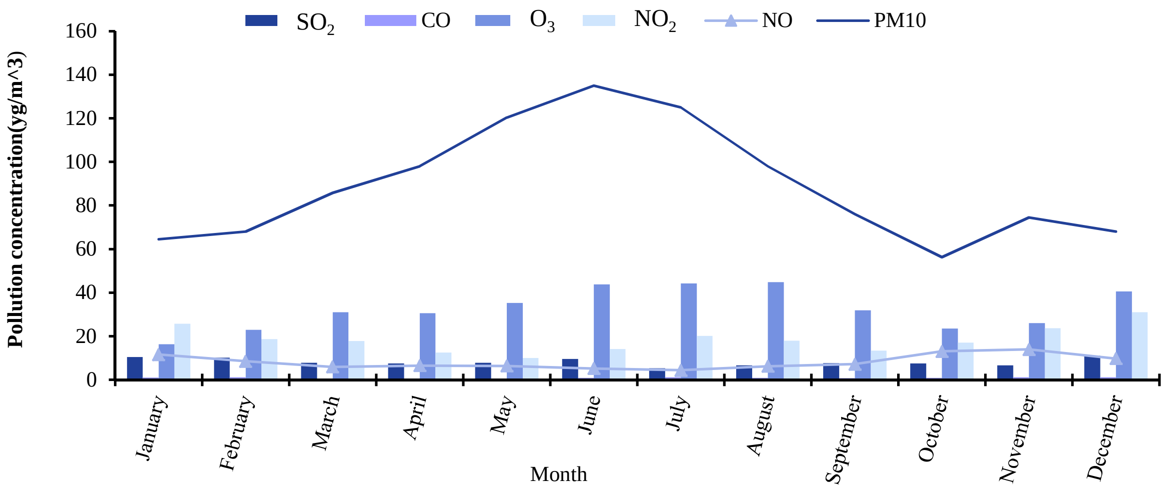

Figure 4. The mean monthly concentration of pollutants in Sanandaj City from 2009 to 2012

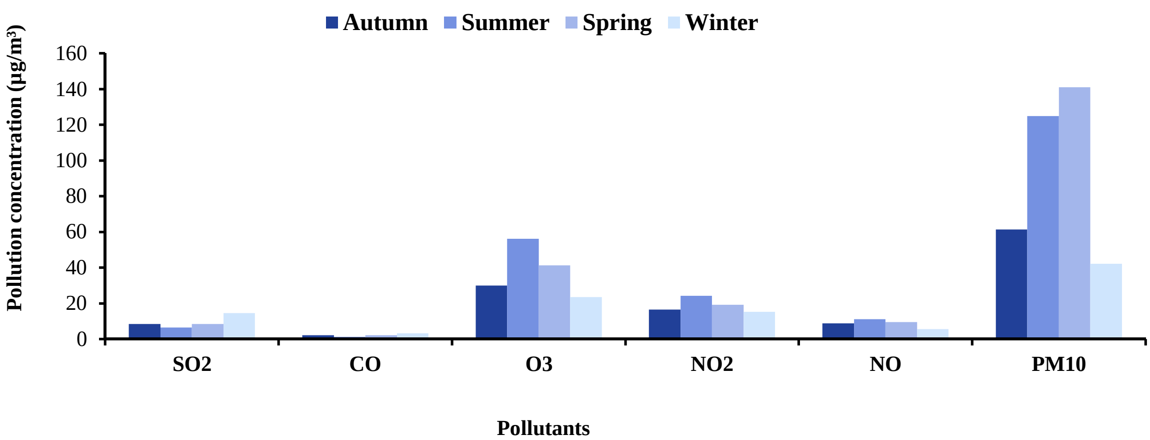

Figure 5. The mean seasonal concentration of pollutants in Sanandaj City from 2009 to 2012

Influence of climatic parameters on pollutant concentration

Climatic parameters have direct effect on dispersion or accumulation of pollutants. The minimum temperature during the cold period of the year caused increasing CO and SO_2 concentrations, while the concentrations of NO, NO_2, O_3, and PM_{10} decreased (Figure 7). On the other hand, gradually increasing temperature during warm days of the year caused a decrease in CO and SO_2 concentrations and increase in O_3, NO, NO_2, and PM_{10} (Figure 8). Decrease in relative humidity during the year caused an increase in pollutant concentration. There is a reverse relationship between CO, SO_2, O_3, NO, and NO_2, and increase in wind speed. The latter resulted in the decreasing of pollutant concentration because of air turbulence on ground surface with high atmospheric levels.

However, a direct relationship was observed between wind speed and PM_{10}. Similar findings have been reported in literature.[23,24]

AQI

Table 2 shows the results of AQI for pollutants during 2009-2012 at Sanandaj station. Except for PM_{10}, all pollutants were within good level (green color), indicating compliance with standards and no need for cautionary instruction. PM_{10} may be the only cause for concern in the city. Its elevated values could be attributed directly to natural dust fallout, which is a natural common phenomenon in Sanandaj, especially in the summer. Al-Awadhi reported that except for PM_{10}, the yearly average AQI of SO_2, NO_2, CO, and O_3 concentrations were within the category of good and moderate in Kuwait.[16]

Table 1. Diurnal concentration and classification of PM_{10} ($\mu g/m^3$) based on air quality index (AQI) in 2012

PM_{10} Concentration Class	50-100 ($\mu g/m^3$)	100-150 ($\mu g/m^3$)	150-200 ($\mu g/m^3$)	200-400 ($\mu g/m^3$)	> 400 ($\mu g/m^3$)
Number of days	158.00	51	12.0	10.0	16
Mean concentration	91.76	140	162.7	265.2	951
Time distribution	April to May	May to June	April to June	May to June	May to July
AQI	68 (Moderate)	93 (Moderate)	104 (Unhealthy for sensitive groups)	155 unhealthy	> 605* (out of range)

* The maximum calculable PM_{10} concentration to AQI is $\mu g/m^3$; hence, the authors considered values greater than this value as very hazardous; AQI: Air quality index

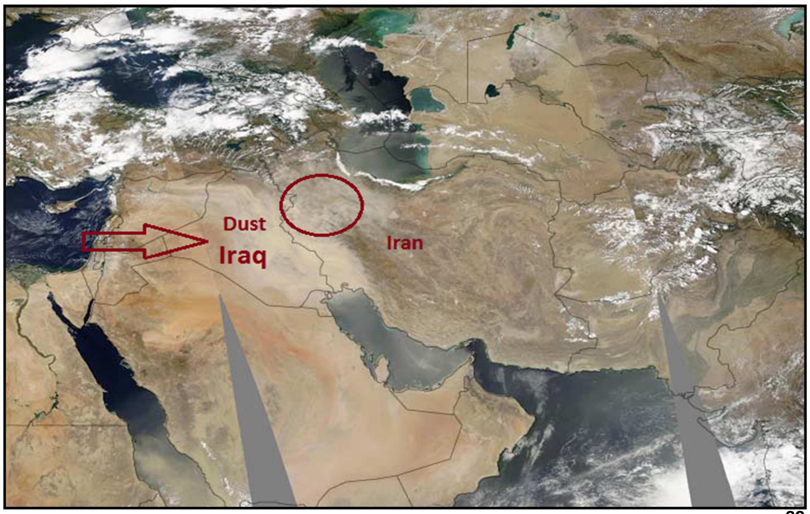

Figure 6. Satellite image of dust phenomenon in Western Iran[22]

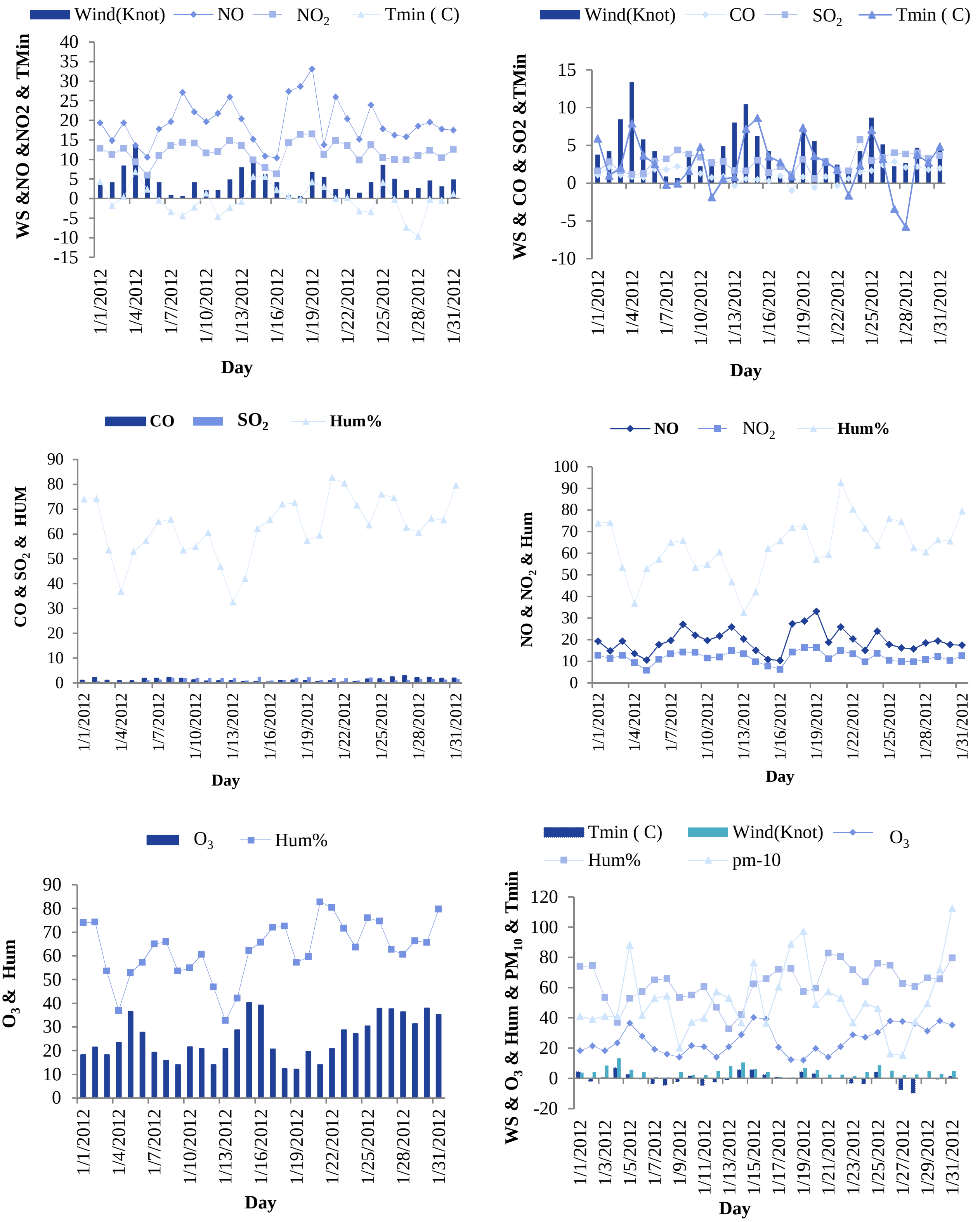

Figure 7. Relationship between pollutant concentration and climatic parameters during cold days

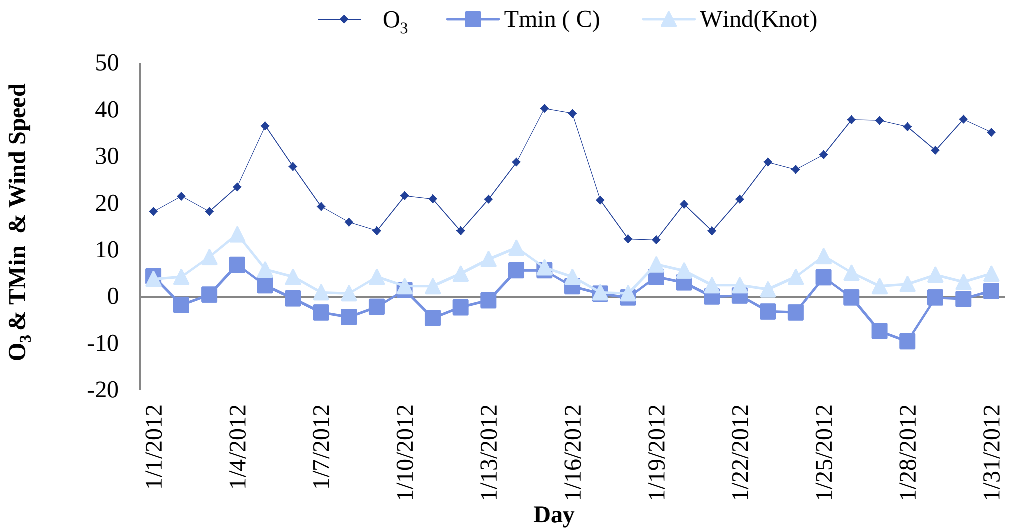

Figure 7. Relationship between pollutant concentration and climatic parameters during cold days (continue)

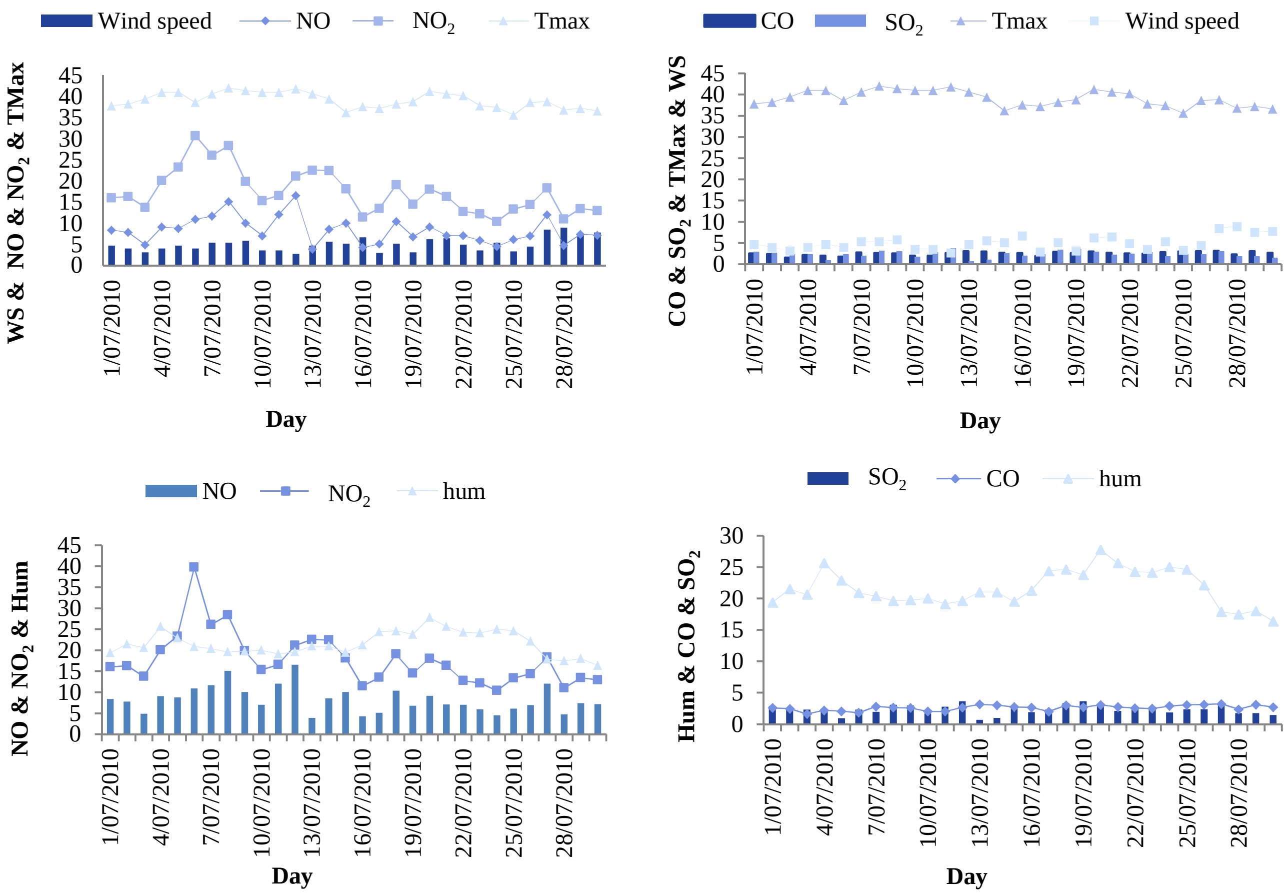

Figure 8. Relationship between pollutant concentration and climatic parameters during warm days

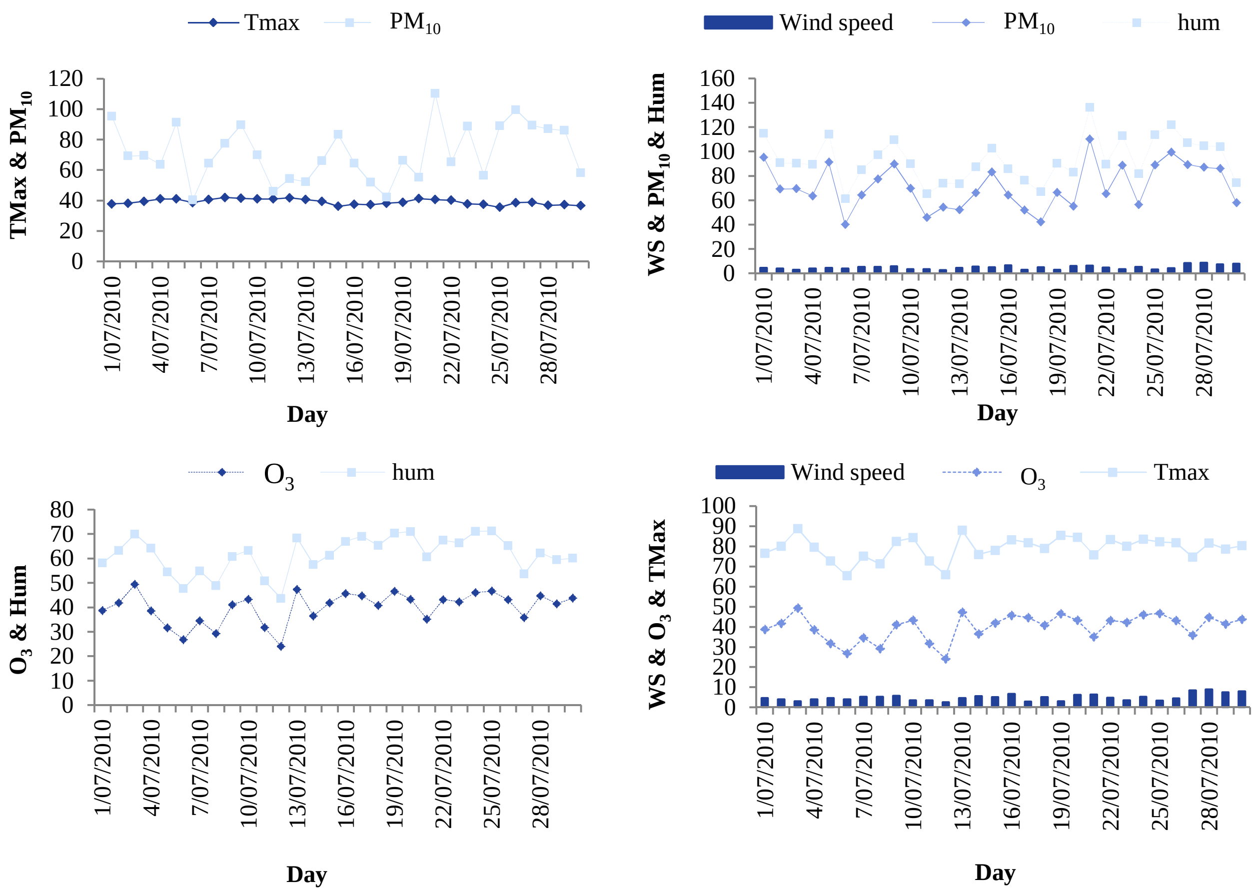

Figure 8. Relationship between pollutant concentration and climatic parameters during warm days (continue)

Data Analysis

Correlation Analysis

The relationships between air pollutant concentrations and meteorological indicators were analyzed based on the Pearson correlation coefficient (Table 3). The results showed that there is a significant relationship between climatic parameters and pollutant concentration. T_{min} had direct relationship with CO ($r = 0.66$, $P < 0.05$) and SO_2 concentrations ($r = 0.75$, $P < 0.05$). Nevertheless, it had a reverse relationship with O_3, NO_2, NO, and PM_{10} concentrations ($r = -0.55$, $P < 0.01$). Moreover, with increasing temperature, the concentration of PM_{10}, NO_2, NO, and O_3 also increased. Relative humidity showed negative and reverse relationship with most of the pollutants, especially PM_{10} ($r = - 0.96$, $P < 0.01$). Wind speed had a controlling effect on pollutant dispersion (for example, in the case of NO, $r = - 0.77$ and $P < 0.01$). The exception was PM_{10}, which could be attributed to the transferring and dispersing property of the wind. Precipitation, as an important climatic parameter, plays an effective role in this respect. There is a reverse relationship between precipitation and concentration of CO ($r = -0.68$, $P < 0.05$), SO_2 ($r = -0. 88$, $P < 0.01$), O_3 ($r = -0. 71$, $P < 0.05$), NO ($r = -0.67$, $P < 0.05$), NO_2 ($r = -0.69$, $P < 0.05$), and PM_{10} ($r = -0.97$, $P < 0.01$). Precipitation is a pollution reducer. As it is expected to have clean air during precipitation, data analysis also revealed that precipitation has a reverse relationship with pollutant concentration.

ANOVA Analysis

The relationship between climatic parameters and pollutant concentration was analyzed using multiple regression technique. Pollutant concentration and climatic parameters were used in regression techniques as a dependent variable and independent variables, respectively. The results of regression analysis are presented in table 4. The research found a significant relationship ($P< 0.05$) between air pollutant concentration and climatic parameters; the highest relationship with O_3 ($r = 80$, $P < 0.05$) and the lowest relationship with PM_{10} ($r = 68$, $P < 0.05$). Therefore, there is a significant relationship between climatic parameters and pollutant concentration.

The coefficient of determination (R^2, from 0.46 to 0.87%) between different factors indicates that the highest amount of pollutant concentration is directly influenced by climatic conditions in different days of the year. The lowest R^2 (0.46) is related to PM_{10}, whereas, the highest ($R^2 = 0.78\%$) is related to O_3, followed by CO, and NO_2. The lower R^2 in PM_{10} reveals that particulate matters in the air of the study area originated from another area such as Iraq that is an external source. Therefore, climatic condition has the lowest role in this regard.

Generally, the results showed that there is a significant relationship and correlation between climatic parameters and pollutant concentration (SO_2, CO, O_3, NO_2, NO, and PM_{10}). Temperature and wind speed are the parameters which have a role in relative increasing of pollutant concentration, but precipitation and relative humidity are effective on decreasing of pollutant concentration (Table 4).

It should be noted that R^2 represents the fraction of the variance in air pollution levels due to the variability of the correlated meteorological parameters. Multiple regression analysis confirmed that meteorological parameters are important for pollutant concentration. Hence, it can be concluded that meteorology plays an important role on pollutant concentration. Temperature, relative humidity, and wind speed seem to be the most important parameters influencing the behavior of air pollutants.

Elminir found that temperature changes did not significantly influence SO_2 concentration, but relative humidity was the most important meteorological parameter influencing the behavior of air pollutants.[25]

Table 2. Air quality index (AQI) for different pollutants in Sanandaj City during 2009-2012

PM_{10}	NO	NO_2	O_3	CO	SO_2	Year
Unhealthy(Orange)	Good (green)	Good (green)	Good (green)	Good (green)	Good (green)	2009
Unhealthy (Orange)	Good (green)	Good (green)	Good (green)	Good (green)	Good (green)	2010
Critica l(Red)	Good (green)	Good (green)	Good (green)	Good (green)	Good (green)	2012

Table 3. Pearson correlation analysis for climatic parameters and pollutant concentration

	CO (ppm)	O_3 (ppm)	SO_2 (ppm)	NO_2 (ppm)	NO (ppm)	PM_{10} ($\mu g\ m^{-3}$)
Min T (°C)	0.75*	-0.6*	0.66*	-0.50	-0.52	-0.54
Max T (°C)	-0.48	0.71**	-0.51	0.59	0.6*	0.87**
Relative humidity (%)	0.62	-0.61*	-0.79**	-0.66*	-0.62*	-0.96**
Wind speed (knot)	-0.77**	-0.56	-0.59	-0.68*	-0.77**	0.68*
Rainfall (mm)	-0.68*	-0.71*	-0.88**	-0.69*	-0.67*	-0.97**

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); PM_{10}: Particulate Matter

Table 4. ANOVA for pollutants and meteorological parameters

Pollutant	Coefficients					
	R^2	Regression square sum	df	F	T	P
SO_2	0.67	676.171	6	6.39	T_{min} = 1.8 Frost day = 1.18 Wind speed = 3.2	< 0.05
CO	0.77	333.910	6	3.82	Precipitation = -2.8 Relative humidity = - 2.32 T_{min} = 3.2	
O_3	0.78	757.232	6	5.97	T_{max}2.3 T_{min} 0.96	
NO_2	0.77	303.967	6	3.80	Rh = -2.23 Precipitation = -1.6 T_{max} = 4.2 Min T = 2.1	
NO	0.63	619.390	6	4.43	Precipitation = -1.9 Frost day = -1.7 T_{max} = 2.3 Wind speed -2.1	
PM_{10}	0.46	1037.098	6	4.71	T_{max} = 2.2 Relative humidity = -2.23 Precipitation = -1.6	

df: Degree of freedom

Grinn-Gofron et al. reported contrary results; they found close relationship between SO_2 concentrations and meteorological conditions in Poland.[26] However, Carreras and Pignata found no relationship between climatic parameters and pollutant concentration in the Cordoba region, Argentina.[27]

The trend of urbanization in Sanandaj has been increasing during the last decade; many new suburban areas have been built by scaling down free areas surrounding the city. With the continuous and rapid urbanization process, more people become exposed to high levels of air pollution. Sanandaj has a natural hole-like structure surrounded by mountains. The main platform of the city is located on semi-flat lands and there is height difference among the city areas. Hence, natural conditions and city environmental constraints are the potential barriers for pollutant dispersion and the created inversion heightens this issue in the city.

Conclusion

This research considered the daily, monthly, and seasonal variations of pollutants in Sanandaj, and assessed the relationship between climatic parameters and pollutant concentration using the Pearson correlation and regression analysis. To indicate healthy days, the AQI was determined. It was observed that, during very cold days, the concentrations of CO and SO_2 were higher compared with other pollutants. However, during the warm days of July with the highest temperature, the concentrations of NO, NO_2, O_3, and PM_{10} were high. The monthly variations of pollutants showed that the maximum concentrations of CO and SO_2 were observed during December-February and that of NO, NO_2, and O_3 during June-August. Nevertheless, the maximum concentration of PM_{10} was observed during April-May. NO, NO_2, O_3, and PM_{10} reached their maximum concentration in the summer. Maximum and minimum temperatures have an effective role in increasing pollutant concentration during the year. However, relative humidity causes a reduction in pollutant concentration. Except for PM_{10}, wind speed reduced the concentration of other studied pollutants. In recent years, PM_{10} has become one of the most dominant pollutants of the area, with its highest concentration in April, May, and June. It is affected by the Arabic dust phenomenon from the deserts of neighboring countries in Western Iran. The Pearson correlation analysis indicated a significant correlation between air pollutants and climatic parameters. Results from AQI determination showed that pollutant concentrations, except PM_{10}, were within good (green color) level, indicating compliance with standards and no need for cautionary instruction. R^2 showed that climatic parameters play an important role in pollutant concentration. The multiple regression analysis indicated the influence of climatic factors on pollutant concentration. ANOVA analysis revealed that variables with the most significant effect on pollutant concentration were air temperature, relative humidity, and wind speed. There is no heavy industry in Sanandaj or its surrounding areas. However, traffic was observed as the main source of high concentrations of pollutants. Air pollution has very negative impacts on society; thus, the survey of climatic parameters and pollutant concentration may help the government to adopt necessary preventive measures to ensure better living conditions.

Conflict of Interests

Authors have no conflict of interests.

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