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The effect of air pollutant and built environment criteria on unhealthy days in Mashhad, Iran: Using OLS regression

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A R T I C L E I N F O

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A B S T R A C T

Air pollution is one of the most important shared challenges among metropolises across the world, especially in developing countries such as Iran.The purpose of this study is to evaluate the effect of air pollutants and built environment on the number of unhealthy days in Mashhad metropolis in 2018. To achieve this goal, seven variables were used as independent variables (including population density, land use diversity, CO, NO_2, SO_2, PM_{10}, $PM_{2.5}$) and the number of unhealthy days was used as a dependent variable. The relationship between variables was analyzed using the Ordinary Least Squares (OLS) regression model in GIS in 40 municipal districts. The results show that the average of unhealthy days in Mashhad is 76 days. But its amount varies from 12 to 155 days in the districts. Furthermore, the correlation coefficient between the dependent and independent variables is ADJ.$R^2 = 0.80$ which represents the effect of 80% of the independent variables on the dependent variable. Among the variables, "$PM_{2.5}$" and "NO_2" have a positive relationship and "CO" had a negative relationship with the number of unhealthy days. The relationship between other independent variables and the dependent variable was not confirmed. In addition, the residual standard deviation is not normally distributed. In general, it can be argued that the establishment of industrial and workshop activities and traffic of motor vehicles on highways have a significant role in CO, NO_2 and $PM_{2.5}$ emissions in the northern, northwestern, eastern and southeastern districts of the city. Therefore, it is suggested that these districts especially those that have more than 100 unhealthy days are given priority in the planning of urban manager actions.

1. Introduction

Air pollution constitutes the most pressing environmental health risk facing our global population (IQAir, 2019) and has been the shared challenge for megacities or metropolitan regions across the world, especially in developing countries such as Iran (Xu et al., 2016). Today, many important cities in Iran have the problem of inappropriate weather conditions, and increasing population, industries and vehicles has led to a decrease in air quality index (Askarishahi et al., 2018; Yousefian et al., 2020; Jafari et al., 2017). According to the study by Kermani et al. (2014), the Air Quality Index (AQI) in large cities of Iran such as Tehran, Isfahan, Arak and Tabriz in more than 80 days a year is higher than the permissible standard by the Environment Department. PM_{10} has been reported as the main cause of pollution in these cities (Kermani et al., 2014). In Iran, energy conversion (e.g., power plants and oil refineries) is responsible for 25% of NO_X and 20% of particulate matter emissions. Approximately 23% of NO_X originated from the household and

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commercial sectors (Yousefian et al., 2020). In terms of $PM_{.2.5}$ concentration, Iran is ranked 27th in the world (IQAir, 2019).

The AQI level is determined by the concentrations of six pollutants including SO_2, NO_2, CO, O_3, $PM_{2.5}$ and PM_{10} (Shen et al., 2017). The air pollutants have acute effects on human health if they exceed the standard (Wang et al., 2018). Nitrogen dioxide (NO_2) and Ozone (O_3) can affect the functioning of the human respiratory system and significantly reduce the lung function indicators in humans (Chen et al., 2011; Yang et al., 2012). Humans will exhibit symptoms including headaches, dizziness, and even nausea if they inhale carbon monoxide. Atmospheric carbon monoxide not only destroys the neurological function of the heart but also affects the central nervous system and even causes suffocation to the point of death (Yang et al., 2012). PM_{10} can cause respiratory and cardiovascular diseases and mortality (Jafari et al., 2017). Also, Exposure to particulate matter, is thought to increase risk of hypertension, raised lipids, atherosclerosis, inflammation, and stroke, all of which also raise risk of cognitive decline and dementia (Peters et al., 2019). Previous studies have revealed that from 2010 to 2016, the number of premature deaths due to global air pollution has increased from 0.22 million to seven million (Chen et al., 2013; IQAir, 2019).

In addition to the role of air pollutants, many previous studies have analyzed the impact of the built environment to examine the factors affecting air quality in cities. Many studies believe that two important factors of urban development pattern can affect urban air quality, including population density and land use diversity (Superczynski and Christopher, 2011; Liu, 2019; Hao and Liu, 2016; Cuspilici et al., 2017).

Regarding the effect of density on air quality, there are two different views. One is that high density leads to proximity and non-motorized travel, and then reducing traffic-related emissions (Calthorpe, 1993; Ewing et al., 2003). Stone et al. (2007) found that a 10% increase in population density in a metropolitan area caused a 3.5% reduction in household vehicle use and emissions (Stone et al., 2007). In China, Liu (2019) found that the coefficient of urban density is significantly negative, and the increase in urban density will reduce air pollution (Liu, 2019). Another view holds that excessive population centralization will lead to traffic congestion and centralization of pollutants, resulting in increased pollution concentrations (Bechle et al., 2011; Clark et al., 2011). Clark et al. (2011) found that population density is related to higher levels of ozone and particulate matter. Furthermore, Hee-Jae and Myung-Jin (2014) showed that population and level of employment are positively related to a comprehensive air-quality index (CAI) in the Seoul metropolitan area.

Numerous studies have been conducted on the relationship between land use patterns and air quality. For example, Superczynski and Christopher (2011) found that conversion of forest, grasslands and farmland to residential housing, industrial complexes and large commercial centers often lead to an increase in emissions. The extreme case of this type of expansion is urban sprawl, which is characterized by decentralized patterns of low-density development, often in an automobile-oriented method (Superczynski and Christopher, 2011). Eun Kang et al. (2017) found that the degree of urban land use diversity, clustering, and concentration of development are significantly associated with better air quality (Eun Kang et al., 2017).

In general, the literature review shows that some studies have examined the trend of annual changes in air quality index and the effect of meteorological parameters on this index and the concentration of pollutants (Askarishahi et al., 2018; Xiao et al., 2018; Jafari et al., 2017; Yousefian et al., 2020; Hadei et al., 2019; Yousefian et al., 2020). Other groups have discussed the correlation between ambient air pollutants (Shen et al., 2017; Mao et al., 2018). Meanwhile, in relation to the effect of built environment on ambient air quality, in addition to the little literature available, most existing studies have examined the effect of urban environmental indicators on one of the ambient air pollutants (Superczynski and Christopher, 2011; Xu et al., 2016; Han and Sun, 2019). It should be noted that all these studies have either focused on environmental pollution monitoring stations or discussed only a part of urban space using buffers in GIS. In fact, the shortcoming of the previous literature is the lack of special attention to the number of unhealthy days (as the worst condition of ambient air quality) and its relationship with various pollutants and built environment variables in all urban districts using the OLS regression model. This vacancy is most felt in studies conducted in Iran. Therefore, this study has been done to reinforce this dimension of the issue. In this study, the effect of air pollutant criteria (CO, NO_2, SO_2, PM_{10}, $PM_{2.5}$) and built environment (population density and land use diversity) on the number of unhealthy days has been investigated using the OLS model in 40 districts of Mashhad, as the second metropolis of Iran with a population of more than three million people (Statistical Center of Iran, 2017) and the annual reception of more than 27 million domestic and foreign tourists. Mashhad observes more than 3.1 million cars daily (Bureau of Transportation Studies and Planning, 2020) which have a decisive role in air pollution along with the industries located in the city.

This study is discussed in the following parts: 1) descriptive analysis, including measuring the status of air pollutants, population density, land use diversity and the number of unhealthy days in 40 municipality boundaries of Mashhad; 2) Inferential analysis using OLS regression model (effect of ambient air pollutants and built environment indicators on the number of unhealthy days in Mashhad).

2. Materials and methods

2.1. Data and variables

Based on the purpose of the research and available data, eight variables were examined in two general groups: air pollution measurement criteria (six criteria) and built environment variables (tow variables).

2.1.1. Air pollution measurement criteria

In this study, six variables for measuring air pollution are used, including nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), PM_{10}, $PM_{2.5}$ (as independent variables) and the number of unhealthy days (as a dependent variable). The data of these variables has been collected from the annual report of 22 air pollution monitoring stations published by Mashhad Environmental

Refining Center in 2018.

It should be noted that because the stations do not completely cover the city. To transmit the results of 22 stations to 40 areas of Mashhad, first, vector point layer (pollutant measuring stations) was interpolated to raster for all variables using the Inverse Distance Weighted technique (IDW). Then the average of each index for the districts was extracted using the zonal statistic and extraction options in GIS.*2.1.2 Built environment variables.*

In this study, the characteristics of built environment include two independent variables as follows:

1. *Land use diversity*. Data were obtained from municipality of Mashhad in 2017. They were examined by "Shannon entropy coefficient".

$$\mathrm{H(X)}\sum_{i=1}^{N}\left(PDEN_i{*}\left(\frac{1}{PDEN_i}\right)\right)\Big/log(N) \quad (1)$$

In this formula, PDEN is the ratio of a land use area to the total land use areas, and N is the number of land uses. The entropy coefficient is in the range of 0 to 1, with values close to 1 indicating a more equitable distribution of urban land use in diverse activities and values close to 0 indicating the degree of more unbalanced distribution and mix (Abbaszadeh and Rahnama, 2008).

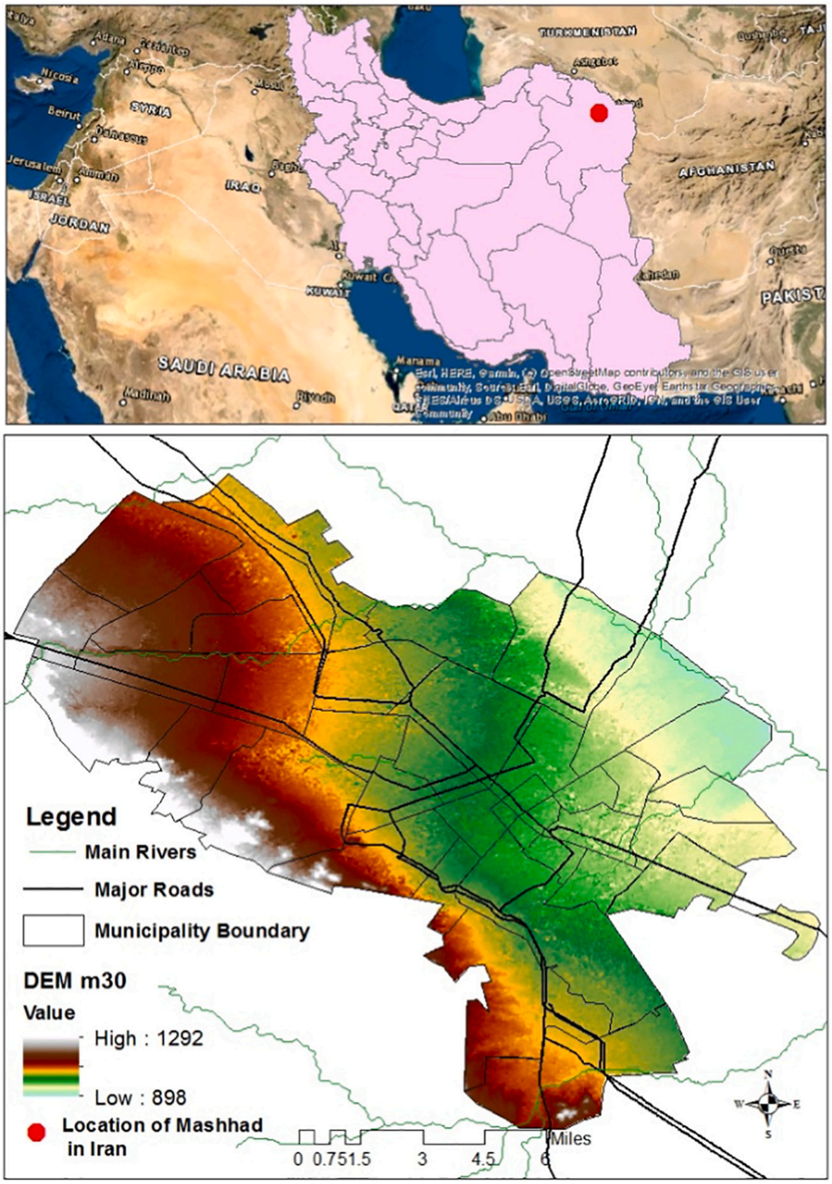

Fig. 1. Location of Mashhad metropolis in Iran.

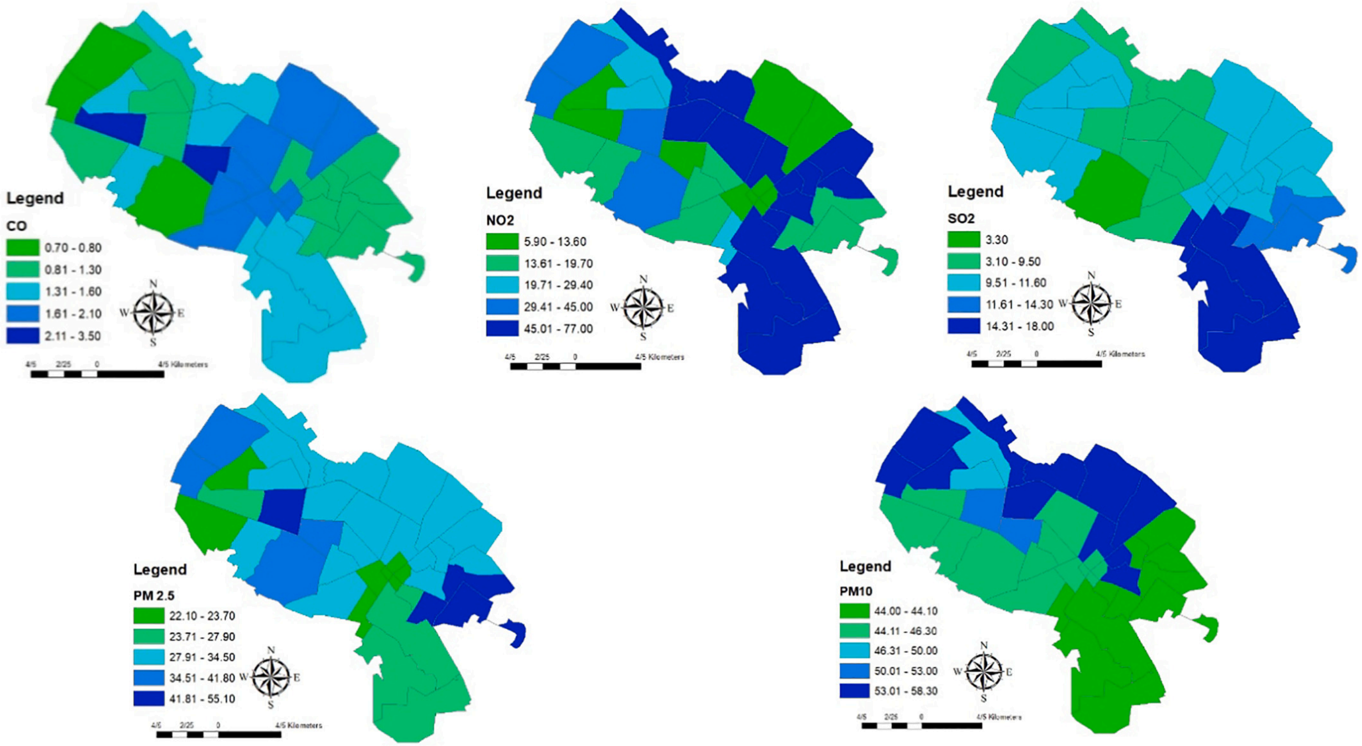

Fig. 2. The situation of air pollutants in the districts of Mashhad metropolis.

2. *Population density*. The density of populations is the number of population per hectare. The initial data were extracted from Statistics Book of Mashhad 2017 (Mashhad Municipulity, 2017).

2.2. Ordinary Least Squares (OLS) regression

The OLS regression equation is as follows:

$$Y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n \quad (2)$$

The relationship between Y, and X variables is described using the multiple regression equation of best fit with α, which indicates the value of Y when X is equal to zero (also known as a buffer) and β which represents the slope of the line (also known as regression coefficient)(Hutcheson, 2011). In this paper, OLS was implemented using the "Spatial Statistics Tool" in GIS.

2.3. Study area

Mashhad, as the second largest city in Iran, located in the northeast of the country in the Khorasan Razavi province, at a distance of 1000 km from the capital (Tehran). This city is located at 59°2′ to 60°37′ east longitude and 35° 43′ to 37° 7′ north latitude (Mashhad Municipulity, 2017). The average altitude of the city is 999 m above sea level and has a relatively dry climate. The city of Mashhad is bounded on the south by the Binalood mountains, and on the north by the Hezar Masjed mountains. Its topographic slope is from southwest to northeast and the prevailing wind direction is northwest-southeast (Fig. 1). Most of the winds blow at a speed of 5.5–10.9 km/h (Jahanshahi et al., 2019; Velayati and Tavassoli, 1992). With an area of 310 km^2, Mashhad accommodates a population of 3,057,679 people (Mashhad Municipulity, 2017). The development pattern of Mashhad is sprawl (Abbaszadeh and Rahnama, 2008). Its economy heavily relies on religious tourism, and it hosts an annual arrival of 27 million domestic and foreign tourists. The enormous population of inhabitants and tourists and its development pattern have raised inner-city trips, so that the number of these trips has increased from 4,035,560 trips per day in 2006 to 6,241,830 trips in 2019 (annual growth of 3.4%). Most of these trips take place along 10 highways in the city, especially northwest to southeast and west to east. During this period, the consumption of petrol and gasoline reached from 179,565 to 2,353,237 l (an annual growth of 21.8%), leading to increase of air pollutants (Transportation Studies and Planning Bureau, 2007; Bureau of Transportation Studies and Planning, 2020). It should be noted that the multiplicity of motor vehicles is only one of the most important causes of air pollution in Mashhad. At the same time, high population, polluting industrial centers, special climatic conditions and being located between the two mountains can be effective (Bonyadi et al., 2011). In the case of industries, currently, about 6500 industrial units are located in and around Mashhad with an area of 86,000 ha. As a result of the physical expansion of the city in recent decades, most of these industries are located within the city (Rahnama & Aghajani, Planning studies of Khorasan Razavi province, 2013). Most of industrial units use fuel oil and diesel which are very effective in increasing air pollution (Talabi, 2019). Mashhad ranks 617th in air pollution in the world and second in the country (IQAir, 2019; Bonyadi et al., 2011).

3. Results and discussion

As mentioned earlier, the purpose of this study was to investigate the relationship between five air pollution measurement criteria and two built environment variables as independent variables and the number of unhealthy days as a dependent variable in the districts of Mashhad metropolis. For this purpose, first in the form of descriptive analysis, the current status of each of these independent and dependent variables has been examined. Then, the relationship between independent variables and the dependent variable was analyzed using the OLS regression model.

3.1. Descriptive analysis

3.1.1. Air pollutants in Mashhad

The results of the study on the air pollutants (including CO, NO_2, SO_2, $PM_{2.5}$, PM_{10}) as independent variables in 40 districts of Mashhad are shown in Fig. 2. The spatial distribution of pollutants is classified in five classes based on its minimum and maximum recorded amounts.

Carbon monoxide (CO) is one of the most important air pollutants that has a lifespan of more than one month and has become a strong indicator of air pollution (Wang et al., 2018). The study of the annual average of CO pollutant indicates that its concentration varies from 0.7 to 3.5 ppm in the municipality districts of Mashhad. 14 districts (35%) experienced a concentration of 0.8–1.3 ppm and then we can see a concentration of 1.6–20.1 ppm in 11 districts (27.5%). Based on computations of the total amount of CO in earth's atmosphere, more than 53% is related to pollution caused by human activities (Asadollahfardi et al., 2017). According to Iran clean air standards approved by the Supreme Council of Environmental Protection of Iran in 2016, the 8-h air quality standard average for carbon monoxide is 9 ppm (Mashhad Environmental Pollutants Monitoring Center, 2018) and as can be seen, the concentration of this pollutant in all districts is lower than the average standard.

The spatial distribution of nitrogen dioxide (NO_2) concentration in Mashhad municipality area varies from 5.9 to 77 ppm. 11 districts (35%) have concentrations of 45.1–77 ppm and 9 districts (22.5%) have concentrations of 13.6–19.7 ppm. NO_2 is mainly due to human activities including industrial and traffic pollutants (Cheng et al., 2018). The annual standard average of air quality for NO_2 is

0.02 ppm (Mashhad Environmental Pollutants Monitoring Center, 2018). However, all areas are above the standard average.

Sulfur dioxide (SO_2) as one of the criteria pollutants can affect air quality and regional climate (Wang et al., 2018). SO_2 concentrations range from 3.3 to 18 ppm. In total, 19 districts (47%) have experienced concentrations between 9.5 and 11.6 ppm, followed by districts with concentrations between 9.5 and 3.1 (11 districts). SO_2 is a key precursor of acid rain that presents a hazard to forests and fresh water ecosystems (Wang et al., 2018). The air quality standard for SO_2 is 0.01 ppm (Mashhad Environmental Pollutants Monitoring Center, 2018). However, all areas have a much higher concentration than the standard.

Particulate matter (PM) is defined as fine inhalable particles that are suspended in the air. The two most common size fractions of PM measures are PM_{10} and $PM_{2.5}$ (Heger and Sarraf, 2018).

Evidence related to $PM_{2.5}$ in Mashhad metropolis indicates that the concentration of this pollutant varies from 22.1 to 55.1 μg/m^3. 18 districts (45%) experienced a concentration between 27.9 and 34.5 μg/m^3 and 8 districts (20%) had a concentration between 22.1 and 23.7 μg/m^3. $PM_{2.5}$ originates from all types of combustion, including motor vehicles, power plants, forest fires, agricultural burning, and some industrial processes (Heger and Sarraf, 2018). The annual air quality standard for $PM_{2.5}$ is 10 μg/m^3 (Mashhad Environmental Pollutants Monitoring Center, 2018). Meanwhile, the concentration of this pollutant in all districts of Mashhad is higher than the standard.

The study of PM_{10} in Mashhad shows that the concentration of this pollutant varies from 44 to 58.30 μg/m^3. In general, 25 districts (62.5%) have concentrations of 46.3–44 μg/m^3 and 11 districts (27.5%) have concentrations between 58.3 and 53 μg/m^3. Sources of PM_{10} include crushing or gridding operations and dust stirred up by vehicle and roads (Heger and Sarraf, 2018). Increasing PM_{10} pollution plays a crucial role in severe haze and degradation of air quality (Wang et al., 2018). The annual air quality standard for PM_{10} is 20 μg/m^3 (Mashhad Environmental Pollutants Monitoring Center, 2018). However, all municipality districts experience higher concentrations.

In general, the study of air pollutants in the districts of Mashhad in comparison with Iran clean air standards approved by the Supreme Council of Environmental Protection of Iran shows that the concentration of NO_2, SO_2, $PM_{2.5}$, PM_{10} in all districts is above the standard. Meanwhile, only CO pollutants in all areas have a lower concentration than the standard (Table. 1).

3.1.2. Population density

The analysis of population density as an independent variable indicates the unequal distribution of this demographic index. The average of population density in Mashhad is 87 person per hectare and varies from 11 to 240 person per hectare. For more comprehensive assessment of the population density, considering the minimum and maximum population density, urban districts are classified into five classes (Fig. 3). In general, based on population density categories including low density (1–100 person per hectare); medium density (100–200 person per hectare); and high density (more than 200 person per hectare); and Hasibuan et al., 2014), 18 districts (45%) have medium to high density and 22 districts (55%) are in the low-density category. This indicates the sprawl of Mashhad. The eastern, southeastern and northwestern districts of Mashhad, which are mainly the focus of informal settlements and industries, have a high population density.

3.1.3. Land use entropy coefficient

Of the total land area of the Mashhad metropolis (31,043 ha), about 26,145 ha (84.2%) is allocated to different land uses and the remaining covers vacant lands (15.7%). The entropy coefficient of the total land uses is 0.7%. Although it is less than 1 but relatively indicates the fair distribution and diversity of the land between different activities. Spatial distribution of relative entropy coefficient of land uses in 40 municipality districts of Mashhad (as an independent variable) shows a significant difference (Fig. 3). Accordingly, 38 districts (95%) have lower relative entropy coefficients than the whole city (this coefficient varies from 0.4 to 0.6). The northwest and southeast districts, which are the focus of industrial activities, have a higher entropy coefficient than the others.

In general, the average of unhealthy days as dependent variable in Mashhad metropolis was 76 days in 2018 and Mashhad has experienced fewer unhealthy days compared to other metropolises of Iran such as Tehran (341 days), Isfahan (322 days), and Shiraz (85 days), respectively (Askarishahi et al., 2018) and some cities in China such as Wuhu (116 unhealthy days) and Bengbu (128 unhealthy days) (Wang et al., 2018). However, a study of Air Quality Index in 40 municipality districts of Mashhad shows that the number of unhealthy days varies from 12 days to 155 days. Generally, in 10 districts (25%), the air quality index is 120–186 days higher than the standard and in the other 10 districts (25%), the air quality is in an unhealthy condition for 12–24 days. A look at the spatial distribution of the number of unhealthy days in Mashhad (Fig. 4) shows that the uttermost number of unhealthy days can be found in the north, northwest, east and southeast parts of the city.

Table 1
Comparison of the average concentration of pollutants in Mashhad with the annual air quality standard approved by the Supreme Council of Environmental Protection of Iran in 2016.

Pollutant	Average concentration	Annual air quality standard
Carbon monoxide (ppm)	1.5	9
Nitrogen dioxide (ppm)	38.5	0.02
Sulfur dioxide (ppm)	11.4	0.01
$PM_{2.5}$ (μg/m^3)	33	10
PM_{10} (μg/m^3)	48.8	20

Source: (Mashhad Environmental Pollutants Monitoring Center, 2018).

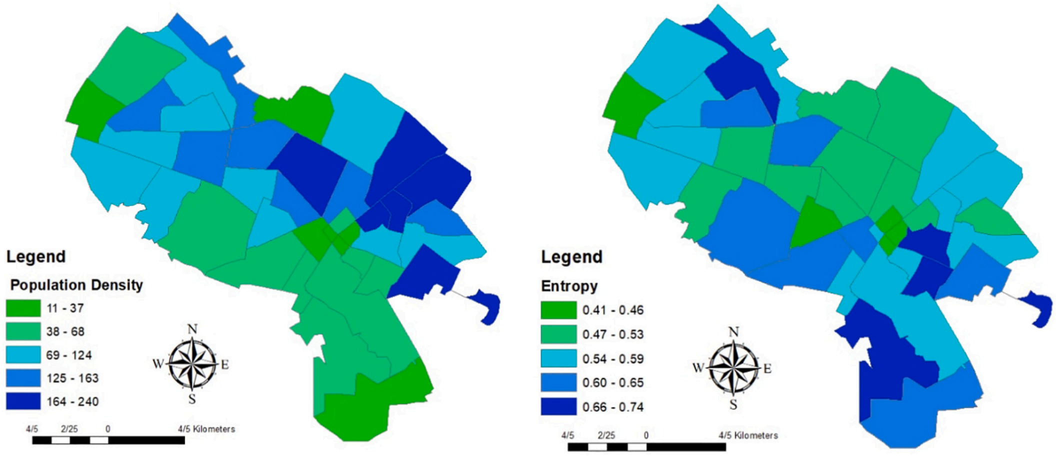

Fig. 3. Population density and Land use entropy coefficient in the districts of Mashhad metropolis*3.1.4 Unhealthy days in Mashhad metropolis.*

3.2. Inferential analysis

3.2.1. Result of OLS regression model

In order to investigate the relationship between air pollutants and built environment with the number of unhealthy days in the Mashhad metropolis, the OLS regression model in GIS has been used. The results of the analysis are presented in Table 2. With regard to the research objective, F-statistic indicates that this model is significant with an error probability of 0.0 (p-value <0.01). The findings result indicate that the ADJ. R^2 value is 0.80, meaning that Pollutants for measuring air quality and built environmental indicators are 80% effective in explaining and predicting the number of unhealthy days in Mashhad metropolis.

In general, OLS results show that the concentration of "$PM_{2.5}$" and "NO_2" has a significant and positive relationship with the number of unhealthy days in Mashhad metropolis. The results of this part are consistent with studies conducted in several Asian cities. Studies in Zhangzhou, Changchun, and the metropolitan areas of King, Wuhan and Nanjing, Whuh and Bengus show that $PM_{2.5}$ is usually the major pollutant among types of air pollutants. Then, among gaseous species, NO_2 has an effective role in reducing ambient air quality and health of sensitive populations (Shen et al., 2017; Wang et al., 2018; Wang et al., 2019). A similar study in Pakistan shows that $PM_{2.5}$ and NO_2 play a key role in increasing Islamabad's unhealthy air. The main sources of emissions are the high concentration of coal-fired industries and power plants located southeast of the capital and on the other hand relies on diesel fuel in the transportation sector (Rasheed et al., 2014). Surveys in Tehran, the capital of Iran, show that citizens were consistently exposed to $PM_{2.5}$ and NO_2, respectively, 3–4.5 and 1.5–2.5 times higher per year than the World Health Organization's air quality guide levels. About 45 to 65% of the air quality index values in the unhealthy subgroup were for sensitive groups and $PM_{2.5}$ is the main air pollutant in Tehran (Yousefian et al., 2020).

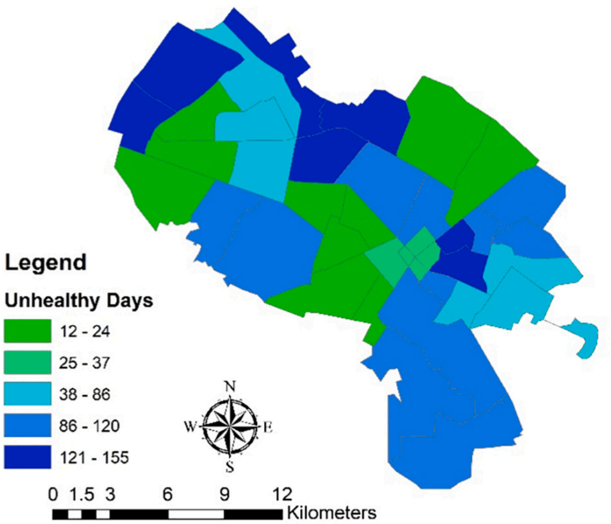

Fig. 4. Number of unhealthy days in the districts of Mashhad metropolis.

Table 2
Results of OLS regression on the relationship between air pollutants and built environment and the number of unhealthy days in Mashhad metropolis.

Variable	Coefficient [a]	StdError	t-Statistic	Probability [b]	Robust_SE	Robust_t	Robust_Pr [b]	VIF [c]
Intercept	−27.8	50.1	−0.5	0.5	36.7	−0.7	0.4	....
Land use entropy coefficient	13.9	46.1	0.3	0.7	35	−0.4	0.7	1.2
CO	−15.8	6.6	−2.3	0.0*	4.9	−3.2	0.0*	1.3
PM10	1.1	0.6	1.7	0.08	0.4	2.5	0.0*	1.3
PM2.5	1	0.4	2.5	0.0*	0.3	3.3	0.0*	1.4
SO2	−1.1	1.2	−0.9	0.3	0.8	−1.2	0.2	1.4
NO2	1.3	0.1	9.4	0.0*	0.1	12	0.0*	1.3
Population density	−0.1	0.05	−1.7	0.09	0.0	−2.9	0.0*	1.3

Multiple R-Squared [d]: 0.8	Adjusted R-Squared [d]: 0.80
Joint F-Statistic [e]: 24.4	Prob(>F), (7.32) degrees of freedom: 0.000000*
Joint Wald Statistic [e]: 280.7	Prob(>chi-squared), (7) degrees of freedom: 0.0*
Koenker (BP) Statistic [f]: 2.2	Prob(>chi-squared), (7) degrees of freedom: 0.9
Jarque-Bera Statistic [g]: 29.2	Prob(>chi-squared), (2) degrees of freedom: 0.0*

Since the main source of $PM_{2.5}$ is the incomplete combustion of motor vehicles and the most important sources of NO_2 are industrial activities and traffic pollutants, a look at Figs. 1, 4 and 5 shows that the northern, northwest, east and southeast districts of Mashhad have experienced the highest concentrations of $PM_{2.5}$ (average 36 μg/m3) and NO2 (average 53.64 ppm) and as a result the highest number of unhealthy days (average 102 days) compared to other areas of the city. On the one hand, they are the center of various industrial parks and workshops and power plants, most of which use fuel oil and diesel. On the other hand, these districts include a significant part of main and secondary arterial passages, which carry the highest traffic load of daily trips made by motor vehicles. It should be noted that the establishment of major industries and traffic axes are parallel to the prevailing northwest-southeast winds, which have a significant role in transferring pollutants to these districts and increasing the number of unhealthy days.

The relationship between CO concentration and the number of unhealthy days is also significant but negative and indicates the uniqueness of this relationship in Mashhad. A study conducted in three metropolises along the Yangtze River, China shows that there is a positive correlation between CO and declining ambient air quality (Mao et al., 2018).

In Mashhad metropolis, no significant correlation was found between the concentration of SO_2 and PM_{10} pollutants and the number of unhealthy days. Meanwhile, studies in Isfahan, Iran and Seoul, China consider PM_{10} to be the most important factor in reducing air quality, which originates from traffic vehicles, excessive construction, the existence of various industries around the city and insufficient green space in the suburbs (Jafari et al., 2017; Park et al., 2019).

Regarding the relationship between environmental variables and the number of unhealthy days, the results of Table 2 show that in the metropolis of Mashhad, there is no significant relationship between population density and land use with unhealthy days. These results contradict numerous studies conducted in this field. For example, A survey of California cities shows that high-density development leads to congestion and pollution that exacerbates poor air quality (Banzhaf and Walsh, 2008). Also, using the spatial econometric model, a study found that population density and land use have a positive relationship with air pollution levels in Shanghai (Han and Sun, 2019).

The Jarque-Bera statistic with an error probability of 0.0 (p-value <0.01) is at the significant level. It means that residual standard deviation (StdRsidual) is not normally distributed over the regression line and there are deviations in the relationships of variables in the model. Fig. 5 shows the status of StdRsidual for municipality districts of Mashhad metropolis. In 19 districts (47.5%), the residuals are slightly different from the regression line and their value is in the range of −0.5 to 0.05. This means that the OLS is a fitting model for these districts and there is no significant deviation from the data; therefore, these districts have a relatively small StdRsidual. The distances of residuals in 10 districts oscillate with the regression line between < −2.5 to −0.5, and finally 11 districts demonstrate a significant difference between residuals in the range of 0.05 to more than >2.5 relative to the fitness regression line. In other words, in these areas, the OLS is a weak fitted model that is significantly deviated from data and therefore has a relatively large StdRsidual.

4. Conclusion

This study analyzed the effect of seven independent air pollutant and built environment variables on the number of unhealthy days as a dependent variable using OLS regression in Mashhad metropolis with a population of more than 3,050,000 people in 2017. The results of examining air pollutant criteria indicate that of the five pollutants studied, SO_2, NO_2, $PM_{2.5}$ and PM_{10} are above the standard approved by the Supreme Council of Environmental Protection of Iran. And it is only in the case of CO concentrations that all districts of the city experience values under the standard. The study of the built environment variables also shows that the average population density of Mashhad is 87 person per hectare and the range of changes in its districts is between 11 and 240 person per hectare. Furthermore, there is a significant difference between areas in terms of the degree of land use diversity so that the average entropy coefficient is 0.7, and its minimum and maximum are 0.41 and 0.74, respectively. In examining the effect of air pollutants and built environment variables on the number of unhealthy days, we found that the correlation coefficient between the variables is $ADJ.R^2 = 0.80$ and represents the effect of 80% of the independent variables on the dependent variable. Of the seven variables studied, only three ambient air pollutants criteria including CO, NO_2 and $PM_{2.5}$ affect the number of unhealthy days. In addition, the spatial distribution of pollutants shows differences in the 40 districts of Mashhad. This different distribution is largely related to the concentration of

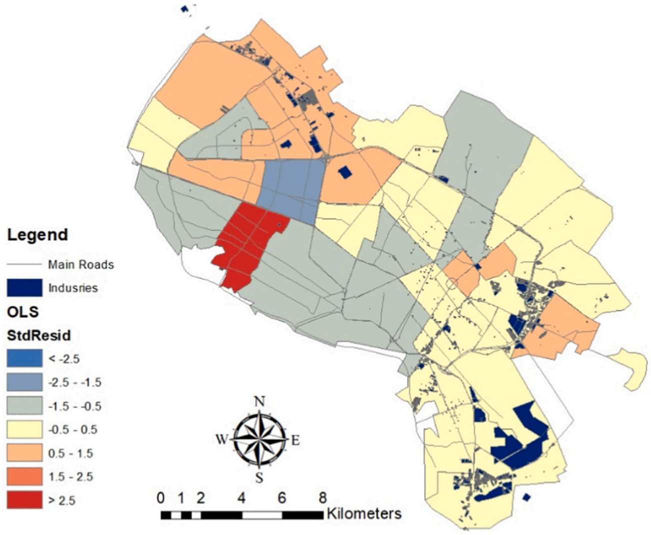

Fig. 5. StdRsidual of the OLS regression in the districts of Mashhad metropolis.

workshop and industrial activities, traffic congestion and the presence of old vehicles with incomplete combustion in the urban transport fleet. According to the obtained results, it is suggested that policies should be the basis of the work of urban policymakers and developers as effective and efficient measures to adjust the problem. The most important of them include organizing and monitoring more polluting activities in workshops and industries located in eastern, southeastern and northwestern of the city, and expanding the implementation and observance of the latest vehicle fuel standards. Finally, to reduce the number of unhealthy days, it is proposed that the effect of socio-economic indicators and travel behavior and natural variables (such as wind, temperature and topography) on ambient air quality be studied.

Author statement

This research was conducted with the participation of both authors. Rahnama has been involved in writing literature reviews and Sabaghi has done technical analysis. Both have contributed equally to the drafting of the article.

Declaration of competing interest

No.

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