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The Influence of Meteorological Parameters on PM_{10}: A Statistical Analysis of an Urban and Rural Environment in Izmir/Türkiye

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Abstract: Air pollution is a substantial menace, especially in industrialized urban zones, which affects the balance of the environment, life of vital organisms and human health. Besides the main causes of air pollution such as dense urbanization, poor quality fuels and vehicle emissions, physical environment characteristics play an important role on air quality. Therefore, it is vital to understand the relationship between the characteristics of the natural environment and air quality. This study examines the correlations between the PM_{10} pollutant data and meteorological parameters such as temperature (T_{air}), relative humidity (RH), and wind speed (WS) and direction (WD) under the European Union's Horizon 2020 project. Two different zones (Vilayetler Evi as an urban zone and Sasalı Natural Life Park as a rural zone) of Izmir Province in Türkiye are used as a case study and the PM_{10} data is evaluated between 1 January 2017 and 31 December 2021. A one-tailed *t*-test is used in order to statistically determine the relationships between the PM_{10} pollutant data and meteorological parameters. As a further study, practical significance of the parameters is investigated via the effect size method and the results show that the RH is found to be the most influencing parameter on the PM_{10} for both zones, while T_{air} is found to be statistically non-significant.

Keywords: meteorological parameters; statistical analysis; effect size; PM_{10}; air quality

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1. Introduction

Industrial development, rapid urbanization and dense population have led to climate change and global warming due to air pollution [1]. On the other hand, exposure to air pollutants is of particular concern for the vulnerable residents, such as elderly, pregnant women and young children [2]. Therefore, air quality in cities is monitored along with atmospheric (airflow direction and intensity) and meteorological parameters (air pressure, temperature, relative humidity, wind speed etc.) [3]. In general, the main causes of air pollution are factories, vehicle traffic density and fossil fuel combustion processes [4]. However, besides anthropogenic causes of air pollution, meteorological parameters over urban areas affect the air quality, since the movement of air pollutants is highly linked with both horizontal and vertical movements and environmental conditions [5].

Air pollutants can be classified as primary pollutants, such as carbon monoxide (CO), sulphur oxides (SO_x), nitrogen oxides (NO_x), hydrocarbons (HC) and particulate matter (PM), and secondary pollutants based on components formed in the lower atmosphere by chemical reactions, such as O_3 [6]. In general, even though the levels of the SO_x and NO_x are high, PM is the most significant pollutant in Türkiye [7]. According to the Environmental Protection Agency (EPA), PM is defined as a blend of the particles and droplets in the air that consists of components such as organic compounds, metals, acids, soil and dust [8]. The $PM_{2.5}$ refers to particles with a diameter of 2.5 μm or less, while the PM_{10} includes particles with a diameter of 10 µm or less [8]. The average daily limit values for $PM_{2.5}$ and PM_{10} are 25 µg/m^3 and 50 µg/m^3, respectively, in Türkiye [7]. Table 1 depicts the limit values of the PM air pollutants in the regulations.

Table 1. Limit values of PM air pollutants in the regulations [9,10].

	Air Pollutant	Time Unit	Average Limit Value (µg/m^3)
TÜRKİYE	$PM_{2.5}$	Ave. for 24 h	25
		Annual ave.	-
	PM_{10}	Ave. for 24 h	50
		annual ave.	40
EU	$PM_{2.5}$	Ave. for 24 h	-
		annual ave.	20
	PM_{10}	Ave. for 24 h	50
		annual ave.	40
WHO	$PM_{2.5}$	Ave. for 24 h	15
		annual ave.	5
	PM_{10}	Ave. for 24 h	45
		annual ave.	15
USA	$PM_{2.5}$	Ave. for 24 h	35
		annual ave.	12
	PM_{10}	Ave. for 24 h	50
		annual ave.	25

The annual PM_{10} average concentration in 97.7% of the 175 stations in Türkiye in 2020, was above the limit value of the World Health Organization (WHO). In addition, in 66.9% of 175 stations, 24 h PM_{10} levels were measured above 50 µg/m^3 [11]. While SO_x and NO_x are produced in industrial zones, the main source of the PM_{10} is found to be domestic heating of buildings [12]. On the other hand, the air quality changes significantly depending on traffic intensity and weather conditions [12].

In the literature, there are studies which show the influence of the meteorological parameters on air quality. Chen et al. [13] shows that the most influential factor on the horizontal movement of the pollutants is the wind. In the literature, there are many studies on air pollutants, specifically PM_{10} and SO_2, which are the most impactful pollutants [13–21]. For instance, Çolak et al. [14] investigated the relationship between SO_2 and meteorological factors by using five different air quality measurement stations. The authors found a positive correlation between SO_2 and pressure, while negative correlations were found with temperature and wind speed. Başar et al. [15] used five-year data of PM_{10} and meteorological parameters in Aydın/Türkiye in the correlations. The authors found a strong correlation between all the parameters, especially in the winter season. Çelik and Kadı [16] examined the relation of wind speed, relative humidity and temperature with the SO_2 and PM concentrations. The authors found moderate and weak relationships between meteorological factors and particulate matter concentrations in Karabuk Province/Türkiye. On the other hand, Çiçek et al. [17] used the PM_{10} data for Ankara/Türkiye to determine the correlations with temperature, wind speed and humidity. The authors found moderate correlations among all parameters. In the study conducted by Buldur and Sarı [18], air pollution in Isparta/Türkiye was found to be above the national limits of Türkiye. The authors defended that climatic conditions were the most influential factor on air pollution. In a report of 2022 [22], Manisa/Türkiye was found in the list of provinces with the highest levels of air pollution. The report presented that the annual PM_{10} pollution in Manisa was about two times higher than the EU limit value. Furthermore, if the wind speed increased, the air pollution decreased in Manisa. Giri et al. [23] conducted a study on the effects of meteorological conditions such as temperature, precipitation, humidity, atmospheric pressure, and wind direction and speed, on the PM_{10} concentrations in Nepal. The study showed that PM_{10} concentration had a negative relationship with precipitation and humidity, and a positive relationship with wind speed and atmospheric pressure. Similarly, Barlık [24] found a relation between PM_{10} and meteorological parameters such as temperature, humidity, pressure, precipitation, and wind. Akbal and Unlu [25] proposed to develop a hybrid deep-learning model in order to predict the $PM_{2.5}$ emissions in the capital of Türkiye, Ankara. Five different locations which include industry and heavy traffic zones, were chosen for the study. Convolution neural network (CNN), recurrent neural network (RNN) and long short-term memory (LSTM) deep-learning methods were used to predict and classify $PM_{2.5}$ values for an early warning system, by using meteorological parameters. The authors indicated that the proposed hybrid model predicted the $PM_{2.5}$ with an accuracy of R^2 of 81%.

Some of the studies found no significant correlations between air quality and meteorological parameters [3,26]. For instance, Ceran et al. [26] statistically examined the changes in the PM_{10} values according to meteorological parameters; however, the authors found no significant correlations among these parameters in Sivas/Türkiye. Similarly, Huebnerova et al. [3] found no significant correlations between the PM_{10} concentrations and meteorological data in Brno, Czech Republic. However, no study was found in the literature which examined the relation of the PM_{10} with the meteorological parameters for the northern region of İzmir/Türkiye.

URBAN GreenUP Project [27], which is funded by the European Union's Horizon 2020 research and innovation programme under grant agreement no 730426, proposes to obtain a tailored methodology to support the co-development of renaturing urban plans, focused on decreasing air pollution, climate change mitigation and adaptation as well as efficient water management, and to effectively assist in the implementation of nature-based solutions (NBSs) in urban areas. Izmir, Türkiye is one of the front-runner cities where various NBSs were implemented. One of the NBSs implemented in the project is to install shaded constructions and change the concrete surfaces with permeable ones in car parks, so that the project aims to determine the improvement on the air quality, water drainage and urban heat island effect. Two intervention sites were chosen for this implementation, one in a highly populated urban area and the other in a rural area. To be able to evaluate the effect of NBSs on air quality, the background data should be evaluated first. Since air quality is highly related with meteorological conditions, background data consist of both air quality and meteorological parameters. Air quality data was collected from air quality monitoring stations located close to the intervention sites, for which the longest period of PM_{10} data (2017–2021) was available. This study is concentrated on the evaluation of the influence of meteorological parameters on the PM_{10} data on the intervention sites of URBAN GreenUP Project. The meteorological parameters are temperature (T_{air}), relative humidity (RH), and wind speed (WS) and direction (WD), and were collected from meteorological stations located at the intervention sites. Finally, the novelty of this paper is to statistically analyse the influence of meteorological parameters on the PM_{10} concentrations in both urban and rural environments of İzmir/Türkiye, with the longest period of data.

2. Materials and Methods

2.1. Study Zone

İzmir is located on the west side of Türkiye, with a 12,012 km^2 surface area, and has a hot Mediterranean/dry summer subtropical climate, which is known as a Csa type climate according to Köppen–Geiger climate classification [28]. İzmir is the third largest city in Türkiye, with a population of 4,425,789 inhabitants in 2021 [29].

In wintertime, poor meteorological conditions, especially inversion, are serious issues in İzmir. Air pollution due to inversion (temperature reversal) is affected by industrial pollution and fossil fuel combustion. Figure 1 shows the sectoral greenhouse gas emissions of İzmir [30]. The total greenhouse gas (CO_2 + CH_4 + NO_2) emissions from industry account for 31.4%, while buildings are responsible for 15%.

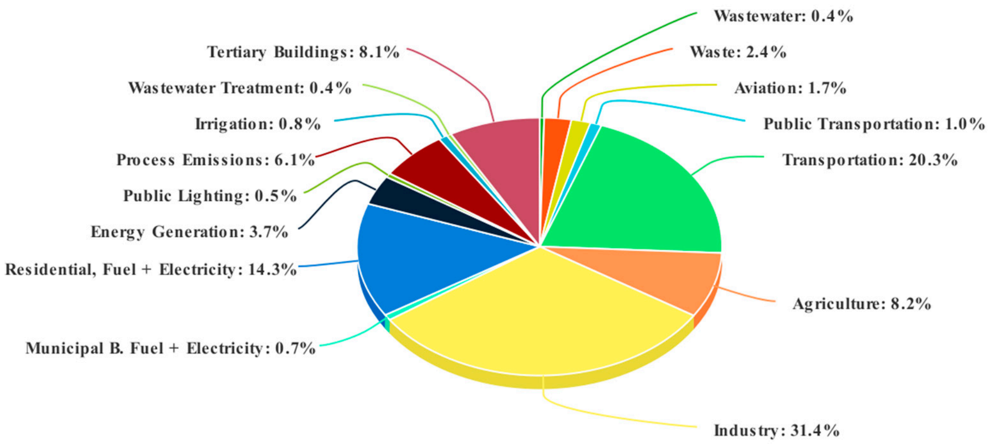

Figure 1. Sectoral greenhouse gas emissions in İzmir [30].

The two different zones studied in this work are Vilayetler Evi and Sasalı Natural Life Park, in İzmir (Figure 2). Vilayetler Evi zone is close to the highway on the coastline. Therefore, it is possible for the air pollution values to be high due to intense traffic. On the other hand, Sasalı Natural Life Park zone is a rural area and is surrounded by forest. However, Sasalı Natural Life Park is also partially surrounded by the industrial zone approximately 3 km to the west. Therefore, the industrial zone can affect this area.

(a)

Figure 2. *Cont.*

(b)

Figure 2. (**a**) The case study area, İzmir/Türkiye, (**b**) Location of the Vilayetler Evi and Sasalı Natural Life Park study zones (The photos are taken from Google Earth).

2.2. Data Collection

The data were collected from the meteorological stations of Vilayetler Evi and Sasalı Natural Life Park zones, which were installed within the scope of the European Union's Horizon 2020 project [27] between 1 January 2017 and 31 December 2021. However, for the statistical analysis, the raw data were subjected to the elimination of outliers and meaningless data. These stations were selected according to urban–nature continuum principles. A total of 21,710 data points of PM_{10} concentrations and meteorological parameters were used in this study. The stations use Model 5014i Beta Continuous Particulate Monitors [31] for PM_{10} measurement. The PM_{10} data were collected hourly by the air quality monitoring stations which are close to the Vilayetler Evi and Sasalı Natural Life Park zones. The meteorological parameters used in the study are wind speed (WS), wind direction (WD), temperature (T_{air}) and relative humidity (RH). Two HOBO RX3000 meteorological stations [32] were installed in two study zones, Vilayetler Evi and Sasalı Natural Life Park (Figure 3). The sensor specifications of the meteorological stations are given in Table 2. The north, east, south and west directions are 0°, 90°, 180° and 270° for the WD. Meteorological stations collect data at 10 min intervals. Since the PM_{10} data are collected hourly at the air quality monitoring stations, meteorological data are also converted to hourly averages.

Figure 3. HOBO RX3000 meteorological station installations (Vilayetler Evi on the left, Sasalı Natural Life Park on the right).

Table 2. Sensor specifications of HOBO RX3000 meteorological station and Model 5014i Beta Continuous Particulate Monitoring Stations.

Specifications	**WS**	**WD**
Measurement Range	0 to 76 m/s (0 to 170 mph)	0 to 355 degrees, 5-degree dead band
Accuracy	±1.1 m/s (2.4 mph) or ±4% of reading, whichever is greater	±5 degrees
Resolution	0.5 m/s (1.1 mph)	1.4 degrees
Specifications	$\mathbf{T_{air}}$	**RH**
Measurement Range	−40 to 70 °C	0 to 100% RH, −40 °C to 70 °C
Accuracy	±0.25 °C from −40 to 0 °C	±2.5% from 10% to 90% (typical) to a maximum of ±3.5% including hysteresis at 25 °C; below 10% RH and above 90% RH ± 5% typical
Resolution	0.02 °C	0.01%
Specifications	**Air Quality Monitoring Station ($\mathbf{PM_{10}}$)**	
Measurement Range	0–10,000 µg/m^3	
Accuracy	<±5% µg/m^3	
Resolution	0.1 µg/m^3	

2.3. Statistical Analysis

Normality analysis of the raw data was conducted before the statistical analysis [33]. To this aim, the Shapiro–Wilks test [34,35] was selected in this study. If the data are normally distributed, the authors can apply *t*-test statistics. Therefore, a null hypothesis is constructed for the normality analysis as follows:

$\mathbf{H_0}$**.** *"The corresponding data is normally distributed"*

The significance level is selected as 0.05 for the Shapiro–Wilks test. Therefore, if the *p*-value is higher than the significance level, the data are assumed to be normally distributed.

A one-tailed *t*-test is applied in the context of linear regression in order to test the null hypothesis which indicates the relation between each meteorological parameter and the PM_{10}. To this aim, the null hypothesis is constructed for each meteorological parameter as follows:

$\mathbf{H_1}$**.** *"The independent variable T_{air} is not significant to explain the PM_{10} concentrations"*

$\mathbf{H_2}$**.** *"The independent variable RH is not significant to explain the PM_{10} concentrations"*

$\mathbf{H_3}$**.** *"The independent variable WS is not significant to explain the PM_{10} concentrations"*

$\mathbf{H_4}$**.** *"The independent variable WD is not significant to explain the PM_{10} concentrations"*

The null hypothesis is evaluated at the significance level of 5% and it is accepted if the *p*-value is found above 0.05. On the other hand, linear regressions for the relation of each parameter with the PM_{10} concentrations, and non-linear relations which include all meteorological parameters with the PM_{10} concentrations are constructed. The linear and non-linear regression equations for the parameters follow Equations (1) and (2).

$$y = a(x_1) + n \tag{1}$$

$$y = b(x_1)^d + c(x_2)^e + \ldots \ldots + n \tag{2}$$

In Equations (1) and (2), a, b, c, d, e and n represent regression coefficients, while y refers to PM_{10} concentrations. Moreover, $x_{1–4}$ indicates meteorological parameters.

A detailed strength level for the regression model between two variables is determined using coefficient of determination (R^2) analysis. The coefficient of determination, for simple linear regressions, corresponds to the proportion of variation in the dependent variable that can be explained by the model based on the independent variable [33,35].

Practical significance is examined in addition to the statistical significance. To this aim, effect size (ES) statistics are used for the relationships between meteorological parameters and the PM_{10} [36]. The Pearson correlation coefficient (r), instead of Cohen's d method, was used for the examination of the effect size, since there were no two different experimental groups in this study. The Pearson correlation coefficient is classified according to Table 3 [37].

Table 3. Classifications of Pearson correlation coefficient (r) values for the effect size [37].

Strength of Association	Pearson's r *
Weak	0.30 to 0.49
Moderate	0.50 to 0.70
Strong	>0.70

* Can be both positive and negative: positive value represents positive correlations, while negative value of r depicts negative correlations.

3. Results

3.1. Descriptive Data Analysis

The descriptive statistics of the data collected between 1 January 2017 and 31 December 2021 for Vilayetler Evi and Sasalı Natural Life Park are given in Table 4.

Table 4. Descriptive statistics of the collected data for each zone.

Vilayetler Evi	Unit	M ± SD *	Range [Max; Min]
T_{air}	°C	20.07 ± 16.75	[1.24; 40.68]
RH	%	60.6 ± 21.5	[18.3; 96.0]
WS	m/s	0.5 ± 0.2	[0.0; 3.9]
WD	Ø	188.79 ± 60.14	[0.01; 355]
PM_{10}	μg/m^3	38 ± 10	[1; 267]
Sasalı Natural Life Park			
T_{air}	°C	17.69 ± 11.16	[−3.81; 40.52]
RH	%	63.0 ± 10.5	[11.0; 99.1]
WS	m/s	0.6 ± 0.3	[0.0; 4.9]
WD	Ø	170.8 ± 87.4	[0.0; 355]
PM_{10}	μg/m^3	33 ± 8	[17; 58]

* In the table, M and SD refers to mean and standard deviation of the data, respectively.

The mean air temperature (T_{air}) of the Sasalı Natural Life Park (17.69 °C) is lower than the Vilayetler Evi mean (20.07 °C). On the other hand, the mean RH and WS are found to be higher in the Sasalı Natural Life Park than the Vilayetler Evi. The mean WD is lower (between south and south-east directions) in the Sasalı Natural Life Park; however, the SD is higher than in the Vilayetler Evi, and this result shows that WD for Sasalı Natural Life Park is more diversified.

The mean PM_{10} values of Vilayetler Evi and the Sasalı Natural Life Park were 38 and 33 μg/m^3, respectively. The PM_{10} values are highly affected by the high traffic density in Vilayetler Evi.

3.2. Statistic Analysis

As discussed in Section 2, the normality test was applied to the collected raw data as a first step of the statistical analysis. Table 5 depicts the Shapiro–Wilk test results on the data.

Table 5. Shapiro–Wilk normality test results.

Distribution of Parameters	*p*-Value
Vilayetler Evi	
T_{air}	0.168
RH	0.176
WS	0.171
WD	0.166
PM_{10}	0.189
Sasalı Natural Life Park	
T_{air}	0.187
RH	0.164
WS	0.170
WD	0.106
PM_{10}	0.108

All the *p*-values of the parameters are larger than the selected significance level; therefore, one can assume that the data is normally distributed and the *t*-test can be applied to the data, as a further step.

After the normality test, one-tailed *t*-test was conducted in the context of linear regression analysis to test the significance of an independent variable (each meteorological parameter) in a linear regression model where PM_{10} is dependent variable. The collected PM_{10} and meteorological data for each study location was used and Table 6 presents the results of the linear regressions and *t*-test results for PM_{10} concentrations in function of each meteorological parameters for Vilayetler Evi and the Sasalı Natural Life Park.

Table 6. Linear regression analysis and *t*-test results for PM_{10} concentrations in function of each meteorological parameters for each location.

Parameters	Equations	Standard Error	t-Value	*p*-Value	R^2
Vilayetler Evi		Intercept Coefficient/Slope Coefficient	Intercept Coefficient/Slope Coefficient	Intercept Coefficient/Slope Coefficient	
T_{air}	0.0729x + 28.51	2856/7.29	0.01/0.01	0.947 ^{NS}/0.985 ^{NS}	0.11
RH	0.0120x + 29.33	12.7/0.05	2.31/2.34	<0.01 **/0.001 **	0.41
WS	−0.1143x + 30.1	15.4/0.05	1.96/1.94	0.024 */0.022 *	0.27
WD	0.0069x + 31.41	14.9/0.03	2.10/2.11	<0.01 **/0.001 **	0.37
Sasalı Natural Life Park					
T_{air}	0.0493x + 31.8	1591/2.46	0.02/0.02	0.754 ^{NS}/0.761 ^{NS}	0.16
RH	0.1189x + 32.64	10.7/0.03	3.06/3.01	<0.01 **/0.001 **	0.51
WS	−1.753x + 41.19	19.6/0.82	2.10/2.11	<0.01 **/0.005 **	0.38
WD	0.0461x + 39.32	14.4/0.02	2.74/2.76	<0.01 **/0.001 **	0.21

^{NS}: not significant, *: significant at %5 level, and **: significant at 1% level.

Table 6 depicts that there was a significant relation between the RH, WS and WD and PM_{10} concentrations for the Vilayetler Evi zone. The RH and WD are significant at the 1% level, while WS is significant at the 5% level in predicting PM_{10} concentrations. On the other hand, the T_{air} is found to be statistically non-significant for the Vilayetler Evi zone.

For the Sasalı Natural Life Park zone, the PM_{10} values are statistically associated with the RH, WS and WD at a 1% significance level. Similarly to the Vilayetler Evi zone, T_{air} is found to be non-significant for predicting PM_{10} concentrations.

Table 6 also shows the linear regression results of the meterological parameters with the PM_{10} concentrations. The results indicate that the strenght of the linear regression for T_{air} is the lowest, with the R^2 of 0.11. The strenghts of the linear regression for RH are given by an R^2 of 0.41 and 0.51 for Vilayetler Evi and Sasalı Natural Life Park, respectively. This means that the proportion of variation in the dependent variable PM_{10} that can be explained by the independent variable RH, is 41% and 51% in each zone, respectively. The reason for the relatively low R^2 values may be the absense of the other meterological parmeters in the equation, since the other meterological parameters could also affect the PM_{10} concentration level.

Table 7 depicts the effect size control tests, in order to investigate the practical significance of the meteorological parameters on the PM_{10} concentrations. Even though *p*-values of the RH, WS and WD for the Vilayetler Evi and Sasalı Natural Life Park zones show statistical significance, the effect sizes of WS are in the range of weak effect sizes, compared to the other parameters, for both zones. This result indicates that the WS may be considered to have a weak association with PM_{10} in the study zones. On the other hand, Table 7 indicates that there are positive correlations between the RH and WD and the PM_{10} concentrations; however, negative correlation is found for the WS for both zones. The result depicts that when the WS increases, the PM_{10} concentrations decrease. On the other hand, if the RH and WD increase, the PM_{10} values also increase for both zones.

Table 7. Pearson correlation between meteorological parameters and PM_{10} concentrations.

Parameters	Pearson's r
Vilayetler Evi	
T_{air}	Null hypothesis is accepted
RH	0.60
WS	−0.15
WD	0.40
Sasalı Natural Life Park	
T_{air}	Null hypothesis is accepted
RH	0.70
WS	−0.41
WD	0.46

Non-linear regression for the PM_{10} was also applied. Equations (3) and (4) represent non-linear regressions for predicting the PM_{10} concentrations based on the meterological parameters.

$$PM_{10} = 2.15998WD^{0.355894} - 0.83072WS^{-0.967422} + 1.9638{T_{air}}^{0.00298} + 1.2927RH^{0.8392} + 1984.7 \quad (3)$$

$$PM_{10} = 0.252159WD^{1.0412} - 5.6703WS^{1.68253} + 0.177812{T_{air}}^{1.24962} + 1.476RH^{0.0021} - 1548.18 \quad (4)$$

4. Discussion

The results of the paper are compared to the literature in this section. The effect of the meteorological parameters on the PM_{10} concentrations highly depends on the location of the stations and selected study zones, such as urban and rural zones. In this paper, the T_{air} is found to be non-significant for the urban zone (Vilayetler Evi) and rural zone (Sasalı Natural Life Park) in İzmir/Türkiye. However, the T_{air} was found to be significant, with a *p*-value of 0.019 (significance level of 5%), for urban zones in Iran, in a paper by Fallahizadeh et al. [38]. In the same paper, the RH was found to be statistically non-significant, with a *p*-value of 0.869. The authors concluded that dust storms are the major reason for these results. On the other hand, Kirešová and Guzan [39] found no correlation between meteorological parameters and the PM_{10} for the rural zones of Kösice, Slovakia. One of the reasons for this result is that the authors did not take the effect of the WS into account in the study. The authors also indicated that wood combustion in rural zones which are surrounded with small villages increases the PM_{10} concentrations without the influence of the meteorological parameters.

In the literature, some papers [40,41] indicated that the RH is negatively correlated with the PM_{10} concentrations in different zones. For instance, Hernandez et al. [40] found that when the RH increases, the PM_{10} values tend to decrease for the sub-tropical climate during winter. However, the RH is found to be positively correlated with the PM_{10} concentrations for İzmir/Türkiye in this paper. The reason for the different results in the literature may be that the RH affects the natural deposition process of the PM_{10} [41]. Moreover, the effect of the RH highly changes during rainfall periods, as discussed in [41]. In a study of Dung et al. [42], WS is found to be negatively correlated with the PM_{10} in Hanoi, Vietnam, similarly to the result of this paper.

The regression analysis in this paper showed that the accuracy of predicting the PM_{10} based on the meteorological parameters was relatively low, similarly to the reference [23]. One of the reasons for the low R^2 values in the regression equations between meteorological parameters and the PM_{10} concentrations may be the sudden change of the PM_{10} values caused by exhaust gases from the vehicles and heavy traffic near the meteorological stations.

Limitations

This study aimed to investigate the relationship between meteorological parameters and PM_{10} concentration levels. Although the study revealed significant results, there were some limitations, due to various reasons. For instance, this study is conducted in İzmir/Türkiye, which has a Csa climate zone classification. Regional differences should be taken into account in further studies and data from areas with other types of climate should be studied. Moreover, seasons and geological areas may affect the results; therefore, more meteorological stations should be installed in order to understand seasonal and geological variations. Finally, sudden changes in the PM_{10} concentrations without any change in meteorological parameters affected the accuracy level of the regression equations. Finally, it is worth remembering that solar radiation is an effective parameter on the air quality and should be included in the statistical analysis as a meteorological parameter.

5. Conclusions

The purpose of this study was to examine the influence of the meteorological parameters on the PM_{10} concentrations, in urban and rural zones of İzmir/Türkiye, under a European Union's Horizon 2020 project. The meteorological parameters T_{air}, RH, WS and WD were investigated in two different zones, namely Vilayetler Evi and Sasalı Natural Life Park. A total of 21,710 data points collected between 1 January 2017 and 31 December 2021 was used in the statistical analysis. The results showed that the RH was the most influencing factor on the PM_{10} concentrations for both zones. On the other hand, the T_{air} was found to be statistically non-significant on the PM_{10} concentrations.

The found accuracy of the regression models to predict the PM_{10} concentrations based on the meteorological parameters is low. By integrating other factors such as precipitation, atmospheric pressure, seasonal effects and human activities, the accuracy of the regression analysis could be increased.

The outcome of this study allows a better understanding of the meteorological conditions affecting the PM_{10} concentrations, especially in Csa-type climate zones. Future studies should address the influence of the meteorological parameters on PM_{10} concentrations in other climate zones.

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References

1. Jang, J.; Leung, D.W.M. The Morpho-Physio-Biochemical Attributes of Urban Trees for Resilience in Regional Ecosystems in Cities: A Mini-Review. *Urban Sci.* **2022**, *6*, 37. [CrossRef]
2. Sharma, A.; Kumar, P. Air pollution exposure assessment simulation of babies in a bike trailer and implication for mitigation measures. *J. Hazard. Mater. Adv.* **2022**, *5*, 100050. [CrossRef]
3. Huebnerova, Z.; Michalek, J. Analysis of Daily Average PM_{10} Predictions by Generalized Linear Models in Brno, Czech Republic. *Atmos. Pollut. Res.* **2014**, *5*, 471–476. [CrossRef]
4. Breuer, J.L.; Samsun, R.C.; Stolten, D.; Peters, R. How to reduce the greenhouse gas emissions and air pollution caused by light and heavy duty vehicles with battery-electric, fuel cell-electric and catenary trucks. *Environ. Int.* **2021**, *152*, 106474. [CrossRef] [PubMed]
5. Kahraman, O. Nevşehir İlinde Hava Kalitesinin ve Meteorolojik Faktörlerin Hava Kirliliği Üzerine Etkilerinin İncelenmesi. *Doğal Afetler Çevre Derg.* **2020**, *6*, 391–404. (In Turkish) [CrossRef]
6. Gustafson, P.; Barregård, L.; Lindahl, L.; Sällsten, G. Formaldehyde Levels in Sweden: Personal Exposure, Indoor, and Outdoor Concentrations. *J. Expo. Sci. Environ. Epidemiol.* **2005**, *15*, 252–260. [CrossRef]
7. Büke, T.; Köne, A.Ç. Assessing Air Quality in Turkey: A Proposed, Air Quality Index. *Sustainability* **2016**, *8*, 73. [CrossRef]
8. Thangavel, P.; Park, D.; Lee, Y.-C. Recent Insights into Particulate Matter ($PM_{2.5}$)-Mediated Toxicity in Humans: An Overview. *Int. J. Environ. Res. Public Health* **2022**, *19*, 7511. [CrossRef]
9. European Union. Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. *Off. J. Eur. Union* **2008**, *152*, 1–44.
10. World Health Organization. WHO Global Air Quality Guidelines: Particulate Matter ($PM_{2.5}$ and PM_{10}), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide. 2021. License: CC BY-NC-SA 3.0 IGO. Available online: https://apps.who.int/iris/handle/10665/345329 (accessed on 18 February 2023).
11. Right to Clean Air Platform. Dark Report Reveals the Health Impacts of Air Pollution in Turkey. 2021. Available online: https://www.temizhavahakki.com/kararapor2021/ (accessed on 10 February 2022).
12. Blazy, R. Living Environment Quality Determinants, Including $PM_{2.5}$ and PM_{10} Dust Pollution in the Context of Spatial Issues—The Case of Radzionków. *Buildings* **2020**, *10*, 58. [CrossRef]
13. Chen, L.; Xiao, H.; Zhu, L.; Guo, X.; Wang, W.; Ma, L.; Guo, W.; He, J.; Wang, Y.; Li, M.; et al. Characteristics of Ozone Pollution and the Impacts of Related Meteorological Factors in Shanxi Province, China. *Atmosphere* **2022**, *13*, 1729. [CrossRef]
14. Çolak, H.E.; Memişoğlu, T.; Bediroğlu, G. Ege Bölgesi için Hava Kirliliği Parametrelerinin (PM_{10}, SO_2) Coğrafi Bilgi Sistemleri Yardımıyla Konumsal Analizi. In Proceedings of the Türkiye Ulusal Jeodezi ve Jeofizik Birliği Bilimsel Kongresi, İzmir, Turkey, 30 May 2018.
15. Başar, P.; Okyay, P.; Ergin, F.; Coşan, S.; Yıldız, A. Air Pollution in Aydin City between 1997–2004. *Meandros Med. Dent. J.* **2005**, *6*, 11–15.
16. Çelik, M.B.; Kadı, İ. The Relation between Meteorological Factors and Pollutants Concentrations in Karabük City. *Gazi Univ. J. Sci.* **2007**, *20*, 87–95.
17. Cicek, İ.; Turkoglu, N.; Gurgen, G. Statistical Analysis of Air Pollution in Ankara. *Fırat Univ. J. Soc. Sci.* **2004**, *14*, 17–18.
18. Buldur, A.D.; Sarı, S. Sıcaklık Terselmesinin Hava Kirliliğine Etkisi (Isparta Şehir Merkezi Örneği). *J. Turk. Stud.* **2018**, *13*, 163–179. [CrossRef]
19. Tsai, C.W.; Hsiao, Y.R.; Lin, M.L.; Hsu, Y. Development of a noise-assisted multivariate empirical mode decomposition framework for characterizing $PM_{2.5}$ air pollution in Taiwan and its relation to hydro-meteorological factors. *Environ. Int.* **2020**, *139*, 105669. [CrossRef] [PubMed]

20. Morozesk, M.; Lara da Costa Souza, I.; Fernandes, M.; Soares, D. Airborne particulate matter in an iron mining city: Characterization, cell uptake and cytotoxicity effects of nanoparticles from $PM_{2.5}$, PM_{10} and PM_{20} on human lung cells. *Environ. Adv.* **2021**, *6*, 100125. [CrossRef]
21. Andac, İ. The Examination of PM_{10} and Concentrated Particulate Materials Released from Industrial Plants in Payas Industrial Zone Using Iscst3 Model. Ph.D. Thesis, Cukurova University, Graduate School of Natural and Applied Sciences, Mining Engineering, Adana, Turkiye, 2013.
22. Zinnur, Y.; Karagözoğlu, M.B. Statistical Analysis of the Temporal Change of PM_{10} Levels in the City of Sivas (Turkey). *Air Qual. Atmos. Health* **2022**, *15*, 1635–1646. [CrossRef]
23. Giri, D.; Krishna Murthy, V.; Adhikary, P.R. The Influence of Meteorological Conditions on PM_{10} Concentrations in Kathmandu Valley. *Int. J. Environ. Res.* **2008**, *2*, 49–60.
24. Barlık, N. Effect of Meteorological Parameters on PM_{10} Concentrations in Ardahan by Wavelet Coherence Analysis. *CBU J. Sci.* **2021**, *17*, 43–49. [CrossRef]
25. Akbal, Y.; Ünlü, K.D. A deep learning approach to model daily particular matter of Ankara: Key features and forecasting. *Int. J. Environ. Sci. Technol.* **2022**, *19*, 5911–5921. [CrossRef]
26. Ceran, C.S.; Cihan, M.; Yücel, D.; Serdar, M.A. Sample Size, Power and Effect Size Revisited: Simplified and Practical Aproaches in Pre-Clinical, Clinical and Laboratory Studies. *Biochem. Med.* **2021**, *31*, 27–53. [CrossRef]
27. Urban GreenUP Project, the European Union's Horizon 2020 Research and Innovation Programme, Grant Agreement No. 730426. Available online: https://urbangreenup.eu (accessed on 14 February 2023).
28. Yılmaz, E.; Çiçek, İ. Detailed Köppen-Geiger climate regions of Turkey—Türkiye'nin detaylandırılmış Köppen-Geiger iklim bölgeleri. *J. Hum. Sci.* **2018**, *15*, 225–242. [CrossRef]
29. Turkish Statistical Institute. Available online: https://data.tuik.gov.tr/Bulten/Index?p=45500 (accessed on 14 February 2023).
30. İzmir Metropolitan Municipality. İzmir Sustainable Energy and Climate Action Plan. 2020. Available online: http://skpo.izmir.bel.tr/Upload_Files/FckFiles/file/2020/WEB_SAYFASI_SECAP-ingilizce.pdf (accessed on 23 September 2021).
31. Model 5014i Beta Continuous Particulate Monitor. Available online: https://www.thermofisher.com/order/catalog/product/5014I (accessed on 14 February 2023).
32. HOBO RX3000—Outdoor Remote Monitoring Station. Available online: https://www.hobodataloggers.com.au/rx3000 (accessed on 15 March 2022).
33. Thode, H.C. *Testing For Normality*, 164th ed.; CRC Press: New York, NY, USA, 2002.
34. Surhone, L.M.; Tennoe, M.T.; Henssonow, S.F. *Shapiro-Wilk Test*, 1st ed.; Betascript Publishing: Roches Brunes, Mauritius, 2010.
35. Çeter, A.E.; Özbey, M.F.; Turhan, C. Gender inequity in thermal sensation based on emotional intensity for participants in a warm mediterranean climate zone. *Int. J. Therm. Sci.* **2023**, *185*, 108089. [CrossRef]
36. Özbey, M.F.; Çeter, A.E.; Örfioğlu, Ş.; Alkan, N.; Turhan, C. Sensitivity analysis of the effect of current mood states on the thermal sensation in educational buildings. *Indoor Air.* **2022**, *32*, e13073. [CrossRef]
37. Abecasis, L.; Gamelas, C.A.; Justino, A.R.; Dionísio, I.; Canha, N.; Kertesz, Z.; Almeida, S.M. Spatial Distribution of Air Pollution, Hotspots and Sources in an Urban-Industrial Area in the Lisbon Metropolitan Area, Portugal—A Biomonitoring Approach. *Int. J. Environ. Res. Public Health* **2022**, *19*, 1364. [CrossRef]
38. Fallahizadeh, S.; Kermani, M.; Esrafili, A.; Asadgol, Z.; Gholami, M. Effects of meteorological parameters on PM_{10}: Health impacts assessment using AirQ+ model and prediction by an artificial neural network (ANN). *Urban Clim.* **2021**, *38*, 100905. [CrossRef]
39. Kirešová, S.; Guzan, M. Determining the Correlation between Particulate Matter PM_{10} and Meteorological Factors. *Eng* **2022**, *3*, 343–363. [CrossRef]
40. Hernandez, G.; Berry, T.-A.; Wallis, S.L.; Poyner, D. Temperature and Humidity Effects on Particulate Matter Concentrations in a Sub-Tropical Climate During Winter. In Proceedings of the International Conference of the Environment, Chemistry and Biology (ICECB 2017), Brisbane, Australia, 20–22 November 2017; Juan, L., Ed.; IACSIT Press: Singapore, 2017; pp. 41–49.
41. Dwamena, H.A.; Tawiah, K.; Kodua, A.S.A. The Effect of Rainfall, Temperature, and Relative Humidity on the Yield of Cassava, Yam, and Maize in the Ashanti Region of Ghana. *Int. J. Agron.* **2022**, *2022*, 9077383. [CrossRef]
42. Dung, N.; Son, D.; Hanh, N.; Tri, D. Effect of Meteorological Factors on PM_{10} Concentration in Hanoi, Vietnam. *J. Geosci. Environ.* **2019**, *7*, 138–150. [CrossRef]

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