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Research Article

The influence of meteorological parameters on $PM_{2.5}$ and PM_{10} values in Ümraniye and Silivri districts of İstanbul

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ABSTRACT

In this study, spatiotemporal relationship between $PM_{2.5}$ and PM_{10} concentrations and meteorological parameters were investigated for Silivri and Ümraniye districts in İstanbul for 2014–2020. For this purpose, hourly $PM_{2.5}$ and PM_{10} concentrations values of two air quality monitoring stations and meteorological data (wind speed, wind direction, relative humidity, total precipitation, minimum and maximum temperature) were examined. In all seasons, while PM concentrations were lowest at 06:00 local time (LT), $PM_{2.5}$ and PM_{10} have peak values around 09:00 and 19:00 LT both in Silivri and Ümraniye mainly due to anthropogenic activities such as vehicle exhaust emissions. In daily perspective, highest PM values were observed on Sundays in winter at Silivri. On the other side, peak PM values are shown on Fridays at Ümraniye. It was found that local emission sources during low wind speeds cause the highest $PM_{2.5}$ concentrations during winter months and southerly winds exceeding 8 m/s increase the PM_{10} levels at Silivri and Ümraniye. The statistical analysis showed that $PM_{2.5}$ and PM_{10} concentrations at Silivri were negatively correlated with wind speed with correlation coefficients of -0.56 (winter), -0.47 (autumn), respectively. Wind speed is negatively associated with $PM_{2.5}$ (r=-0.48) and PM_{10} (r=-0.38) in winter season at Ümraniye. In addition to this, relative humidity showed negative relationship with PM10 (r=-0.43)in spring at Silivri, while a positive correlation was found between PM_{10} (r=0.40) and $PM_{2.5}$ (r=0.38) measured in the summer season and the maximum temperature. In addition to the anthropogenic factors (e.g. urbanization, transportation, and industrialization) that decrease air quality of İstanbul, local meteorological variables and atmospheric transport of pollution are observed to be the other factors that contribute to air pollution.

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INTRODUCTION

Air pollution is one of the most serious environmental concerns, influencing all living things and having severe and fatal health consequences. The main air pollutants are known as particulate matter (PM_{10}<10 µm particles and $PM_{2.5}$<2.5 µm particles), sulfur dioxide (SO_2), carbon monoxide (CO), ground-level ozone (O_3), lead (Pb) and nitrogen dioxide (NO_2). Particularly, particulate matter plays an important role in urban and regional air pollution and causes serious health effects according to the World Health Organization [1]. Many epidemiological studies have shown that exposure to particulate matter is associated with numerous adverse health effects, including respiratory diseases (e.g.

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asthma, COPD, bronchitis) and cardiovascular diseases [2–8].In addition, the International Agency for Research on Cancer (IARC) included particulate matter in the list of carcinogenic agents in 2013 [9]. Moreover, particulate matter pollution can generate haze, which can lead to airline delays or cancellations, as well as highway closures [10–12].

Nowadays, air pollution is increasing as a result of anthropogenic factors like urbanization, transportation, and industrialization. In addition to these emissions, local [13]and large-scale meteorological factors are also crucial for transport and distribution of air pollution [14, 15]. Furthermore, meteorological factors affect the concentrations and residence times of pollutants in the atmosphere. Even if the amount of pollutants emitted into the atmosphere does not change, pollutant concentrations can change over time. On days with high PM pollution, the effect of meteorological factors (e.g. temperature, wind speed, precipitation, pressure and inversion) is particularly important. Generally, high temperature values increase the concentration of particulate matter, while precipitation reduces these values by removing particulate matter from the atmosphere [16–19]. Wind speed plays an important role for dilution, distribution and transport of particulate matter and reduce air pollution [20–22]. Since wind removes pollutants from their sources, wind patterns also provide information about where pollutants are transported [23, 24]. Some pollutants pollute the air directly when released from the source, while others are formed in the atmosphere as a result of a reaction between two pollutants. This is caused by meteorological factors such as temperature and humidity. Li et al. [25] indicated that PM concentrations have negative correlation with wind speed in most season but found positive correlations with temperature, relative humidity and pressure over Shenyang in China. Li et al. [26] found that the $PM_{2.5}$, PM_{10}, and SO_2 values were significantly associated with precipitation, temperature and wind speed. Ansari et al. [27] investigated the relationship between the $PM_{2.5}$ concentrations and meteorological factors in Iran. They found weak correlations between $PM_{2.5}$ and average temperature and humidity.

Air pollution has become a major issue in Türkiye due to urbanization, which has led to increased unemployment in rural areas, causing migration from rural to urban areas. With the population growth in cities, transportation activities have increased. As a result, the amount of pollutants in cities has increased dramatically. These sources grow mutually, resulting in air pollution, particularly in urban areas. Although association between air pollution and meteorological factors is important, very limited studies have been carried up for Afyon, Bolu, Erzurum, Karabük, Zonguldak [28–32]. Celik and Kadi [29] indicated that PM concentrations have negative correlation with wind speed, humidity and temperature in Karabük. Tecer et al. [31] found high correlation between particulate matter and relative humidity, cloudiness, and lower temperature at episodic events. Sari et al. [33] examined the relationship between the PM_{10}, $PM_{2.5}$, SO_2, CO, O_3, NO, NO_2, NO_x, and CH_4 concentrations and meteorological parameters (temperature, wind speed, wind direction, and relative humidity) in Bursa. They found strong correlations between pollutant concentrations and wind speed.

İstanbul, with its significant population growth, industrial activities, and traffic congestion, is one of Türkiye's most polluted cities. A high concentration of pollutants have been observed in recent years, due to population growth, industrial activities, and the use of low-quality fuel. Air pollution studies in industrial regions and settlements with a high pollutant source type variety and heavy concentration loads aid in the development of solutions to improve air quality.

This study aimed to examine the association between $PM_{2.5}$ and PM_{10} concentrations and meteorological parameters (average temperature, minimum temperature (Tmin), maximum temperature (Tmax), total precipitation, average relative humidity and average wind speed) in, Ümraniye and Silivri for 2014 to 2020.

MATERIALS AND METHOD

Description of Study Area

İstanbul is the major metropolitan city with 16 million population, located in the Marmara region (northwestern Türkiye) [34]. The city is divided into two sides by the Bosphorus and lies in both Europe and Asia. The total area of the city is 5.343 km^2. İstanbul is located at the latitude of 41.15984°N and longitude of 29.07412°E in the northern hemisphere, with an average altitude of 40 m from the sea level. İstanbul's climate is a transition between Mediterranean and Black Sea, with mild winters and hot summers [35]. Seasonal temperature values of Ümraniye district show that the highest average temperature was measured in summer with 23 °C and the lowest average temperature was measured in winter with 6.2 °C. Average temperatures were found as 16.4 °C in the autumn season and 12.9 °C in the spring season. In Silivri district, the highest average temperature was found in summer season as 22.6 °C and the lowest average temperature was found in winter as 5.7 °C. Average temperature was 15.9 °C in autumn and 12.6 °C in spring. When the seasonal precipitation data of Ümraniye is examined, the highest total precipitation was measured as 2179 mm in winter, followed by 1331 mm in autumn, 1000 mm in spring, and 911 mm in summer as the lowest. In Silivri, the highest total precipitation was 1219 mm in winter, followed by 1082 mm in autumn, 960 mm in spring and 807 mm in summer. When the two districts are compared in terms of precipitation, Ümraniye district receives more precipitation than Silivri district. When the wind rose chart of İstanbul province is examined, the prevailing wind direction is found as northeast, and the second dominant wind direction is found as southwest.

In İstanbul, air quality of the city decreases due to anthropogenic activities such as transportation, coal consumption and urban transformation and the environment and public health are adversely affected. Air pollution becomes a chronic problem in İstanbul due to population growth, expansion of city, destruction of nature and encouraging the use of individual vehicles instead of public transportation.

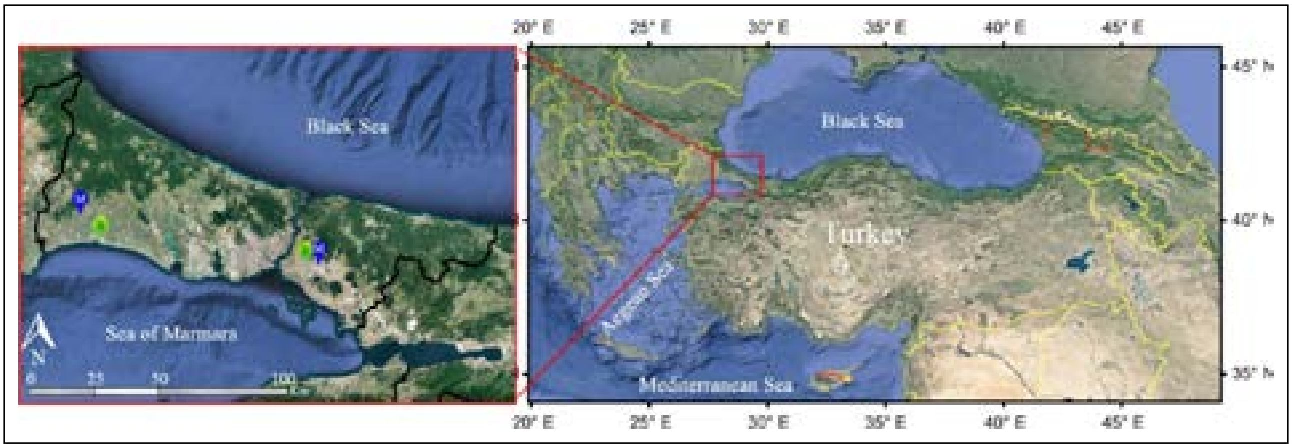


Figure 1. Locations of air quality monitoring stations (green) and meteorological stations (blue) in İstanbul.

Air Quality and Meteorological Data

Marmara Region (MR) is the most developed region of Türkiye. Industry, trade, tourism, and agriculture sectors take an important place compared to other regions. Therefore, MR faces more serious environmental and public health problems than other regions. For this reason, this study is carried out in the province of İstanbul, which is located in the MR, where the population and industrial activities are dense and traffic-related emissions are high. To investigate the relationship between $PM_{2.5}$ and PM_{10} concentration values and meteorological factors in İstanbul, hourly air quality data ($PM_{2.5}$ and PM_{10}) of Silivri and Ümraniye stations between 01/01/2014 and 31/12/2020 were obtained from National Air Quality and Monitoring Network database [36]. Furthermore, hourly wind speed (m/s), direction, temperature, minimum temperature, maximum temperature, total precipitation, relative humidity values of the meteorological stations, which are closest to the air quality stations, are provided by the Turkish State Meteorological Service. Meteorological data used in this study represent the characteristic meteorological properties of the pollutant source area. Missing air quality data are eliminated from the study. Figure 1 shows the locations of air quality monitoring stations and meteorological stations.

In order to preserve the environment and public health, limit values for $PM_{2.5}$ and PM_{10} pollutants have been determined by WHO, EU and various country. 24-hour average limit value of PM_{10} is 45 μg/m³ for WHO and 50 μg/m³ for EU [37, 38]. PM_{10} limit values in Türkiye have been gradually improved and leveled with the European Union regulation no 2008/50/EC starting from 2008. $PM_{2.5}$ is recognized as one of the most harmful air pollutants by the European Union and the World Health Organization. The daily limit values of $PM_{2.5}$ were set as 15 μg/m³ for WHO to protect the public from the health effects of particulate matter. In Türkiye, there is no legal limit value for $PM_{2.5}$ concentrations.

$PM_{2.5}$ and PM_{10} concentrations in the atmosphere vary depending on meteorological parameters (air temperature, wind speed and direction, relative humidity, precipitation, dew point temperature, average pressure, cloud cover and mixing layer). In this study, the effects of hourly wind speed (m/s), wind direction, average temperature, minimum temperature (Tmin), maximum temperature (Tmax), total precipitation and relative humidity on particulate matter values were investigated for Silivri and Ümraniye stations.

Statistical Analysis

Correlation matrix was used to analyze the strength of the association between $PM_{2.5}$ and PM_{10} concentrations and meteorological factors (wind speed, wind direction, temperature, minimum temperature, maximum temperature, total precipitation, relative humidity). All the statistical calculations and graphics were done using R version 3.1.2 [39].

RESULTS AND DISCUSSION

Table 1 shows the statistical information on air pollutants and meteorological parameters from 2014 to 2020 for Silivri station. The annual mean $PM_{2.5}$ and PM_{10} concentrations were calculated as 19.1 μg/m³ and 34.1 μg/m³, respectively.

The descriptive statistics of air pollutant sand meteorological parameters for Ümraniye station were shown in Table 2. The annual mean $PM_{2.5}$ and PM_{10} concentrations at Ümraniye station were both higher than Silivri station as 22.9 μg/m³ and 44.8 μg/m³, respectively.

When hourly PM_{10} values of Silivri station were seasonally analyzed, highest mean PM_{10} concentration was found as 38.6 μg/m³ in spring season followed by 35.5 μg/m³ in winter and 32.6 μg/m³ in autumn. In the spring and autumn months, there is intense dust transport to Türkiye with the effect of the Asiatic characteristics of surface low and it increases the particulate matter concentration [40]. The dry and hot air originating from the surface Asian monsoon low is the primary cause of dust storms during the summer and fall seasons. Arabian dust particles are transported to the region via dry hot air, leading to high levels of PM concentration during dust episodes [15]. The lowest mean value was measured in summer (11.1 μg/m³), similar to other studies [7]. When $PM_{2.5}$ value is examined, the highest average value was recorded in winter with 23.2 μg/m³, followed byspring (20.6 μg/m³), autumn (18.3 μg/m³) and summer (10.3 μg/m³) seasons. Many studies indicate that the con-

Table 1. The statistical information of air pollutants and meteorological parameters in Silivri, 2014–2020

Variables	Mean±SD	Min	P_{25}	P_{50}	P_{75}	Max
Particulate matter (μg/m^3)						
$PM_{2.5}$	19.1±10.2	3.2	12.2	15.9	22.8	80.4
PM_{10}	34.1±18.9	4.8	21.7	29.8	41.5	318.0
Meteorological factors						
Avg. relative humidity (%)	78.3±14.3	15.0	69.0	78.3	89.2	100
Avg. temperature (°C)	14.3±7.2	-7.7	7.2	14.5	21.1	28.2
Total precipitation (mm)	1.7±5.6	28.2	0	0	0.4	98.3
Avg. wind Speed (m/s)	4.1±1.7	1.1	2.7	3.8	5.2	13.1

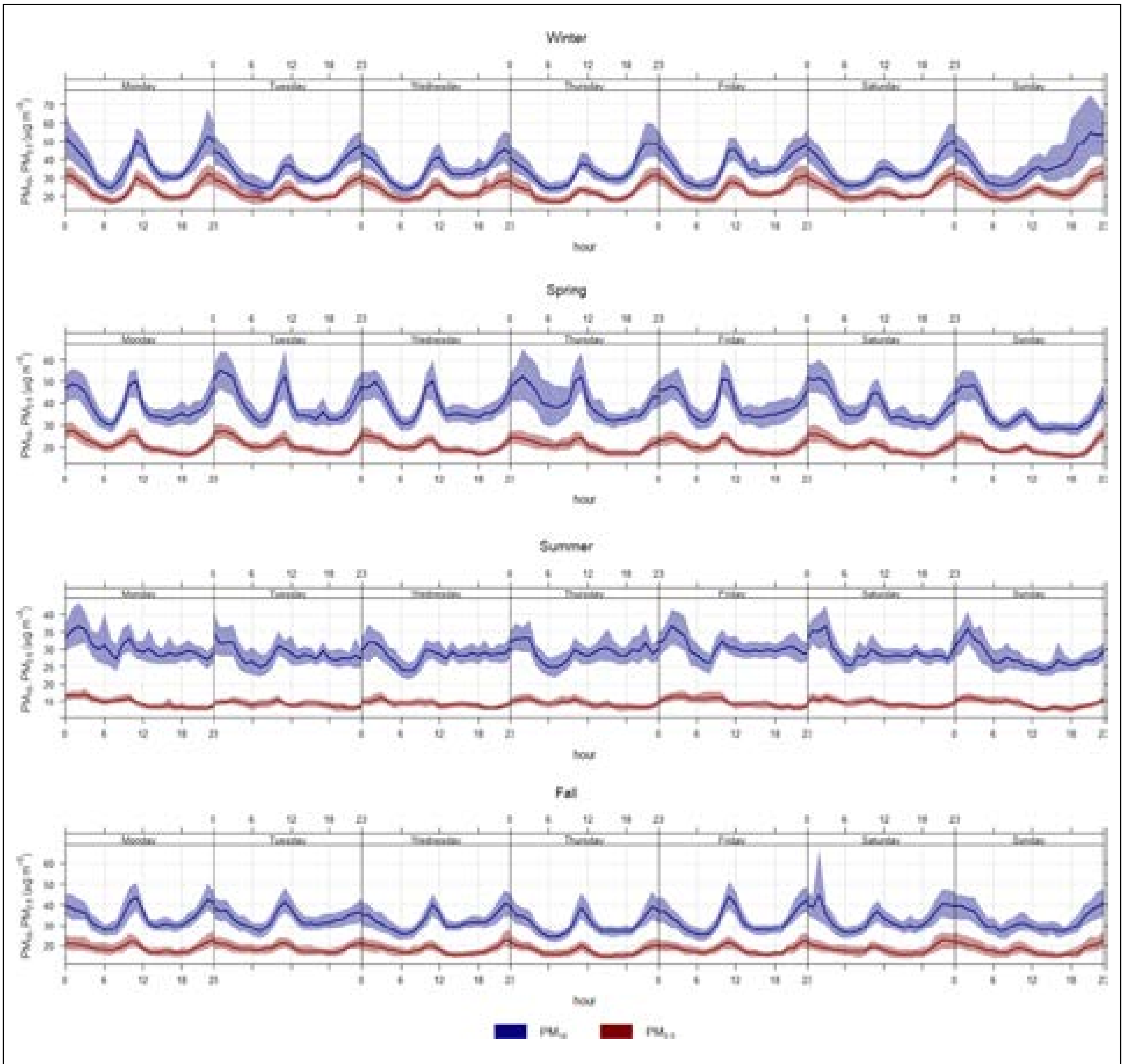


Figure 2. Seasonal variation of PM_{10} and $PM_{2.5}$ concentrations throughout the period 2014–2020 for Silivri Station (the blue lines show the values of PM_{10}, and the red line represents the values of $PM_{2.5}$).

centration of particulate matter is generally high during the winter months [41, 42]. When the hourly PM_{10} and $PM_{2.5}$ concentration variations are examined in Figure 2, the increase and decrease of pollutants show similar characteristics. The highest particulate matter concentration values were measured in winter, depending on local factors such

Table 2. The statistical information of air pollutants and meteorological parameters in Ümraniye, 2014–2020

Variables	Mean±SD	Min	P_{25}	P_{50}	P_{75}	Max
Particulate matter (μg/m³)						
$PM_{2.5}$	22.9±12.5	2.8	14.8	20.1	27.9	88.9
PM_{10}	44.8±24.3	5.7	28.8	39.6	54.8	315.1
Meteorological factors						
Avg. relative humidity (%)	77.4±14.8	3.0	68.7	78.7	88.4	100
Avg. temperature (°C)	14.8±7.3	-5.0	8.9	15.1	21.5	30.6
Total precipitation (mm)	2.2±5.7	0	0	0	1.2	77.5
Avg. wind Speed (m/s)	3.2±1.1	0	2.4	3	3.9	8.8

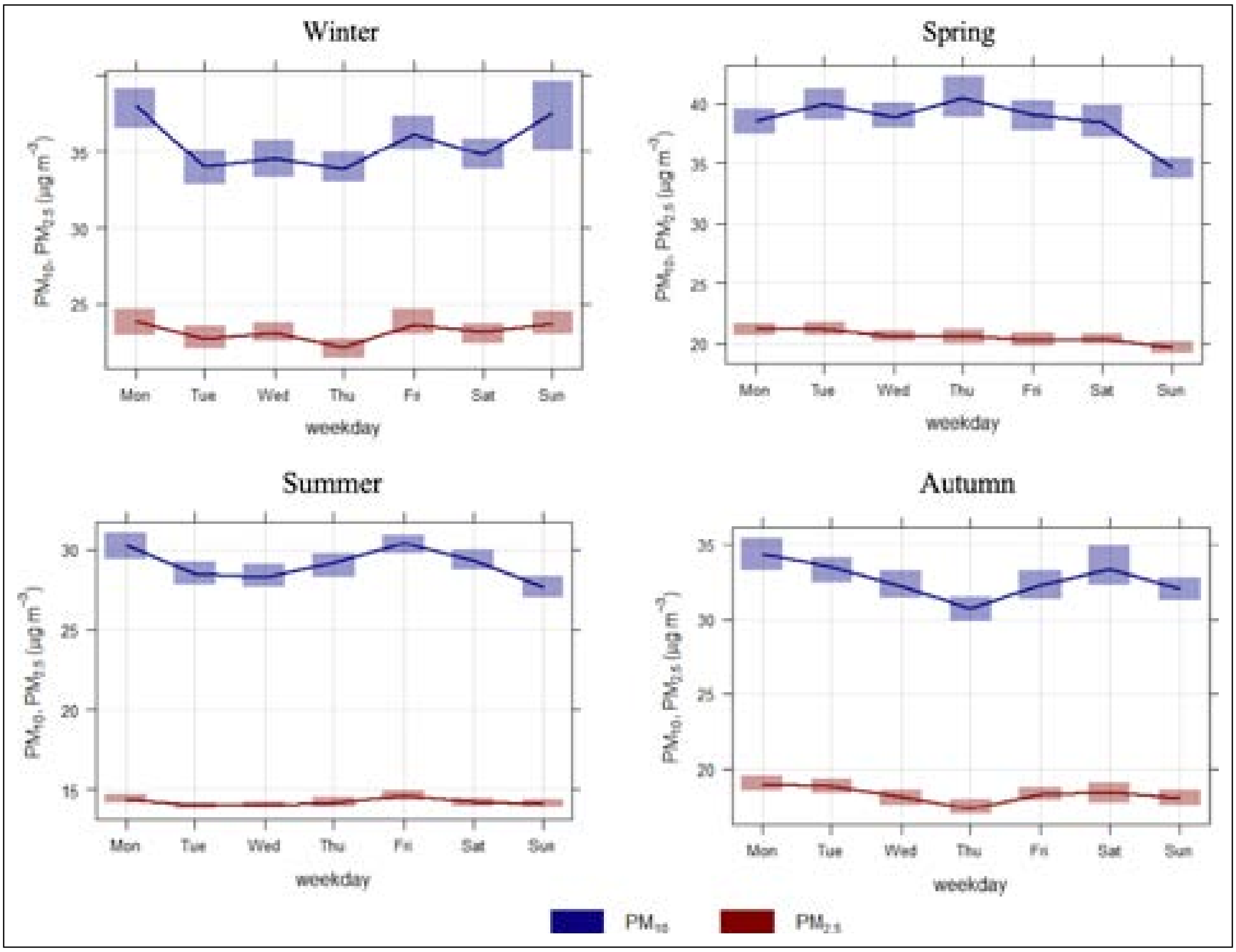


Figure 3. Daily variation of PM_{10} and $PM_{2.5}$ concentrations throughout the period 2014–2020 for Silivri Station (the blue lines show the values of PM_{10}, and the red line represents the values of $PM_{2.5}$).

as domestic warming. When particulate matter concentrations in the winter months were examined, pollutants show increase at noon and also in the evening hours. In the spring season, while the lowest values are recorded at 06:00 in the morning, increases are shown at noon and night hours. Higher pollutant amount was measured on Thursdays compared to other days of the week. The lowest particulate matter values are recorded in summer when PM_{10} and $PM_{2.5}$ values are more uniformly distributed. In autumn, PM_{10} values increase especially at midday (Fig. 2).

When the daily PM_{10} and $PM_{2.5}$ values at Silivri station are analyzed, it is seen that there is an increase in pollution on Sundays and Mondays in winter, Mondays and Fridays in summer, and Mondays and Saturdays in autumn, depending on traffic density (Fig. 3). In the spring season, the lowest particulate matter values were recorded on Sundays and a more uniform distribution is observed on other days.

When the hourly PM_{10} values of Ümraniye station are examined seasonally, the highest average PM_{10} concen-

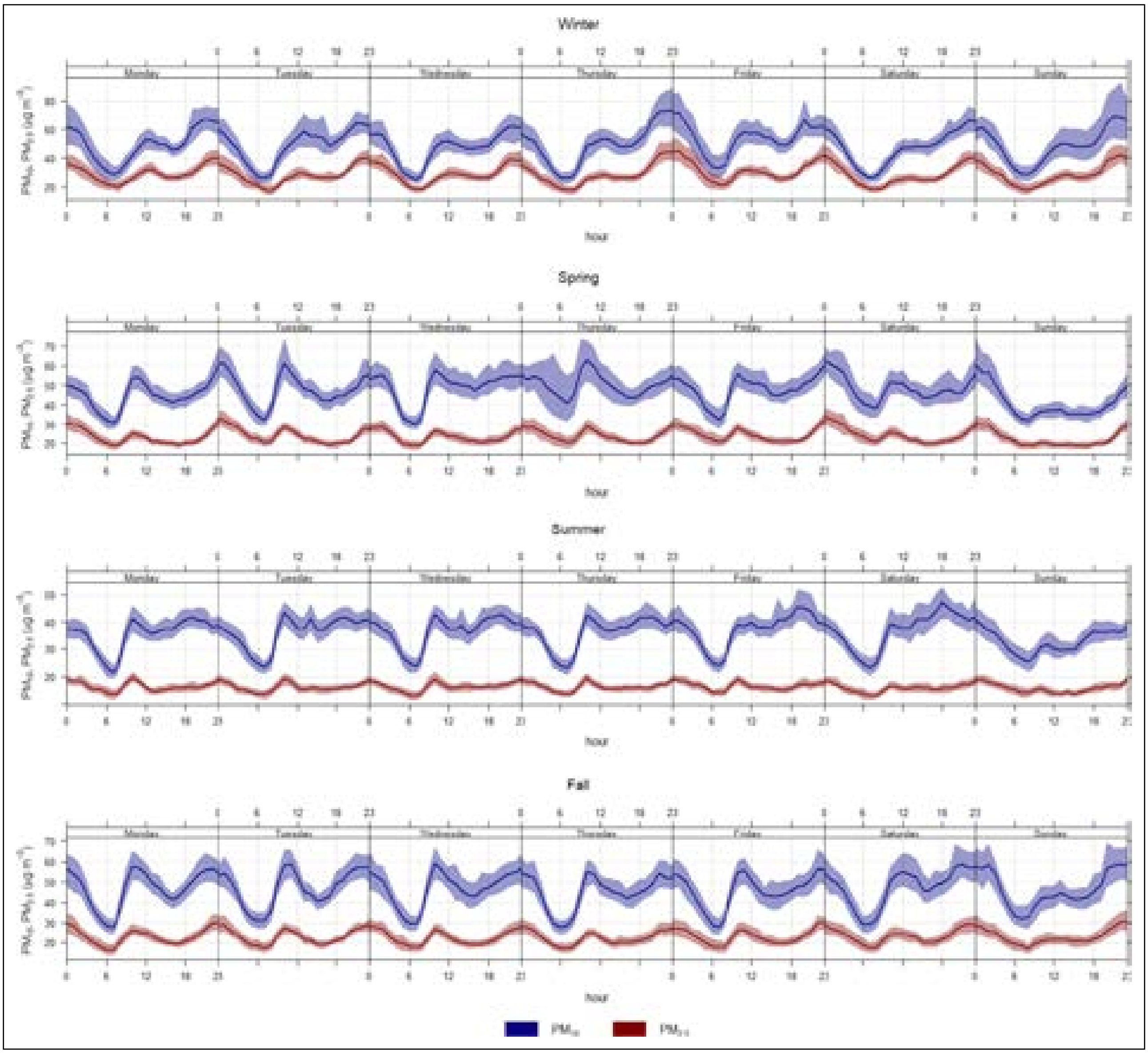


Figure 4. Seasonal variation of PM_{10} and $PM_{2.5}$ concentrations throughout the period 2014–2020 for Umraniye Station (the blue lines show the values of PM_{10}, and the red line represents the values of $PM_{2.5}$).

tration is recorded with 49.4 µg/m³ in winter, followed by 47.2 µg/m³ in spring and 46.5 µg/m³ in autumn. Particularly in the spring months, dust transport occurs and there is a significant increase in the concentration of particulate matter [14, 15, 43]. The lowest average value is measured in summer (40.0 µg/m³). Similar to PM_{10} values, $PM_{2.5}$ values are highest in winter (29.2 µg/m³) and lowest in summer (16.3 µg/m³).

When the hourly values of PM_{10} and $PM_{2.5}$ at Ümraniye station are examined seasonally, decreases in particulate matter values are observed between 00:00–06:00 due to low traffic activity. These values increase with the traffic density between 06:00 and 09:00. There is a similar increase related to traffic in the evening hours. In winter and autumn, pollutant values increase gradually, especially on weekends. The lowest values are measured around 6 am for all seasons (Fig. 4).

When daily PM_{10} and $PM_{2.5}$ values are examinedfor Ümraniye station, PM_{10} and $PM_{2.5}$ values show similar trends. There is a significant increase in traffic-related concentrations especially on Fridays in the winter season (Fig. 5). In the spring season, the highest particulate matter value is recorded on Thursdays, and the lowest value is recorded on Sundays. The lowest values are measured on Sundays in the summer season and on Thursdays in the autumn season (Fig. 5).

The level of particulate matter is higher in Ümraniye district than in Silivri district. Examining Ümraniye Station data with respect to European Union PM_{10} limit value (50 µg/m³) showed that 37% of autumn data, 35% of winter data, 33% of spring data and 15% of summer data exceeded the limit value. On the other hand, in Silivri Station, 22% of spring data, 18% of winter data, 13% of autumn data and 6% of summer data exceeded the limit value.

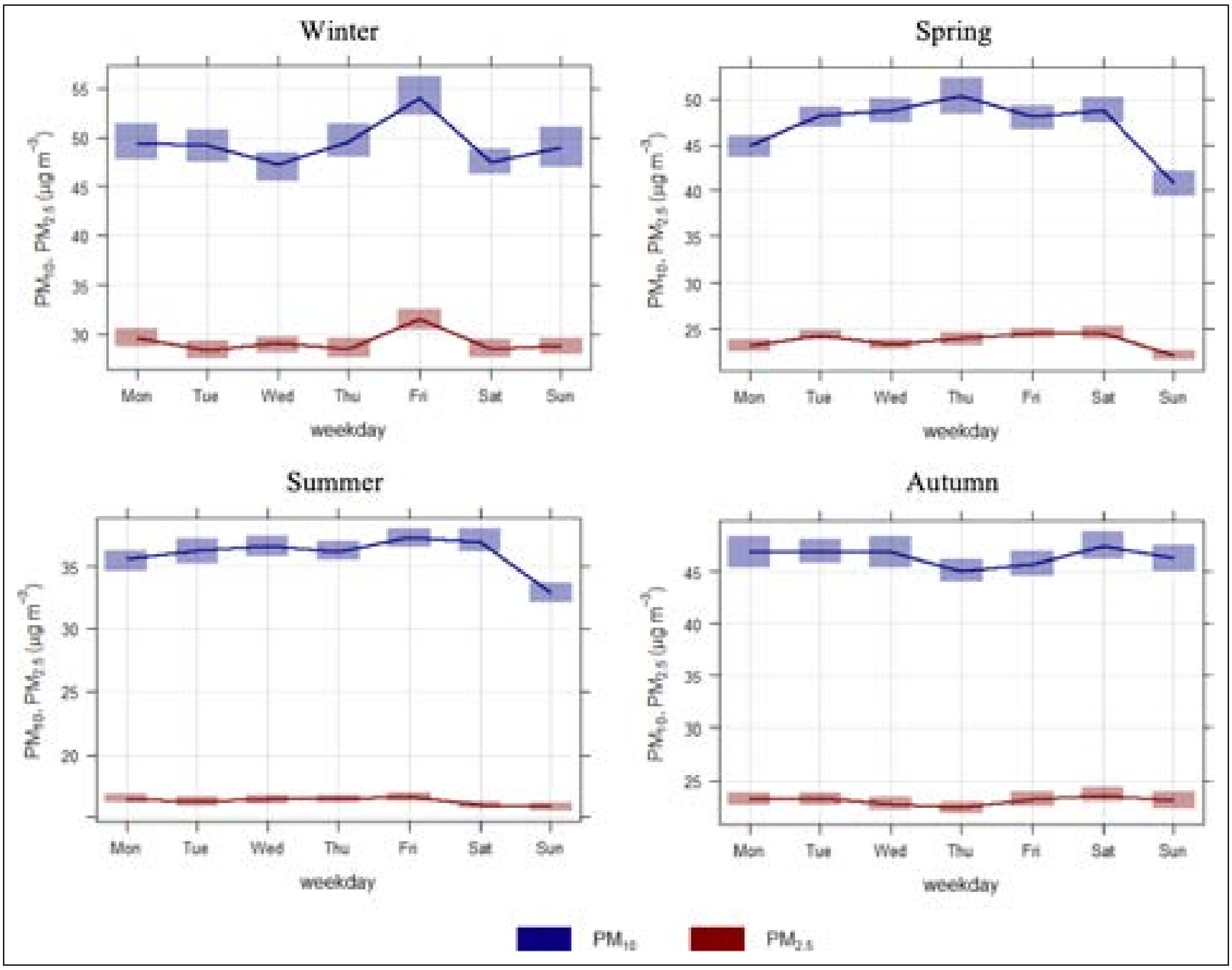


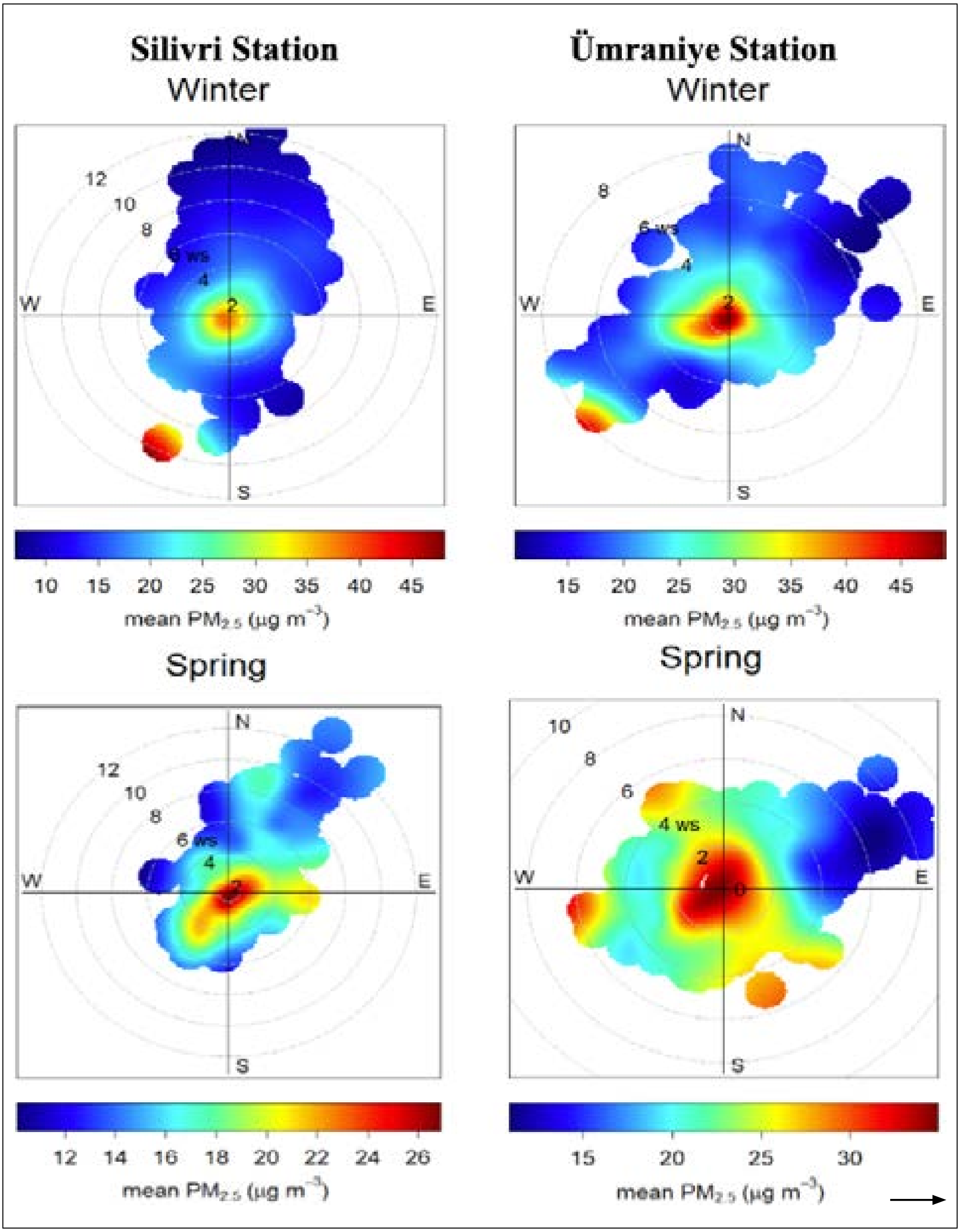
Figure 5. Daily variation of PM_{10} and $PM_{2.5}$ concentrations throughout the period 2014–2020 for Ümraniye Station (the blue lines show the values of PM_{10}, and the red line represents the values of $PM_{2.5}$).

Furthermore, while highest exceedance of limit values occurred in autumn season in Ümraniye Station, in Silivri Station highest exceedance was found in spring season.

In Figure 6, polar plots of PM_{10} and $PM_{2.5}$ are prepared to examine the relationship of pollutant concentrations with wind speed and wind direction. When the polar plots for the $PM_{2.5}$ concentration of Silivri and Ümraniye stations are examined, the highest $PM_{2.5}$ values are measured in winter due to domestic heating, while the lowest values are measured in summer. In winter, when the wind speed is less than 2 m/s, local factors significantly reduce the air quality of the region. In addition, when wind speed increases (2–8 m/s), the $PM_{2.5}$ concentration decreases. This indicates that a decrease in wind speed may restrict the dispersion of particulate matter, resulting in higher concentrations of $PM_{2.5}$. Conversely, an increase in the wind speed can help mitigate the accumulation of particulates, leading to a reduction in $PM_{2.5}$ concentrations. However, as the wind speed continues to escalate, an unexpected resurgence in PM concentration occurs. When the wind speed exceeds 8 m/s, southwestern dust transports increase the amount of particulate matter. In spring, summer and autumn seasons, generally local sources reduce the air quality of Silivri and Ümraniye.

When the polar plots of the PM_{10} values of Silivri and Ümraniye stations are examined, Figure 7 shows that when the wind speed is measured higher than 8 m/s in the winter season, the dust transports from the southwest increase the particulate matter value significantly. Pollution values were measured above the limit value (50 $\mu g/m^3$) for 221 days in winter months, 213 days in spring months, and 234 days in autumn months due to local sources. When the polar plots of the summer season are examined, it is seen that the northerly transports increase the concentration of particulate matter at the Ümraniye station.

Figure 8 shows multiple correlation charts that are plotted to examine the relationship of PM_{10} and $PM_{2.5}$ values with meteorological factors seasonally. The highest negative correlation at Silivri station was calculated as r=-0.56 between $PM_{2.5}$ and wind speed in winter. In other seasons, correlations were found as r=-0.50 (spring), -0.37 (summer-spring). Wind speed is effective in dilution, dispersion and transport of particulate matter and reduces the concentration of particulate matter in the atmosphere. However, when the wind speed exceeds certain values, it can also reduce the air quality by caus-



ing dust transport. In addition, a negative correlation (r=-0.43) was found between relative humidity and PM_{10} in the spring season. On the other hand, a positive correlation was found between especially Tmax values and PM_{10} (r=+0.40) and $PM_{2.5}$ (r=+0.38) in summer.

In Ümraniye station, a negative correlation (r=-0.48) was found between $PM_{2.5}$ and wind speed in autumn and winter seasons. The next highest correlation was calculated between PM_{10} and wind speed in winter (r=-0.38) and between $PM_{2.5}$ and wind speed in spring (r=-0.38).

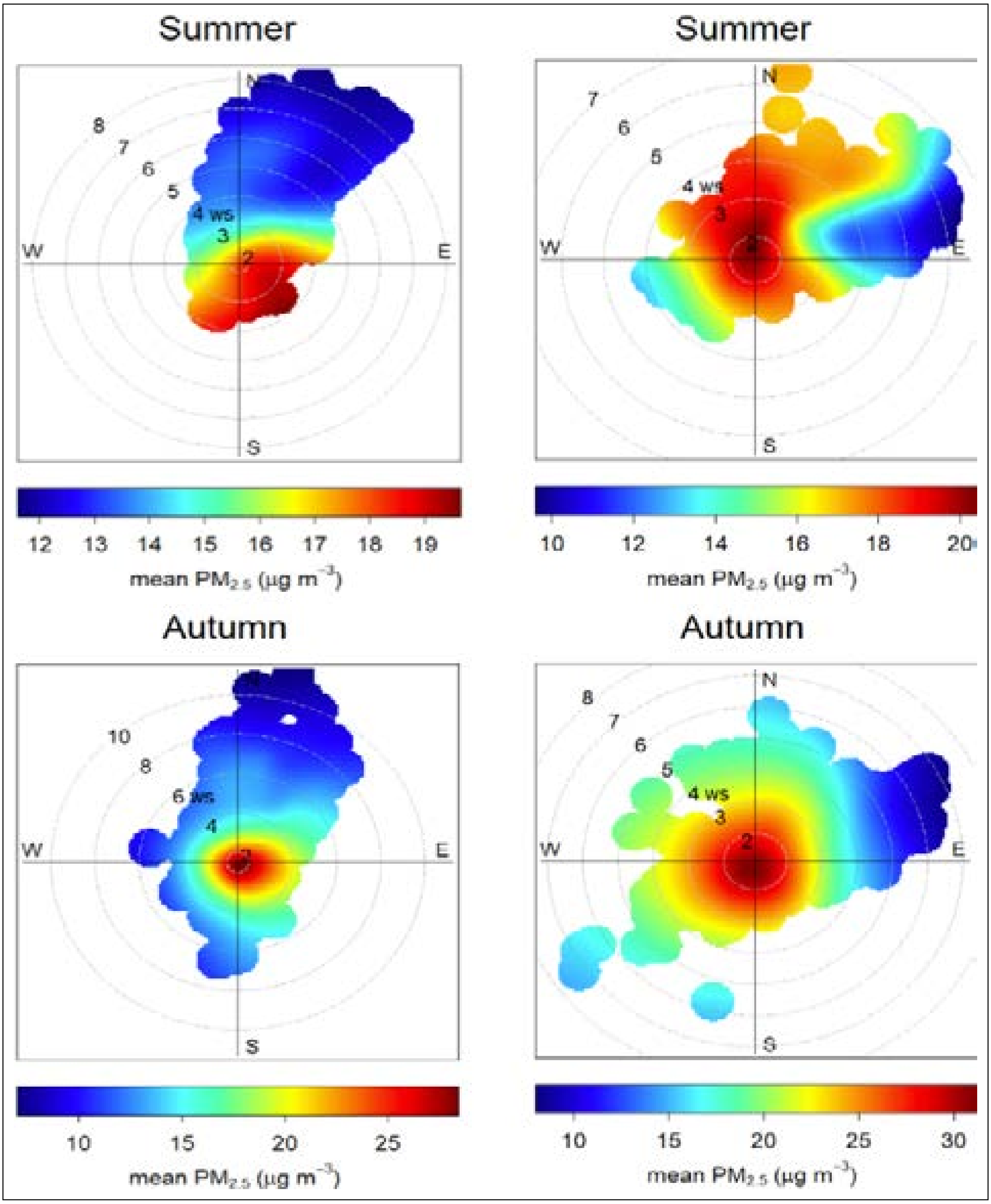
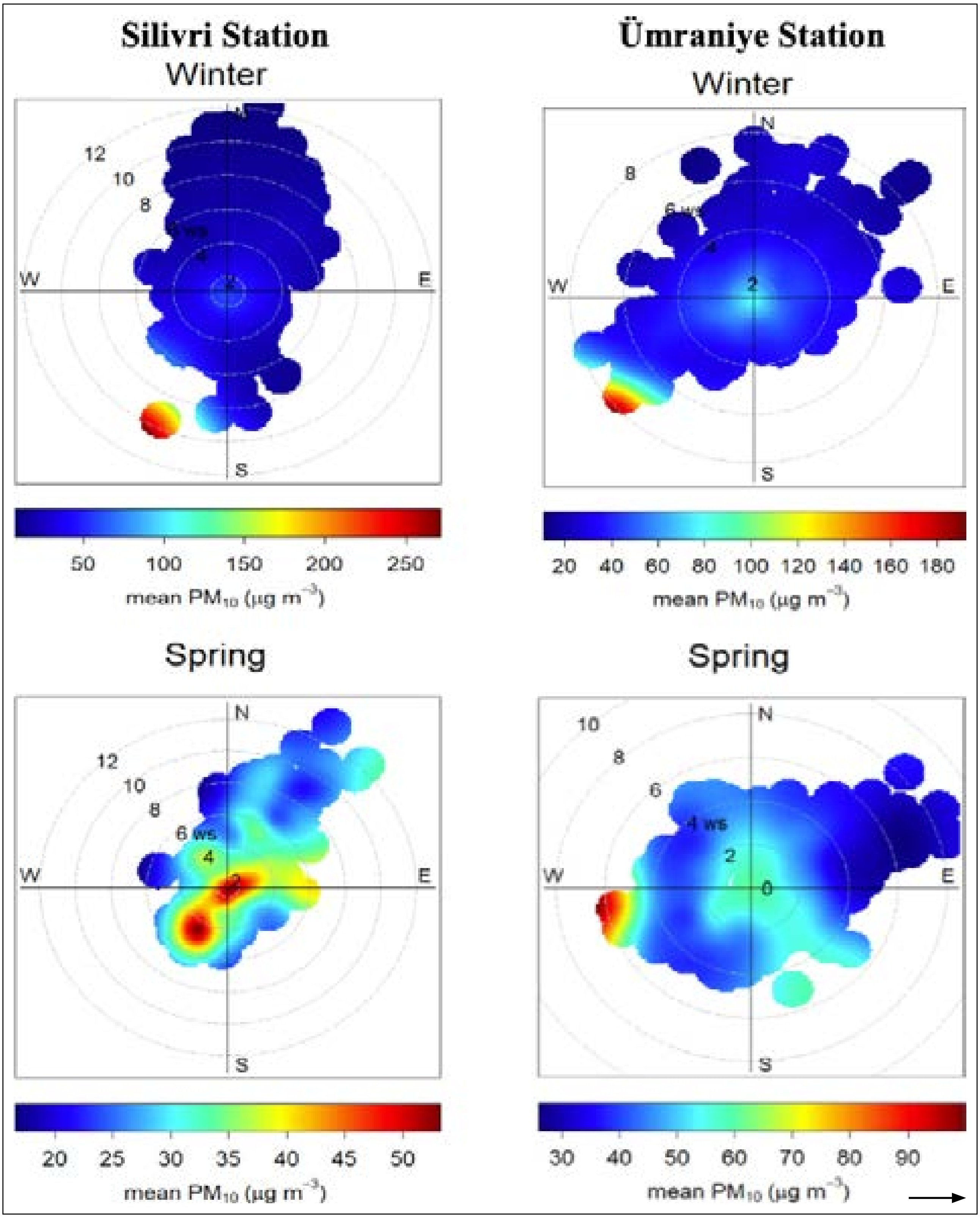


Figure 6. Seasonal polar plots of $PM_{2.5}$ mean concentrations for 2014–2020.

CONCLUSION

In recent years, the air pollutant values measured in İstanbul have risen significantly. The air pollution problem in İstanbul is increasing due to reasons such as population growth,rapid urbanization, vehicle emissions, industrial activities. Industrial and residential areas have various pollutant types and heavy pollutant loads. Air pollution studies carried out in these areas contribute to providing solutions to improve air quality. In this study, relationship between $PM_{2.5}$, PM_{10} and meteorological data (wind speed, wind direction, relative humidity, total precipitation, Tmin, Tmax, temperature) from Silivri and Ümraniye stations in İstanbul were analyzed spatially and temporally for 2014–2020 period.



Diurnal analysis data shows that, the particulate matter concentration peaks between 09:00 and 19:00 LT in all seasons due to anthropogenic reasons such as vehicle emissions and residential heating. The highest particulate matter values were measured at Silivri station on Sundays in winter. At Ümraniye station, highest values were measured on Fridays depending on vehicle emissions. $PM_{2.5}$ values increase depending on local sources and low wind speeds. At speeds higher than 8 m/s, southerly winds increase PM_{10} values at Silivri and Ümraniye stations.

When the relationship between meteorological data and particulate matter for Silivri station in winter was examined, negative correlation (r=-0.56) was found,whereas for Ümraniye in winter season the negative correlation

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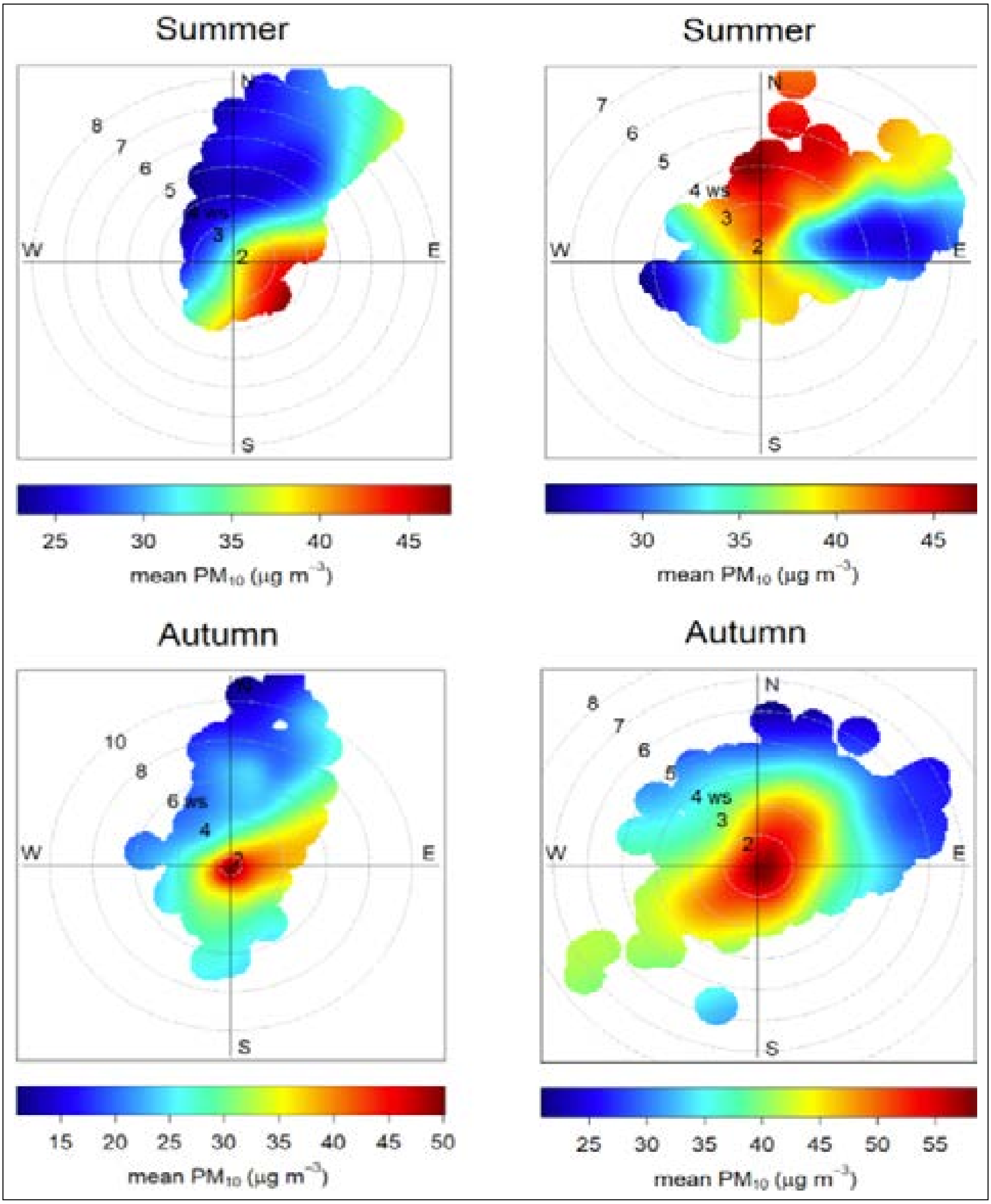

Figure 7. Seasonal polar plots of PM_{10} mean concentrations for 2014–2020.

(r=-0.48) was calculated for $PM_{2.5}$ and significantly weak relationship (r=-0.38) was calculated for PM_{10}. In addition to these, significantly weak correlation (r=-0.43) was found between relative humidity and PM_{10} in Silivri district in spring season. In addition to anthropogenic sources such as industrial activities and residential heating, meteorological factors also affect air quality significantly.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

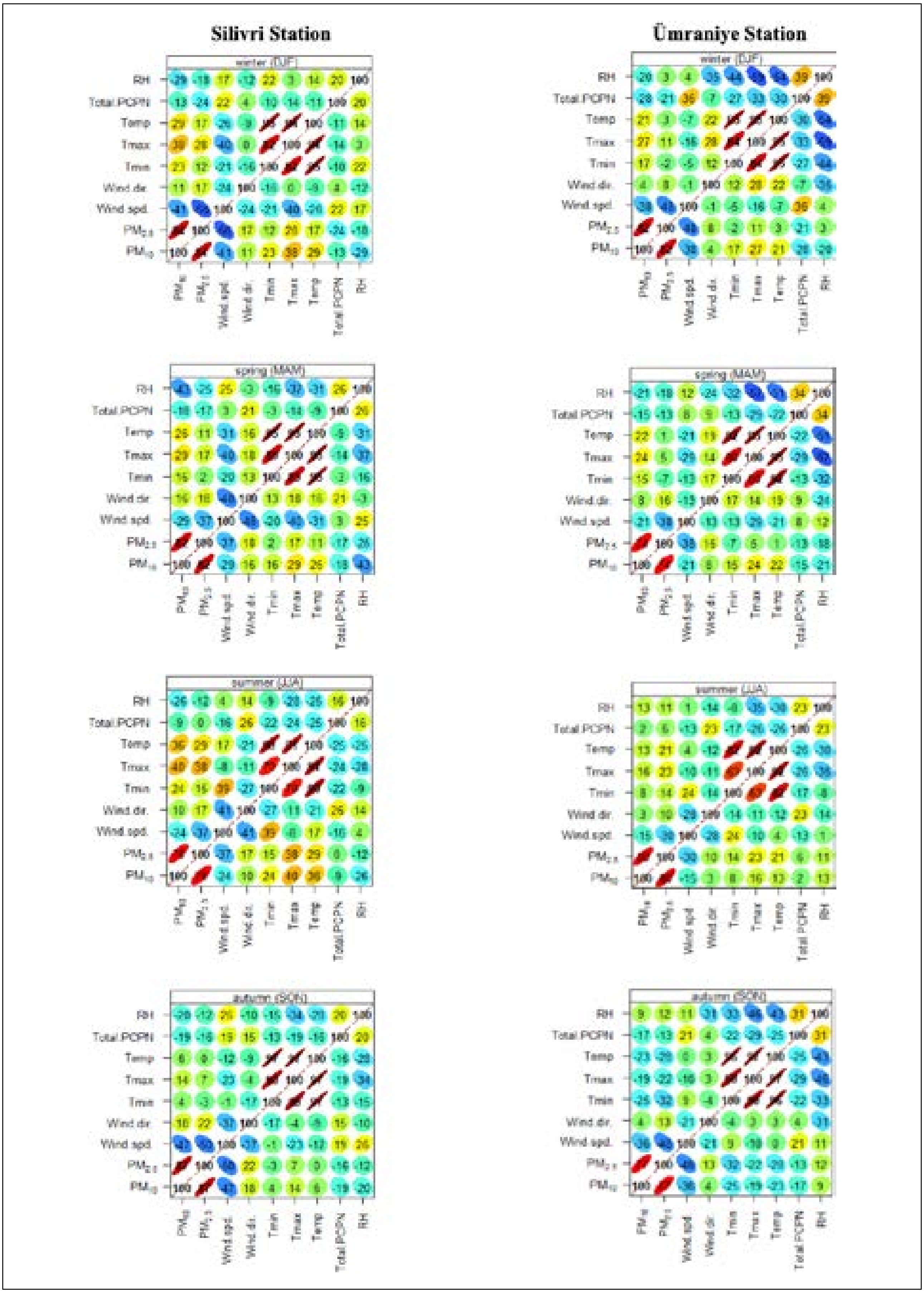

Figure 8. Correlation plots of PM_{10}, $PM_{2.5}$, wind speed, minimum temperature, maximum temperature, total precipitation, relative humidity usingly hourly data from January 2014 to December 2020 in İstanbul.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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