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Statistical analysis of the temporal change of PM10 levels in the city of Sivas (Turkey)

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Abstract
The objective of this study is to statistically examine the variation of PM10 values measured at three stations in the center of Sivas between the years 2016 and 2020. Hourly PM10 measurement values were taken from three different stations (İstasyon Kavşağı, Meteoroloji, and Başöğretmen AQMSs) in the city center. Then the mean values of the measurements obtained between 2016 and 2020 were compared according to the years and the stations, as well as with the limit values given in the Regulation on Air Quality Assessment and Management(RAQAM). Analyses of variance were conducted to determine any differences between PM10 levels and 24-h limit values of PM10 for Turkey and between PM10 values of stations over the years. Considering the 5-year mean values, the mean value of all PM10 concentrations measured in the city center was calculated as 56.36 μg/m^3. No statistical difference was found between the PM10 values measured in 2017 and 2018 at the İstasyon Kavşağı AQMS, and the comparisons of PM10 between stations over the years showed no difference between the Meteoroloji AQMS and the Başöğretmen AQMS in 2019 and 2020. The Spearman's rank-order correlation results of PM10 over the years among the stations in the city showed that the strongest relationship was a moderate one between the years 2019 and 2020 with regard to the İstasyon Kavşağı AQMS. Probable dust transports were examined for the days when PM10 was at its highest, and the conclusion was that desert dust coming from the continent of Africa (south) to the center of Sivas had been effective.

Keywords Air pollution · PM10 · SPSS · Turkey

Introduction

Air pollution is the presence of foreign substances in the atmosphere in solid, liquid, and gaseous forms with concentrations and durations that can harm human health, life, and ecological balance (Müezzinoğlu 2004). Air quality in big cities is inversely proportional to heating, uncontrolled traffic increase, urban sprawl, growth in urban population, decrease in urban forests, and increase in traffic emissions, and all these conditions significantly contribute to increasing air pollution worldwide (Samet et al. 2000; Jacob and Winner 2009; Kulshrestha et al. 2009; Shen et al. 2010; Dall'Osto et al. 2012; Rashki et al. 2013; Pascal et al. 2014; Kim et al. 2015; Von Schneidemesser et al. 2015; Sharma et al. 2016). Air pollution negatively affects the nervous system (Genc et al. 2012), digestive system (Kaplan et al. 2013), and even urinary system (Calderon-Garciduenas et al. 2004) in humans. Air pollution is the cause and aggravating factor of many respiratory diseases such as chronic obstructive pulmonary disease (COPD) (Calderón-Garcidueñas et al. 2008; Oberdörster et al. 2009), asthma (Peters et al. 2006; Oberdörster et al. 2009), and lung cancer (Watson 2006; Craig et al. 2008; MohanKumar et al. 2008; Gold and Samet 2013).

Particulate matter (PM), an air pollutant characterized by the wide physicochemical diversity of atmospheric aerosol components and sources, is the main pollutant in the air (Moreno et al. 2006; Gieré and Querol 2010; Calvo et al. 2013). PM consists of micro-sized particles suspended in the air. Inhalable PM is categorized according to its size (diameter) as coarse (smaller than 10 mm, called PM10), fine (smaller than 2.5 mm, called PM2.5), and very fine (smaller than 0.1 mm) (Mukherjee and Agrawal 2017). PM shows variation in terms of physical properties and chemical

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compositions depending on meteorological conditions and sources of emission (Seinfeld and Pandis 1998). Particulate matter produces different effects on health and climate depending on the concentration of its various components. The main components of particulate matter make up a few percent or even more of the total mass of PM. Depending on location and sources of emission, carbonaceous particles (organic carbon—OC, elemental carbon—EC, and carbonate carbon—CC) make up 50% of the total mass of PM10 and 80% of the total mass of PM2.5, which shows a great biogenic effect. Additionally, inorganic ions contribute 40% of the mass of particulate matter, and trace elements generally represent less than 1% of PM (Szidat et al. 2004; Styszko et al. 2015).

Atmospheric PM10 originates from cars, factories, and fossil fuels and is emitted into the atmosphere (Chen et al. 2013; Kim et al. 2019; Yun and Yoo 2019). Previous studies have shown that particulate matter in the air has an impact on climate change, biogeochemical cycles in ecosystems, cloud formation, visibility, and human health (Nriagu 1988; Nriagu and Pacyna 1988; Dockery et al. 1993; Dockery and Pope 1996; Husar et al. 1997; Broecker 2000; Ramgolam et al. 2009).

Today, most of the world's population is concentrated in urban areas, generally located close to industrial zones. Therefore, determining the share of industrial sources is a great concern as emissions of air pollutants may negatively affect human health by adding toxic elements and compounds to atmospheric pollution (Pope III 2007).

The first objective of this study is to evaluate the temporal nature of PM10 in Sivas between 2016 and 2020 using surface measurements at three locations. It is examined whether the places where these measurements are made comply with the air standards in Turkey or not. The second objective is to statistically examine the variation of PM10 values measured at three stations (according to sources: industry, urban, and traffic) in the center of Sivas between the years 2016 and 2020; examine the similarities, differences, and relationships between and over the years; and determine where the PM10/dust transport to the city center originates from.

Materials and methods

In this study, the objective of which is to figure out the differences or similarities of hourly PM10 concentrations between 2016 and 2020 at three air quality monitoring stations in Sivas; hourly data was converted into daily mean data in order to examine PM10 changes on a yearly basis. Analyses of variance (The Wilcoxon signed-rank test and the Kruskal–Wallis test) were conducted to determine any differences between PM10 levels and 24-h limit values (µg/m^3) (Table 1) of PM10 for Turkey and between PM10 values of stations over the years.

Along with analysis of variance, post hoc multiple comparison tests were used to analyze changes (differences) in pollutant levels in terms of air pollution between 2016 and 2020 and when this pollutant was at their highest and lowest levels over the past 5 years.

PM10 in the regulation on air quality

The current limit values for the PM10 parameter in Turkey are determined according to the provisions of the Regulation on Air Quality Assessment and Management (RAQAM). In Turkey, limit values for air pollutants have been reduced starting from 2009; the limit values for PM10, which were 300 µg/m^3 per day and 150 µg/m^3 per year in 2009 and previous years, were reduced in equal measure until 2014 (Zeydan 2021). In 2019, the PM10 limit value was made equal to those used in European countries. Since 2019, PM10 limit values in Turkey have been 50 µg/m^3 and 40 µg/m^3 for daily and annual periods, respectively (Official Gazette of the Republic of Turkey 2008). Table 1 shows the change in the limit values for PM10 by years. The Regulation on Air Quality Assessment and Management states that the daily limit value for the PM10 parameter cannot be exceeded more than 35 times a year. As the limit values for PM10, the World Health Organization has recommended 50 µg/m^3 as the daily mean and 20 µg/m^3 as the annual mean (European Environment Agency 2020).

Location of the study

With a population of 635.889, according to data from the Turkish Statistical Institute for 2020 (Turkish Statistical Institute (TURKSTAT) (2021)), and a surface area of 28.488 km^2, Sivas is the second largest city of Turkey in terms of land. The city experiences a harsh, continental climate. Winters are cold and severe with a lot of snowfall, and the city is covered in snow for a mean of 4–5 months. Summers in the city are hot, dry, and short, and the spring and autumn months see lots of rainfall (Lale 2008).

Table 1 PM10 limit values for Turkey by years (µg/m^3) (Zeydan 2021)

	2015	2016	2017	2018	2019	2020
24 h	90	80	70	60	50	50
Year	56	52	48	44	40	40

Table 2 Geographical coordinates of the air quality monitoring stations (T.R. Ministry of Environment and Urbanization 2021)

Station name	Latitude	Longitude
Meteoroloji	39° 44′ 37″	37° 00′ 06″
Başöğretmen	39° 44′ 55″	37° 01′ 32″
İstasyon Kavşağı	39° 44′ 50″	37° 00′ 47″

There are three air quality measurement stations in Sivas. Table 2 shows the coordinates of the three air quality monitoring stations in Sivas, and Fig. 1 shows the locations of the stations on the map.

Meteoroloji AQMS is located in a residential area, İstasyon Kavşağı AQMS is located on the street that sees the most intense traffic and human crowds in the city, and Başöğretmen AQMS is located close to an area known as the small industrial site of Sivas. İstasyon Kavşağı AQMS is approximately 1 km away from both Meteoroloji and Başöğretmen AQMS, while Meteoroloji AQMS and Başöğretmen AQMS are 2.09 km away from each other.

The stations were categorized according to their locations with Meteoroloji AQMS being categorized as urban, İstasyon Kavşağı AQMS as traffic, and Başöğretmen AQMS as (small) industrial and then statistically compared with each other. Additionally, the three monitoring stations are in different directions that represent various dominant urban traffic characteristics associated with high, medium, and low densities.

Methodology

Data were categorized in various datasets using spreadsheets (Excel) and statistical analysis software (SPSS V.22) to examine the changes in PM10 concentration over the years.

In the first stage of the study, the general descriptive statistical parameters (means, confidence intervals for the mean at 95% significance level, standard deviations, min/max values) of the air pollutant (PM10) that make up the large data set were calculated.

Determining how the measured PM10 parameter changes annually may be important in terms of understanding the characteristic features of the region where the air quality is analyzed. For this reason, in the second stage of the study, variance analysis tests were conducted on air pollutants and to examine whether there was a difference between the annual changes in pollutants and the changes according to stations. For the statistical tools, namely SPSS (Statistical Package for the Social Sciences), Wilcoxon signed rank, and Kruskal–Wallis tests, $p_{\text{value}} = 0.05$ for probability and its reliability is 95%. $p_{\text{value}} < 0.05$ means there is a difference between the mean of the two global variables and the PM10 concentration, and $p_{\text{value}} \geq 0.05$ means there is a similarity between the mean of the two global variables.

In the third stage of the study, bivariate correlation analyses were performed (Spearman's rank-order correlation) to examine the years of each measured hourly variable and their statistical correlations with each other. In the last stage of the study, the transport of particulate matter and dust to the city center was examined in detail. Because of this, the model on the Barcelona Supercomputing Center software, showing possible dust transports to the center of Sivas on the days

Fig. 1 Locations of the air quality monitoring stations on the map (Google Earth Image© 2019)

with the maximum PM10 value, was used to examine the dust transports to Sivas between 2016 and 2020, and even the dust loads coming from other countries or continents.

Results and discussion

General statistics of PM10 parameter

Table 3 shows the general descriptive statistical parameter means, confidence intervals for the mean at 95% significance level, standard deviations, and min/max values of the air pollutant PM10 that make up the large data set obtained from the three air quality monitoring stations.

Hourly measurement values were taken for each parameter in this study. In order to represent the period covering the last 5 years (2016–2020) with daily and monthly means, 43,848 data required for the measured parameter for each station and a total of 122,614 data obtained from the stations were included in the analysis. Taking into account the 5-year mean value, the mean values of all PM10 concentrations measured were calculated as 53.55, 49.16, and 66.22 μg/m^3 at Başöğretmen, Meteoroloji, and İstasyon Kavşağı AQMS, respectively. Estimations show the mean PM10 at a statistical 95% significance level is between 53.01 and 54.10 μg/m^3 at Başöğretmen AQMS, 48.75 and 49.56 μg/m^3 at Meteoroloji AQMS, and 65.67 and 66.77 μg/m^3 at İstasyon Kavşağı AQMS.

Table 4 shows the highest hourly and daily PM10 levels measured at the three stations in μg/m^3.

All 5-year maximum daily PM10 values in October 2018 were measured, and according to RAQAM, these values for PM10, which has a 24-h limit value of 60 μg/m^3, are approximately 6 to 15 times higher than the legal limit (Official Gazette of the Republic of Turkey 2008). Table 5 shows the maximum daily PM10 values measured at stations over the years and the number of days exceeding the PM10 limit value permitted in RAQAM.

It is important to examine what parameters air pollution in city centers consists of and how those parameters change over the years. Figure 2 consists of the graphs showing the daily PM10 distributions of the three stations in the city center where measurements were taken for the 5-year period (2016–2020).

The months with the highest mean PM10 concentrations in the 5-year measurement period at the air quality monitoring stations were determined as November 2016 with 126.01 μg/m^3 at Başöğretmen AQMS, November 2019 with 96.86 μg/m^3 at Meteoroloji AQMS, and November 2016 with 115.74 μg/m^3 at İstasyon Kavşağı AQMS. Looking at graph 2, PM10 values vary from day to day. In

Table 3 General descriptive statistics of PM10 pollutant by stations

		Başöğretmen AQMS	Meteoroloji AQMS	İstasyon Kavşağı AQMS
Mean (μg/m^3)		53.55	49.16	66.22
Confidence intervals for the mean at 95% significance level	Lower limit (μg/m^3)	53.01	48.75	65.67
	Upper limit (μg/m^3)	54.10	49.56	66.77
Standard deviation (μg/m^3)		55.72	41.97	57.17
Minimum (μg/m^3)		0.24	0.02	0.00
Maximum (μg/m^3)		3554.02	779.14	4766.95
Interval (μg/m^3)		3553.78	779.12	4766.95
Number of data		40,202	41,041	41,371

Table 4 The highest hourly and daily PM10 levels measured at the three stations (μg/m^3)

The highest hourly PM10 level			
Date of measurement	Time of measurement	Station	$PM10_{max}$ (μg/m^3)
16.10.2018	01:00	Başöğretmen AQMS	3554.02
15.10.2018	21:00	Meteoroloji AQMS	779.14
16.10.2018	01:00	İstasyon Kavşağı AQMS	4766.95
The highest daily PM10 level			
Date of Measurement	Day	Station	$PM10_{max}$ (μg/m^3)
16.10.2018	Tuesday	Başöğretmen AQMS	723.08
16.10.2018	Tuesday	Meteoroloji AQMS	365.78
16.10.2018	Tuesday	İstasyon Kavşağı AQMS	927.52

Table 5 The maximum daily PM10 values (µg/m^3) measured at stations and the number of days exceeding the permitted limit value

Year	Station	PM10$_{max}$ (µg/m^3)	Date	The number of days exceeding the PM10 limit value permitted in RAQAM
2016	Başöğretmen AQMS	316.82	26.11.2016	66
	Meteoroloji AQMS	194.23	7.11.2016	38
	İstasyon Kavşağı AQMS	198.27	26.11.2016	118
2017	Başöğretmen AQMS	417.96	23.04.2017	122
	Meteoroloji AQMS	240.15	21.12.2017	80
	İstasyon Kavşağı AQMS	401.16	25.10.2017	158
2018	Başöğretmen AQMS	723.08	16.10.2018	83
	Meteoroloji AQMS	365.78	16.10.2018	108
	İstasyon Kavşağı AQMS	927.52	16.10.2018	153
2019	Başöğretmen AQMS	170.34	28.01.2019	121
	Meteoroloji AQMS	177.06	23.11.2019	111
	İstasyon Kavşağı AQMS	260.08	28.01.2019	186
2020	Başöğretmen AQMS	153.05	19.02.2020	89
	Meteoroloji AQMS	129.55	28.11.2020	91
	İstasyon Kavşağı AQMS	174.99	19.02.2020	156

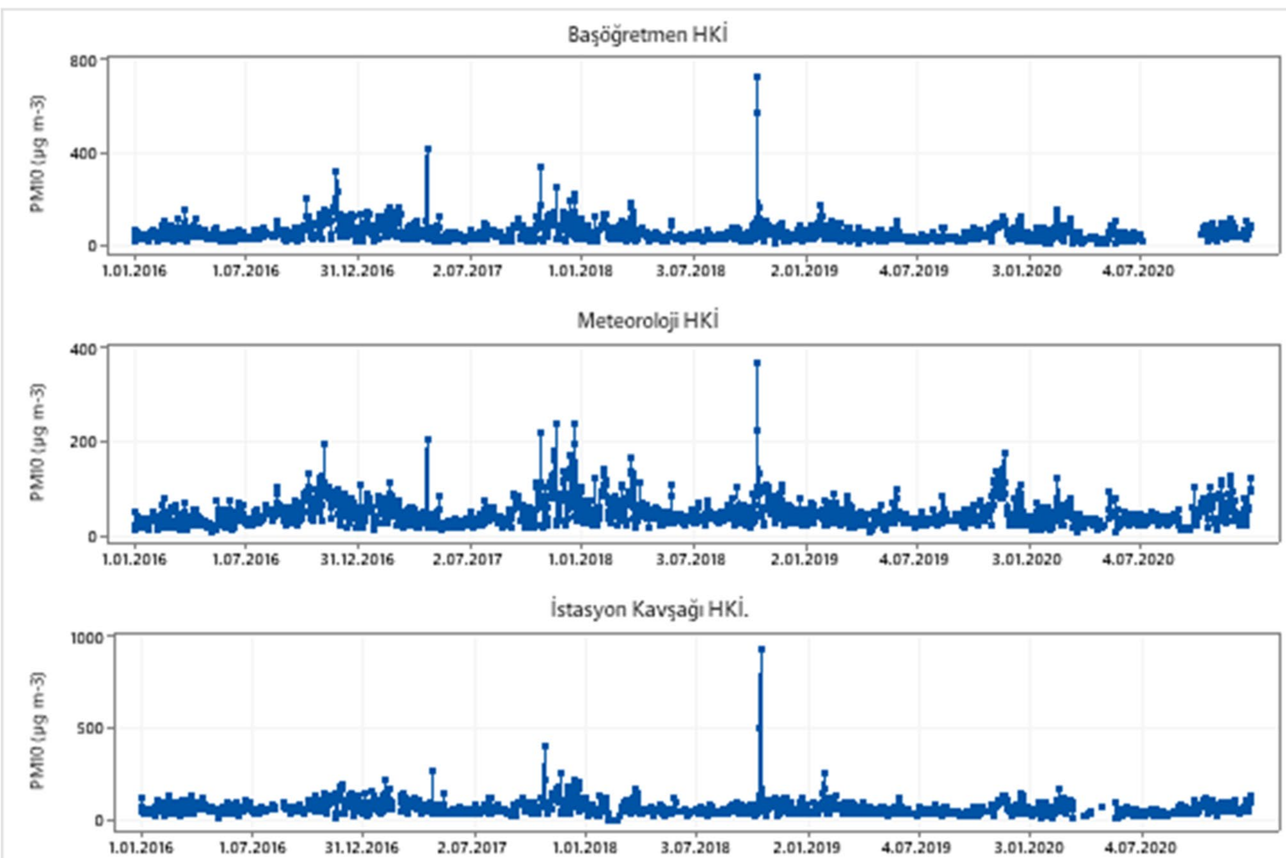

Fig. 2 Graphs showing the daily PM10 distributions of the three stations in the city center where measurements were taken for the 5-year period (2016–2020)

general, it is seen that PM10 levels in Sivas are lower in hot months than in cold months.

Distribution of PM10 by years and analysis of variance

At this stage of the study, hourly data were converted to daily mean data to examine PM10 changes over the years. Analyses of variance (the Wilcoxon signed-rank test and the Kruskal–Wallis test) were conducted to determine any differences between PM10 levels and 24-h limit values (μg/m^3) (Table 1) of PM10 for Turkey and between PM10 values of stations over the years.

Table 6 presents the results of variance analyses and descriptive statistics showing the changes in PM10 over years based on evaluations.

Wilcoxon signed-rank test revealed that the comparison between the PM10 pollutant measured at stations in three different locations and the 24-h limit values in Table 1 showed that there were differences between stations in the relevant years ($p_{value} < 0.05$), except for the years 2017 ($p = 0.06$) and 2018 ($p = 0.08$) at İstasyon Kavşağı AQMS. The measurement results of the stations for the same years were also compared with the Kruskal–Wallis test. As a result of the statistical test, the station values for all years were determined to be different from one another and the difference between them was statistically significant at 95% significance level ($p = 0.00$).

In addition to the results of variance analyses and descriptive statistics showing the changes in PM10 over years, the PM10 changes of previous years were also analyzed. Along with analysis of variance, post hoc multiple comparison tests were used to analyze changes (differences) in pollutant levels between 2016 and 2020 and when those pollutants were at their highest and lowest levels over the past 5 years (Table 7).

According to the PM10 statistics for the years presented in Tables 6 and 7 and the Kruskal–Wallis analysis selected for the post hoc multiple comparison test, the highest annual mean of PM10 levels was measured in 2017 and the lowest annual mean in 2020 at Başöğretmen AQMS, and Wilcoxon signed-rank test results showed that the annual mean values were not equal to each other ($p_{value} = 0.000$). According to the post hoc/Kruskal–Wallis comparison test, a difference was observed between all years and the difference between them was determined to be statistically significant at 95% significance level ($p_{Bonferroni} = 0.000$).

The highest annual mean of PM10 levels was measured in 2018 and the lowest annual mean in 2020 at Meteoroloji AQMS, and Wilcoxon signed-rank test results showed

Table 6 Analysis of variance of PM10 by stations and time

Year	Station	*N*	Mean	Confidence interval for 95% mean		Standard deviation	Min	Max	Wilcoxon signed-rank test sig
				Lower limit	Upper limit				
2016	Başöğretme*n*	8111	58.686	57.485	59.886	55.147	1.31	1645.48	0.000
	Meteoroloji	8287	46.950	46.193	47.707	35.144	0.02	756.62	0.000
	İstasyon K	8400	71.713	70.723	72.702	46.252	2.87	461.46	0.000
	Kruskal–Wallis test $p_{value} = 0.000$								
2017	Başöğretmen	8667	64.293	63.005	65.581	61.184	1.81	1658.15	0.000
	Meteoroloji	8559	53.177	52.106	54.248	50.539	1.16	612.38	0.000
	İstasyon K	8349	78.966	77.701	80.231	58.970	0.74	920.79	0.061*
	Kruskal–Wallis test $p_{value} = 0.000$								
2018	Başöğretmen	8687	51.483	49.923	53.043	74.167	0.49	3554.02	0.000
	Meteoroloji	8293	55.771	54.804	56.737	44.918	4.00	779.14	0.000
	İstasyon K	8714	62.747	60.974	64.521	84.439	0.00	4766.95	0.084*
	Kruskal–Wallis test $p_{value} = 0.000$								
2019	Başöğretmen	8355	46.451	45.711	47.191	34.504	0.82	315.28	0.000
	Meteoroloji	7832	47.467	46.593	48.342	39.473	0.03	495.54	0.000
	İstasyon K	8598	59.822	58.986	60.658	39.528	1.13	334.43	0.000
	Kruskal–Wallis test $p_{value} = 0.000$								
2020	Başöğretmen	6382	44.549	43.691	45.407	34.967	0.24	341.47	0.000
	Meteoroloji	8070	42.013	41.234	42.792	35.706	0.17	570.38	0.000
	İstasyon K	7310	57.027	56.180	57.874	36.932	2.67	286.70	0.014
	Kruskal–Wallis test $p_{value} = 0.000$								

N, number of data. * The difference is not statistically significant at the 95% significance level

Table 7 Post hoc/Kruskal–Wallis test results showing comparisons of PM10 by year

Station	Year	2019 Sig.*	2018 Sig.*	2017 Sig.*	2016 Sig.*
Başöğretmen	2020	.000	.000	.000	.000
	2019		.000	.000	.000
	2018			.000	.000
	2017				.000
Meteoroloji	2020	.000	.000	.000	.000
	2019		.000	.006	1.000
	2018			.000	.000
	2017				.023
İstasyon K	2020	.000	.000	.000	.000
	2019		.218	.000	.000
	2018			.000	.000
	2017				.000

*Significance values were corrected with the Bonferroni correction ($p_{\text{Bonferroni}} = 0.05/10 = 0.005$) for replicate tests

Table 8 Post hoc/Kruskal–Wallis test results showing comparisons of PM10 between stations over years

	2016 Sig.*	2017 Sig.*	2018 Sig.*	2019 Sig.*	2020 Sig.*
Meteoroloji-Başöğretmen	.001	.000	.000	.556	1.000
Meteoroloji-İstasyon K	.000	.000	.001	.000	.000
Başöğretmen-İstasyon K	.000	.000	.000	000	.000

*Significance values were corrected with the Bonferroni correction ($p_{\text{Bonferroni}} = 0.05/3 = 0.017$) for replicate tests

that the annual mean values were not equal to each other ($p_{\text{value}} = 0.000$). According to the post hoc multiple comparison test, a difference was observed between at least 2 years and the difference between them was significant. The results of the post hoc bivariate comparison test that was conducted to understand from which years the difference originated revealed that in terms of PM10 values, there was not a statistically strong difference between 2016 and 2019 ($p_{\text{Bonferroni}} > 0.005$) only, and although there were numerical differences between 2016–2017 and 2017–2019, there was no statistical difference ($p_{\text{Bonferroni}} > 0.005$).

The highest annual mean of PM10 levels was measured in 2017 and the lowest annual mean in 2020 at İstasyon Kavşağı AQMS, and Wilcoxon signed-rank test results showed that the annual mean values were not equal to each other ($p_{\text{value}} < 0.05$). According to the post hoc multiple comparison test, a difference was observed between at least 2 years and the difference between them was significant. The results of the post hoc bivariate comparison test that was conducted to understand from which years the difference originated revealed that in terms of PM10 values, there was not a statistical difference between 2018 and 2019 ($p_{\text{Bonferroni}} > 0.005$) only.

The values measured at the stations over the years were not equal to each other ($p_{\text{value}} = 0.000$) and the differences between them were determined to be significant. According to the post hoc bivariate comparison test, station measurements showed that there was no difference between Meteoroloji AQMS and Başöğretmen AQMS in 2019 and 2020 ($p = 0.556$ and $p = 1.00$, respectively), and that there were differences between PM10 values of the other stations by years ($p = 0.00$ and $p = 0.01$) (Table 8).

Correlations of PM10 by years

The PM10 values measured at stations over the years were evaluated with the Kolmogorov–Smirnov test for normality. As a result of the normality tests performed for all measured years and all stations, the data in all series did not comply with the normal distribution ($p < 0.05$). Spearman rank-order correlation analysis was performed on these series that did not conform to the normal distribution (Özdamar 2013), and Table 9 shows the respective coefficients.

The correlation coefficient is a ratio and a value between -1 and $+1$. When the correlation coefficient is $-0.3 < r < 0.3$, the relationship between factors is considered to be "weak association." When this value is $0.3 < r < 0.7$ or between -0.7 $r-0.3$, the relationship between factors is considered to be "moderate association." When the correlation coefficient is greater than 0.7 or less than -0.7, the relationship between factors is considered to be "strong association." The Spearman's rank-order correlation results of PM10 over the years among the stations in the city showed that at İstasyon Kavşağı AQMS, there was a moderate association between 2016–2019 ($r = 0.311$, $p = 0.00$), 2017–2020 ($r = 0.310$, $p = 0.00$), and 2019–2020 ($r = 0.352$, $p = 0.00$). However, a weak association was found between PM10 values measured at Başöğretmen AQMS and Meteoroloji AQMS over all years.

PM10 and dust transport modeling

Dust transport event is an important meteorological disaster. Presence of dust transport adversely affects the environment, living and human health, and the effects of climate change. In order to mitigate the effects of all these, analysis and early warning of dust transport are crucial for risk reduction and resilience (Oğuz and Pekin 2019). According to the highest PM10 concentrations measured in these three stations in Sivas in the last 5 years (Table 5), dust transports from the surrounding area are important for monitoring the extraordinary circumstances of the days when PM10 is highest, and they seem to be impactful at times (Mutlu 2019).

Table 9 Results of the Spearman's rank-order correlation

Station	Year		2016	2017	2018	2019	2020
Başöğretmen AQMS	2016	Correlation coefficient (r)	1.000	0.213*	0.199*	0.273*	0.242*
		p_{value}		0.000	0.000	0.000	0.000
	2017	Correlation coefficient (r)	0.213*	1.000	0.192*	0.235*	0.218*
		p_{value}	0.000		0.000	0.000	0.000
	2018	Correlation coefficient (r)	0.199*	0.192*	1.000	0.265*	0.170*
		p_{value}	0.000	0.000		0.000	0.000
	2019	Correlation coefficient (r)	0.273*	0.235*	0.265*	1.000	0.258*
		p_{value}	0.000	0.000	0.000		0.000
	2020	Correlation coefficient (r)	0.242*	0.218*	0.170*	0.258*	1.000
		p_{value}	0.000	0.000	0.000	0.000	
Meteoroloji AQMS	2016	Correlation coefficient (r)	1.000	0.148*	0.073*	0.154*	0.195*
		p_{value}		0.000	0.000	0.000	0.000
	2017	Correlation coefficient (r)	0.148*	1.000	0.098*	0.171*	0.130*
		p_{value}	0.000		0.000	0.000	0.000
	2018	Correlation coefficient (r)	0.073*	0.098*	1.000	0.184*	0.102*
		p_{value}	0.000	0.000		0.000	0.000
	2019	Correlation coefficient (r)	0.154*	0.171*	0.183*	1.000	0.174*
		p_{value}	0.000	0.000	0.000		0.000
	2020	Correlation coefficient (r)	0.195*	0.130*	0.102*	0.174*	1.000
		p_{value}	0.000	0.000	0.000	0.000	
İstasyon Kavşağı AQMS	2016	Correlation coefficient (r)	1.000	0.199*	0.249*	0.311*	0.260*
		p_{value}		0.000	0.000	0.000	0.000
	2017	Correlation coefficient (r)	0.199*	1.000	0.223*	0.290*	0.310*
		p_{value}	0.000		0.000	0.000	0.000
	2018	Correlation coefficient (r)	0.249*	0.223*	1.000	0.255*	0.238*
		p_{value}	0.000	0.000		0.000	0.000
	2019	Correlation coefficient (r)	0.311*	0.290*	0.255*	1.000	0.352*
		p_{value}	0.000	0.000	0.000		0.000
	2020	Correlation coefficient (r)	0.260*	0.310*	0.238*	0.352*	1.000
		p_{value}	0.000	0.000	0.000	0.000	

*The correlation coefficient at the significance level is $p_{value} < 0.01$ (the difference is statistically significant at 99% significance level)

The main objective at this stage of the study is to examine and analyze the effects of dust particles in the city with satellite and ground-based observations, in addition to the "Barcelona Supercomputing Center Dust Regional" dust transport prediction model, while keeping in mind the sample dust transport events that have been identified. Dust transport forecasts were created for North Africa, the Middle East, and Europe with the Barcelona Supercomputing Center prediction model and the software developed based on it. Figure 3 shows the dust transport patterns created by the Barcelona Supercomputing Center (WMO 2020) for the days between 2016 and 2020 with the maximum PM10 value.

To be able to expertly analyze the dust and particulate matter transport, the model developed for Eastern Europe and the Middle East region should be put into effect at least 2 to 3 days before the first day of study and the dust transport should be examined in detail. Accordingly, the dust transport models developed for the city of Sivas were started 2 days in advance of the dates in the study, and dust loads from other countries or continents were examined using the data from the software.

The possible dust transports to the center of Sivas for the days when PM10 was the highest were examined using the software created by Barcelona Supercomputing Center, and on 26 November 2016, the particulate matter came from the provinces to the west and south-west of Sivas; to the cities where the transport to the center of Sivas originated, the particulate matter is estimated to have come from Syria, Lebanon, Israel, and Egypt. Examinations using the dust transport model showed that on 23 April 2017, dust transport originated from cities in the west, south-west, south, and east and came to those cities from the African continent (Table 10).

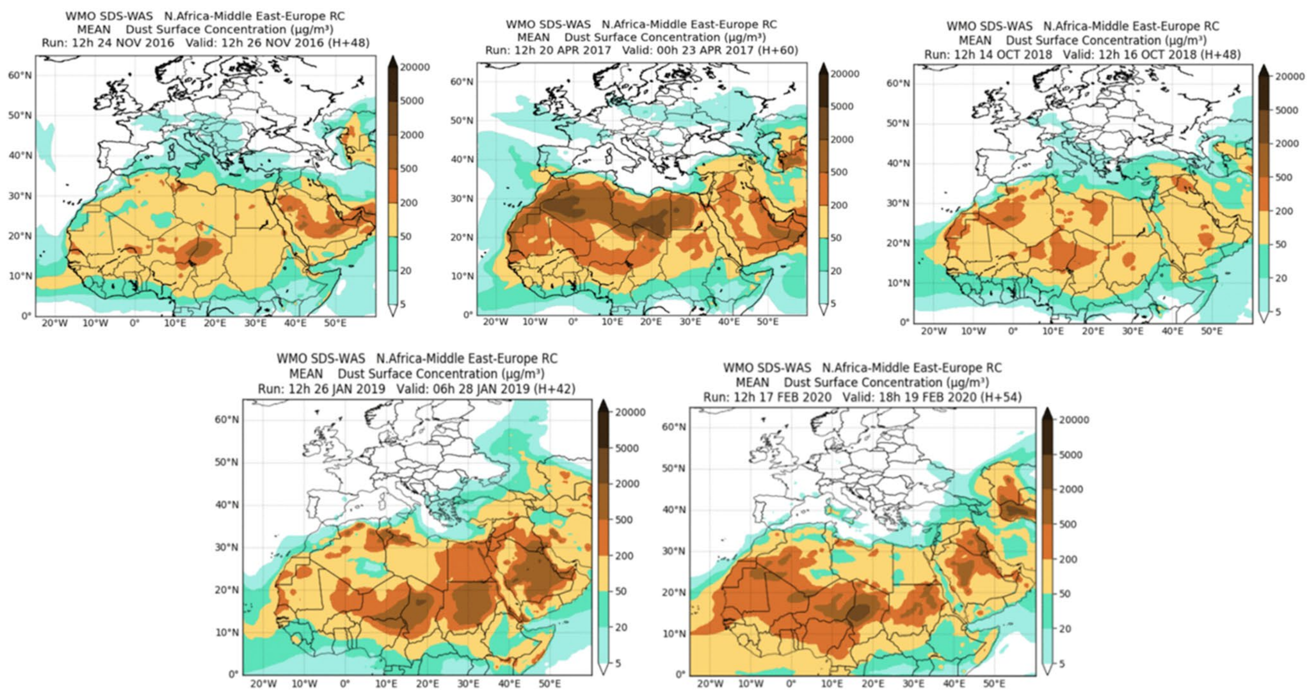

Fig. 3 Dust transport patterns for the days between 2016 and 2020 with the maximum PM10 value

Table 10 Possible dust transports to the center of Sivas on the days between 2016 and 2020 with the maximum PM10 value according to the Barcelona Supercomputing Center software

Years	Regions where dust transport may come from	Countries where dust transport to the center is possible
26 November 2016	From cities to the west and south-west of Sivas	Syria, Lebanon, Israel, and Egypt
23 April 2017	From cities to the south-west, south, and east of Sivas	From Syria, Iraq, and Iran
16 October 2018	From cities to the south-east and east of Sivas	From Syria, Iraq, and Iran
28 January 2019	From cities to the west of Sivas	From Libya and Egypt
19 February 2020	From cities to the east of Sivas	From Syria and Iraq

Results and discussion

This study was conducted to figure out the differences or similarities of hourly PM10 concentrations between 2016 and 2020 at three air quality monitoring stations in Sivas. The hourly PM10 values measured at the stations in the center of the city of Sivas were observed to have increased for all three stations between 2016 and 2017, and decreased in the following years. One of the reasons for the observed decrease in the PM10 values may be the decline in fossil fuel consumption and the increase in the use of natural gas in the city (Çetin and Demirci 2016). Additionally, in 2020, as part of the COVID-19 restrictions, the Turkish government imposed temporary, complete, and partial curfews, industrial production was halted, domestic and international travel was restricted, and use of private vehicles and public transport decreased. The extraordinary circumstances may be noted as another reason for the possible reduction in air pollution and the decrease in PM10 levels in 2020.

An examination of the number of days exceeding the limit value permitted in RAQAM reveals that the PM10 24-h limit value was gradually reduced from 80 μg/m^3 in 2016 to 50 μg/m^3 in 2019. The data show that PM10 pollution increased between 2016 and 2017, and the number of days that exceeded the permitted limit value for PM10 in 2017 increased due to the reduction of the permitted limit value in the current regulation. However, there was no proportional course between the PM10 values measured in other years and the number of days that exceeded the permitted limit value after the PM10 limit values in the regulation was reduced. The city of Sivas seems to exceed the PM10 limit values specified in the regulation. This could suggest that the PM10 parameter plays a significant role in Sivas in terms of air pollution.

The evaluations made in this section have been made considering the RAQAM limit values for PM10 and SO2. It is clear that this situation aims to protect human health in the most effective way. In a similar study, it was calculated that the limit value given according to RAQAM exceeded 31.9% of the year for PM10 between 2010 and 2019 in Nevşehir (Oğuz 2020). In a similar study, it was reported that PM10 exceeded 47.2% days of the year, according to the limit values recommended by RAQAM between 2015 and 2017 in Siirt province (Alkan 2018). Considering the changing conditions over the years, according to RAQAM, the PM10 values at the three stations in Sivas, where the measurements were obtained, exceeded the limit values on a mean of 23.9% days out of the year in Meteoroloji AQMS, 28.2% in Başöğretmen AQMS, and 43.1% in İstasyon Kavşağı AQMS. The calculations show that according to EU standards, the PM10 values at the three stations in Sivas, where the measurements were obtained, exceeded the 24-h limit value of 50 µg/m^3, 37.6% of the year at Meteoroloji AQMS, 40.8% at Başöğretmen AQMS, and 63.9% at İstasyon Kavşağı AQMS. Additionally, a comparison between years showed that 2020 was the lowest year for all three stations in terms of mean PM10 concentrations. Despite this decrease in PM10 parameter in view of the standards in Turkey in 2020, the annual permitted limit value (annual mean 40 µg/m^3) appears to have been exceeded and the daily permitted limit value (mean 50 µg/m^3 and maximum 35 times a year) appears to have been exceeded 2.5–4.5 times more.

In a study conducted in Balıkesir between 2014 and 2018, no difference was observed between the PM10 levels between 2014 and 2018 ($p > 0.05$) at the measuring station. Between the other years, PM10 levels were found to be different from each other ($p < 0.05$) (Mutlu 2019). A study conducted in Los Angeles showed a very good year-round correlation ($r^2 = 0.80$) in the coastal region (LDS and GRD) in West Los Angeles. Also, a relatively weak correlation ($r^2 = 0.46$) was found between the two stations, although the distance between the 2 measurement stations in the semi-rural area (VBR and GRA sites) in Los Angeles was less than 3 km (Pakbin et al. 2010).

As a result of statistical estimations, the values measured at all three stations were found to have differed ($p_{value} < 0.05$) within their respective years. Post hoc/Kruskal–Wallis test showed that the measurements were different between all years at Başöğretmen AQMS ($p < 0.05$), that there was no difference for 2016–2017 and 2016–2019 at Meteoroloji AQMS ($p_{Bonferron} > 0.005$), and that there was no difference for 2018–2019 at İstasyon Kavşağı AQMS ($p_{Bonferroni} > 0.005$), while the other years showed difference among themselves ($p_{Bonferroni} < 0.005$). Statistical estimations of station measurements within the years have shown that there was no difference between the measurements of Meteoroloji AQMS and Başöğretmen AQMS in 2019 and 2020 ($p_{Bonferroni} > 0.017$), but that there was a difference between the measurements of the stations in other years ($p_{Bonferroni} < 0{,}017$). After the discovery of differences between the years within the stations, a correlation analysis was performed and a significantly weak association was found, but could no strong associations were revealed. The strongest association ($r = 0.352$) was estimated to have been between the years 2019 and 2020. For variance statistics estimations, the low level of association revealed by the correlation analysis due to the differences in the values at all stations among years indicates compatibility.

The model on the Barcelona Supercomputing Center software, showing possible dust transports to the center of Sivas on the days with the maximum PM10 value, was used to examine the dust transports to Sivas between 2016 and 2020, and even the dust loads coming from other countries or continents. There seems to be need for improvement of the current dust transport models in order to be able to acquire more information about particulate matter and dust transport in Sivas.

Since Turkey is a country that may be exposed to desert dust due to its location, this study is important in order to determine the effect of transport. In a study, it was aimed to evaluate the desert dust transport that affected Hatay and its surroundings in September 2015. It has been concluded that the deserts in Iraq and Syria at an altitude of 1500 m to Turkey, and the deserts of Saudi Arabia, Jordan, and Syria at an altitude of 3000 m form the source area as a result of long-distance transport (Topuz and Karabulut 2017). Within the scope of the examined model, estimations suggest that dust transport mostly originates from the neighboring cities to Sivas, and that to those neighboring cities, desert dusts are transported especially from neighboring countries of Syria, Iraq, and Iran as well as African countries such as Israel, Egypt, and Libya. With the HYSPLIT model analysis, it was concluded that the desert dusts were transported from the center of the source area to the surrounding areas at a long distance.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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