TEMPORAL AND SPATIAL ANALYSIS OF PM_{10} AND SO_2 CONCENTRATION WITH THE USE OF GIS IN SOUTHEASTERN ANATOLIA REGION CITIES OF TURKEY (2010-2020)

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Abstract. This study aims to determine the effect of the mandatory use of natural gas for heating to prevent air pollution in 2020 in 9 provinces in the Southeast Anatolian Region (SAR), the fastest developing region of Turkey, that were using coal for heating in 2010. Monthly PM_{10} and SO_2 concentrations of SAR provinces in 2010 and 2020 were analysed and evaluated by means of GIS-IDW mapping method. As a result of the 12-month evaluation, it was determined that the use of natural gas, especially in the winter months, reduced the PM_{10} and SO_2, while it didn't reduce the amount of SO_2 in provinces with high population growth and increased number of vehicles (an increase of 288% in vehicles in Kilis and an increase of 35% in population in Sanliurfa). Regarding Turkey's SAR border provinces, it was determined that PM was transported atmospherically from the Sahara, Syrian and Arabian Peninsula desert in the spring and autumn months both in 2010 and 2020, and therefore an increase was found in PM_{10} by the HYSPLIT model. The countries are recommended to measure the PM_{10} and SO_2 daily, which directly affect human health, create maps and develop policies to reduce the values.
Keywords: *air pollutants, particulate matter (PM), Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model, Southeast Anatolian Region (SAR)*

Introduction

Clean air is one of the fundamental prerequisites of human health. However, in the age of economic development, air pollution has been and continues to be a serious threat to health around the globe. The causes of air pollution include economic development, urbanization, energy consumption, transportation, and motorization (Chen and Kan, 2008).

Air pollution problem has recently been one of the biggest problems in most of the developed and developing countries (Gorai et al., 2018). The main environmental pollutants that cause diseases and deaths worldwide are particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon monoxide (CO), respectively (Zhu et al., 2019; Fischer et al., 2020). PM is considered as an important component of ambient air, as it plays a vital role in human health and air quality. PM with aerodynamic diameters less than 10 $\mu g/m^3$ is called PM_{10} (Talbi et al., 2018). Particulate matter (PM_{10} and $PM_{2.5}$) is the most harmful and dangerous part of aerosol pollutants because of inhalation risks (Zeydan, 2021). In urban areas, airborne PM is considered a strong air pollutant. Industries, coal and biomass incineration, vehicles, and oil sources are among the largest sources of PM_{10} (Li et al., 2018). Like most pollutants, SO_2 has both natural and anthropogenic sources (Ray and Kim, 2014). On a global scale, SO_2 emissions from anthropogenic activities are about ten times higher than emissions from natural sources (Qiao et al., 2018). SO_2 is discharged into the atmosphere at a rate of 73%

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from power plants and 20% from other industrial facilities by burning fossil fuels containing sulfur, as well as 7% from natural resources (Hosseiniebalam and Ghaffarpasand, 2015; Sari and Esen, 2021).

Many pollutants are among the main causes of diseases among humans. PM, which is among the pollutants with various sizes, enters the body through inhalation and causes dysfunctions in the central nervous system, cancer, cardiovascular diseases and damage to the reproductive system (Manisalidis et al., 2020). It has been stated that individuals suffer tom asthma and related disorders such inflammation of lungs, oxidative stress, increased respiratory symptoms, and poor lung function due to being exposed to PM_{10} and SO_2 for short or long periods of time (US EPA, 2017; Huang et al., 2019). Such adverse health effects of pollutants result in increased respiratory morbidity, respiratory mortality, emergency room visits or hospitalization in individuals (Rajak and Chattopadhyay, 2019).

The seasonal variation of air pollution is associated with the seasonal variation that leads to the formation of summer and winter periods, also known as the "warming" season, and the specificity of certain months. The occurrence of higher air pollution values in different months of the year is associated with the type of climate and resulting different atmospheric conditions in certain months, changing weather conditions on a given day, and anthropogenic activity. The emergence of these conditions results in different levels of air pollution for a given period (Cichowicz et al., 2017).

The problem of air pollution can only be solved by determining the present situation. With the advances in technology, both developed and developing countries can evaluate the size of air pollution through measurement stations. However, $PM_{2.5}$ is still not measured at many stations, as there is not yet a regulatory limit for the atmospheric concentration of this pollutant, while PM_{10} is measured at all stations in Turkey (UCTEA, 2017).

According to the studies carried out by the World Health Organization (WHO), the air quality limit values are exceeded in the areas where 91% of the world population live, and 4.2 million individuals die due to air pollution every year (WHO, 2020; Zeydan, 2021). Therefore, the air quality directive 2008/50/EC sets legal limit values for particulate matter (PM_{10}) concentrations in ambient air, which is 50 $\mu g/m^3$ for the daily average. Continuous monitoring of PM_{10} and SO_2 levels is required to improve air quality in an area (Caselli et al., 2009; Ceylan and Bulkan, 2018). Therefore, there are many studies in the literature on future predictions of atmospheric SO_2 and PM_{10} concentrations (Schornobay-Lui et al., 2019; Gündogdu, 2020). Sengupta et al. (1996) identified the population and risky areas that are exposed to air pollution through GIS. Fiala et al. (2001) determined the sulfur accumulation in the atmosphere using annual SO_2 concentration and precipitation data. Elbir (2004) studied on a GIS-based decision support system for the forecasting, mapping and analysis of air pollution in many metropolitan cities in Turkey.

Air pollution caused by PM is currently a major problem in all countries of the world and is a very important issue in Turkey. Accordingly, research on this subject is increasing regarding various specific regions and cities. It was reported by Karaca (2012) that the regions with the highest PM_{10} levels in Turkey are the eastern region of the Black Sea, the eastern part of Turkey, the northeastern part of the Central Anatolian region and the western part of the Northeastern Anatolia (Toros et al., 2013) examined 16 metropolitan cities in terms of PM_{10} to evaluate the overall air quality of Turkey. It is clearly stated that 75% of these cities exceed the daily average PM values. The average daily total PM_{10}

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concentration in the Central Anatolian Region of Turkey was reported to be 148 μg/m^3 by Ozel and Çakmakyapan (2015) using Poisson processes (Cekim, 2020).

One of the crucial factors affecting the air quality in Turkey is urbanization. Significant attempts have been made in recent years, such as transition from coal to natural gas, which aim to minimize air pollution levels in Turkey. In many metropolitan cities, natural gas pipeline systems have been installed for residential heating and industrial use. Thus, it has been reported that the air quality of some cities has improved and there have been changes in air pollution rates in Turkey (Deniz and Durmusoglu, 2008; Karaca, 2012b). However, since there seems to be no study on this matter in the related literature, the purpose in this study is to fill the gap in literature.

The aim of this study is to determine, analyze and map monthly changes in daily concentrations of SO_2 and PM_{10}, which are among the most threatening health pollutants, between 2010 and 2020 in 9 provinces located in the southeast region of Turkey (SAR). As a result of the comparison over the last 10 years: (a) the effect of the transition from coal use for heating purposes in 2010 to natural gas in 2020 was determined, (b) the impact of the atmospheric particulate matter transport on the provinces bordering the deserts (Sanliurfa, Mardin, Gaziantep, Kilis, Sirnak) was determined by the HYSPLIT model, (c) the relationship between population growth and PM_{10} and SO_2 increase was analyzed, and (d) the effect of the increase in motor vehicles on PM_{10} and SO_2 was determined. This study is significant in terms of determining the air quality of Turkey's SAR provinces on a monthly basis and revealing the outcomes of the measurements, monitoring and evaluation policy for the improvement of air quality in a 10-year period.

Material and Methods

Study field and data collection

The Southeastern Anatolia Region of Turkey, selected as the study area, consists of 9 provinces (Sanliurfa, Mardin, Sirnak, Kilis, Batman, Diyarbakir, Adiyaman, Gaziantep, Siirt) located on an area of 76.327 km^2 (*Table 1, Fig. 1*).

Table 1. *The location of monitoring stations*

States	Stations	Latitude (N)	Longitude (E)
Adiyaman	Adiyaman Meteorological Service	37.755	38.279
Batman	Batman Provincial Directorate of Environment, Urbanization and Climate Change	37.872	41.171
Diyarbakir	Diyarbakir Provincial Directorate of Environment, Urbanization and Climate Change	37.909	40.212
Gaziantep	Gaziantep Provincial Directorate of Environment, Urbanization and Climate Change	37.058	37.351
Kilis	Kilis Provincial Directorate of Environment, Urbanization and Climate Change	36.709	37.112
Mardin	Mardin Provincial Directorate of Environment, Urbanization and Climate Change	37.313	40.738
Siirt	Siirt Meteorological Service	37.931	41.935
Sanliurfa	Sanliurfa Meteorological Service	37.159	38.796
Sirnak	Sirnak Provincial Directorate of Environment, Urbanization and Climate Change	37.522	42.456

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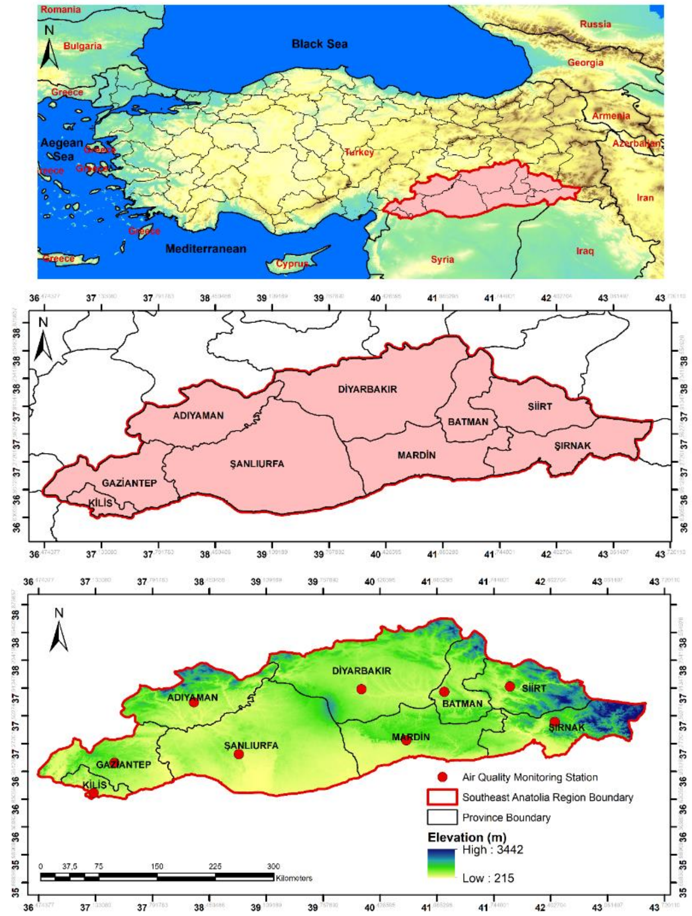

***Figure 1.** The study area of the provinces of the SAR of Turkey showing the stations with PM_{10} and SO_2 concentrations*

When SAR provinces are examined as in (*Table 2*), negative effects on air quality are estimated due to rapid population growth and an increase in motor vehicles. However, the transition to natural gas over time (for the last five years) and to using natural gas for heating in all provinces in 2020 is important, while coal was used in 2010 for heating.

***Table 2.** Information of SAR Provinces in 2010 and 2020 (TSI, 2021)*

Provinces	Population (n)			Area (km^2)	Number of vehicles (n)		
	2010	2020	Percentage		2010	2020	Percentage
Adiyaman	590,935	632,459	7,003	7,337	64,962	110,433	6,9
Batman	510,200	620,278	21,575	4,477	34,381	45,916	33,5
Diyarbakir	1,528,958	1,783,431	16,643	15,272	320,032	540,397	68,8
Gaziantep	1,700,763	2,101,157	23,542	6,803	96,272	124,672	29,5
Kilis	123,135	142,792	15,963	1,412	28,457	110,430	288,05
Mardin	744,606	854,716	14,787	8,779	51,921	76,605	47,5
Siirt	300,695	331,070	10,101	5,718	13,596	20,394	50
Sanliurfa	1,663,371	2,115,256	27,166	19,451	194,193	255,664	31,6
Sirnak	430,109	537,762	25,029	7,078	28,475	29,145	2,3

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In order to accurately measure air pollution, the Turkish Ministry of Environment and Urbanization established the National Air Quality Monitoring Network throughout Turkey. The air pollutant parameters (SO_2 and PM_{10}), monitored from the established air pollution measurement stations, can be measured automatically. The collected data at the measurement stations are transferred to the Environment Reference Laboratory Data Processing Center of the Ministry via this network (VPN) by means of GSM Modems, are monitored and broadcast simultaneously. However, the fact that the data from this station has not been revealed with respect to the effect of air pollution for many years is a significant gap in the literature. For this reason, the 24-hour average values of PM_{10} and SO_2 of the 9 provinces located in SAR were obtained from the database of the Ministry of Environment Urbanization and Climate Change (MEUCC) (www.havaizleme.gov.tr) for the analysis of air pollution between the periods of 2010 (January 1, 2010-December 31, 2010) and 2020 (January 1, 2020-December 31, 2020) and were evaluated on a monthly basis (TR_MEUCC, 2019).

One-fifth of the earth is covered by deserts. PM in micrometer size that form the deserts is easily lifted by the effect of cyclones, pressure, and winds, and is suspended in the air and carried many kilometers away. Desert dust consisting of atmospheric particulate matter is transported from the Sahara Desert, the Arabian Peninsula and the Syrian desert to the border provinces of the SAR (Sanliurfa, Gaziantep, Kilis, Mardin, Sirnak). This has serious influences on air quality. To determine desert dust transport to these provinces, backward trajectories of the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model were used in order to determine the direction of the inflow of air masses (Stein et al., 2015). The HYSPLIT model has so far been successfully used in analysis of the inflow and conditions of both anthropogenic dispersions, i.e., PM, SO_2, NO (Lee et al., 2013), radionuclides (Draxler et al., 2015), as well as natural air pollution, i.e., volcanic dust and forest fires (Palarz and Celıńskı-Mysław, 2017).

Method

The IDW (Inverse Distance Weighted) interpolation method in the Spatial Analyst module of ArcGIS 10.2 software was used to generate the spatial distribution maps that show the monthly averages of PM_{10} and SO_2 values for the years 2010 and 2020 of the 9 provinces in the study area.

Inverse distance weighted (IDW) interpolation method

This interpolation method estimates cell values by means of the mean values of sample data points located around each cell. IDW prefers data or point value closer to each other. The assumption is that distance reduces the local influence of the measured points, the more relative are the points to the target region, the higher weight they have (Gómez-Losada et al., 2019; Shukla et al., 2020). That is, the high weight value is given to the sample points with closest distance to the cell. Moving away from the estimation location reduces the effects of the points. In cases when any point is in an area different from the estimation location, considering a very distant point may not be suitable in this method. Considering a sufficient number of points and creating a surface for small areas can solve this problem. The amount, distribution and surface character of the sample points may determine the number of points (Esri, 2014). The basis of this method is the calculation of distances from the desired point to data points, and the linear weighting of the effect of data points on the value at the desired point using an inverse function (Loyd, 2010).

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$$Z\,(Xo) = \frac{\sum_{i=1}^{n} Z\,(Xi).\,d_{i0}^{-r}}{\sum_{i=1}^{n}\, d_{i0}^{-r}} \qquad \text{(Eq.1)}$$

Here (*Eq.1*), the predictions are conducted in the Xo position, which is a function of adjacent measurements, n [Z (Xi) and i = 1, 2, …, n,]. r refers to the exponential number determining the assigned weight of each observation, and d is the distance between the observation position (Xi) and the estimated position (Xo).

The assigned weight of observations at a given distance from the estimation location becomes smaller depending on how large the exponent is. Increases in exponents indicates that the estimations are very similar to the closest observations (Aksu and Hepdeniz, 2016).

Results and Discussion

Evaluation of PM_{10} concentration

PM_{10} concentrations values measured daily by air quality measurement station in SAR provinces were calculated as monthly average values. The monthly average PM_{10} exposure according to the 24-hour average values within the scope of the air quality standards determined by the WHO is 50 µg/m^3 and this has been compared with the average PM_{10} concentrations of the SAR provinces (WHO, 2006).

Considering monthly average, the PM_{10} concentrations in 2010 given in *Fig. 2*, it was determined that the WHO limit value of 50 µg/m^3 was exceeded in 9 provinces in November, December, January, February, March, and April, and the air quality was at levels to threaten health. In May and June 2010, PM_{10} concentration was measured as 5 and 10 µg/m^3, respectively, and below the WHO standard only in Gaziantep. In 2020, PM values decreased considerably in 9 provinces in January, February, March, and April and remained below the WHO limit value. PM_{10} concentration was high in Kilis during February and March in 2020 with values of 202 and 96 µg/m^3. As a consequence of a forest fire in Sirnak in May 2020, the PM_{10} concentration increased to 557 µg/m^3, which was the highest value creating threats to health. In 2010, PM_{10} concentration was measured quite low in summer months (June, July, August) compared to winter months. This was mainly a consequence of not using coal for heating. As a result, PM_{10} values were lower in summer months and higher in winter months. Due to the use of coal in 2010, the values exceeded the WHO standard, but in 2020, it remained below the WHO value, except for a few provinces, and it was determined that natural gas use had a positive effect on air quality.

Palarz and Celiński-Mysław reported in the study conducted in small towns located in the basins of the Polish Carpathians, i.e. Jaslo, Zakopane, and Zywiec that the use of poor quality coal increased the amount of PM_{10} and SO_2, despite the fact that towns were small. The highest concentrations of PM_{10}, SO_2 and NO_2 were observed during the winter season, which seems to have stemmed from decreases in solar radiation, lower temperatures, and increased air pollutant emissions due to furnaces home furnaces (Palarz and Celiński-Mysław, 2017).

Due to the insufficient air quality monitoring stations in Malaysia, reliable mapping was developed with IDV and the maximum and minimum values were determined as 76 µg/m^3 and 42 µg/m^3 in the PM_{10} thematic map produced by IDW (Tella and Balogun, 2021).

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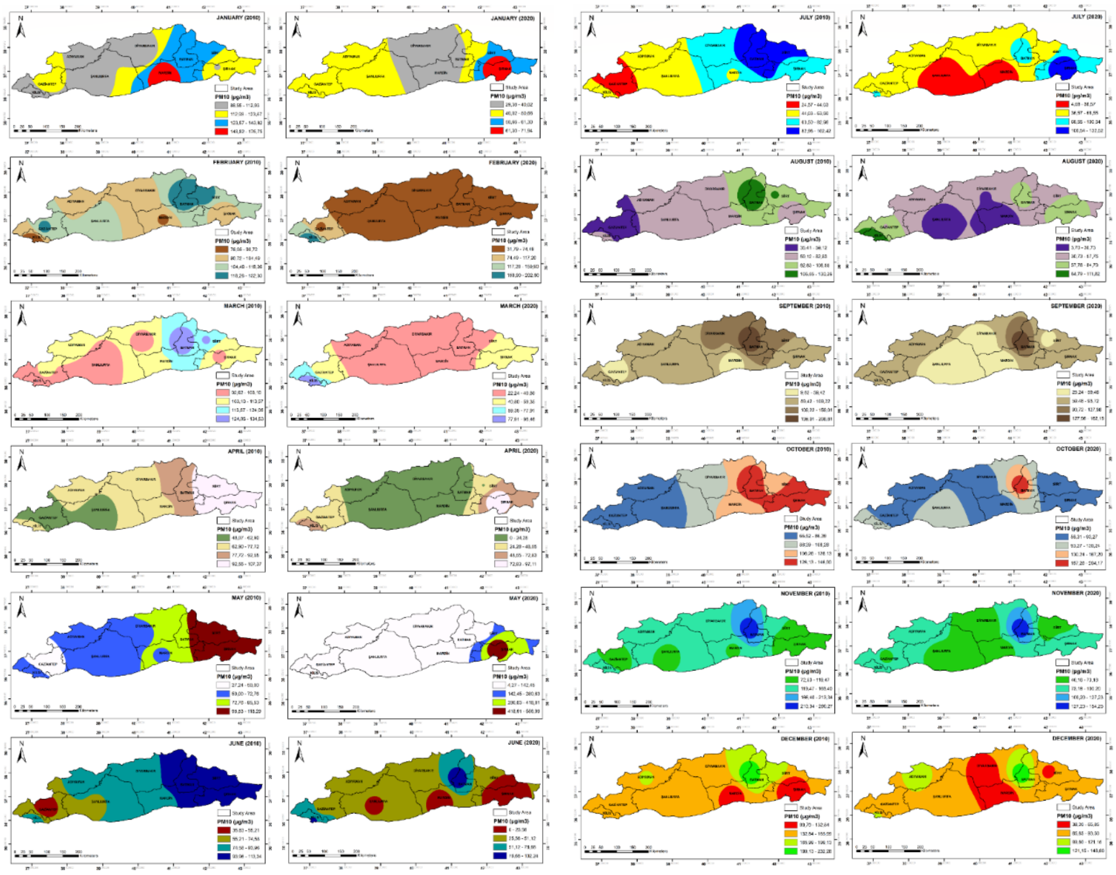

Figure 2. *Spatial distributions of PM10 in 9 provinces of the SAR in 2010 and 2020 (12 months)*

Atmospheric particulate matter transport from deserts and the HYSPLIT model

Many studies in the literature have reported that the amount of PM_{10} increases especially because of the use of coal for heating purposes during winter months. However, in our study, it was observed that PM_{10} concentration increased in border provinces, especially in the spring and autumn months. One-fifth of the earth is covered with deserts. These deserts consist of particulate matter with different sizes. These particulate matters constitute atmospheric particles that are transported many kilometers away by meteorological phenomena and pressure.

In *Fig. 2*, the PM_{10} concentration in March (spring) 2010 was determined as follows for the the SAR provinces: Sanliurfa 92.62 μg/m^3, Diyarbakır 98.73 μg/m^3, Sirnak 99.76 μg/m^3, Kilis 100.29 μg/ m^3, Gaziantep 103.65 μg/m^3, Adiyaman 107.06 μg/m^3, Mardin 112.54 μg/m^3, Siirt 125.16 μg/m^3 and Batman 134.53 μg/m^3. As a result of the measurement, the values were found to exceed the WHO standards.

Atmospheric particles (PM_{10} and smaller particles) have received increasing attention in recent years due to a vital role they play in altering air quality, human health, and climate change (Gray, 2015; Sakhamuri and Cummings, 2019). One of the most common natural sources of particulate matter is desert dust since one-fifth of the earth is covered with arid and semi-arid regions. Dusts from these sources are suspended fine particles that can be transported and deposited in the downwind side due to atmospheric transport. A study conducted by NASA researchers has shown that an average of 182 million tons

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of dust is transported each year from desert areas (Gray, 2015). The Sahara is the largest hot desert in the world, covering around 10 million square kilometers, about the size of the United States (Goudarzi et al., 2015). It expands across the following eleven countries: Algeria, Chad, Egypt, Libya, Mali, Mauritania, Morocco, Niger, Western Sahara, Sudan and Tunisia. The content of the dust originating from the Saharan desert may change based on the agricultural and industrial practices of the people living in these countries. Particulate matter transported from the Saharan Desert can reach not only to countries in the vicinity (such as Turkey) but also North and South America as well as Caribbean region. border provinces (Sanliurfa, Kilis, Gaziantep, Mardin and Sirnak) is under the influence of Sahara Desert, which is the largest desert in the world, Syria desert and the Arabian Peninsula together with Simoom, Khamsin and Sirocco winds. Therefore, the city is exposed to particulate matters from these regions as a result of atmospheric transport. With the developments in technology, we are now able to determine which desert source affects a particular region by giving coordinates through HYSPLIT model program at different height levels (500, 1000, 1500 m). When we look at the daily examinations in 2020, Sanliurfa province has been affected by particulate matter from the deserts of Syria and the Arabian Peninsula on many days of the year, especially in Spring (March-April-May) and Autumn months (September-October-November) as it is neighbor to Syria and in the direction of Sahara air flow (Dogan et al., 2021). This atmospheric desert transport leaves the city only when it rains. However, rainfall may not occur during spring. In this case, dust can remain suspended in the air for 3 days and sometimes weeks. Since the PM is inhalable, the environment, including many living and non-living organisms especially children and the elderly, is affected. Also, the dust reduces the range of sight and there can be accidents and problems in transportation as a result. In the case of precipitation containing dust, traditionally known as muddy rain, also pollutes the city.

When the PM_{10} concentration in Sanliurfa province was examined at 500-1000-1500 meters by means of the HYSPLIT model as shown in *Fig. 3a*, it was determined that the increase in the PM_{10} concentration was caused by transport from Syria, the Arabian Peninsula and the Sahara deserts with the effect of the winds on 10-11-12 March, 2010 (*Fig. 3a*). It was reported by Dogan et al. in their study that atmospheric dust particles are transported to Sanliurfa in spring and autumn, leading to a 4.57% decrease in the efficiency of solar panels (Dogan et al., 2020). In addition, PM_{10} concentration values in October, the autumn month of 2020, were measured as follows: 69.48 $\mu g/m^3$ in Mardin, 76.96 $\mu g/m^3$ in Sirnak, 81.31 $\mu g/m^3$ in Gaziantep, 103.91 $\mu g/m^3$ in Sanliurfa, 107.15 $\mu g/m^3$ in Kilis, which were all above the WHO standards in all SAR provinces. When the province of Sanliurfa, which had the highest score, was examined with the HYSPLIT model, it was determined that the reason for the PM_{10} concentration values during 26.27 $\mu g/m^3$ and 28 October, 2020 to be above the standards, especially in the border provinces with a maximum level, was the increase in desert dusts during autumn months (*Fig. 3b*).

Evaluation of SO_2 concentration

The sources of air pollutants are mainly combustion processes, various technological processes, as well as vehicle traffic (Lelieveld et al., 2015). It should also be noted that pollutants are emitted from low-emission sources mostly during the heating season, and remote systems do this in varying intensities all year round (Lin et al., 2011).

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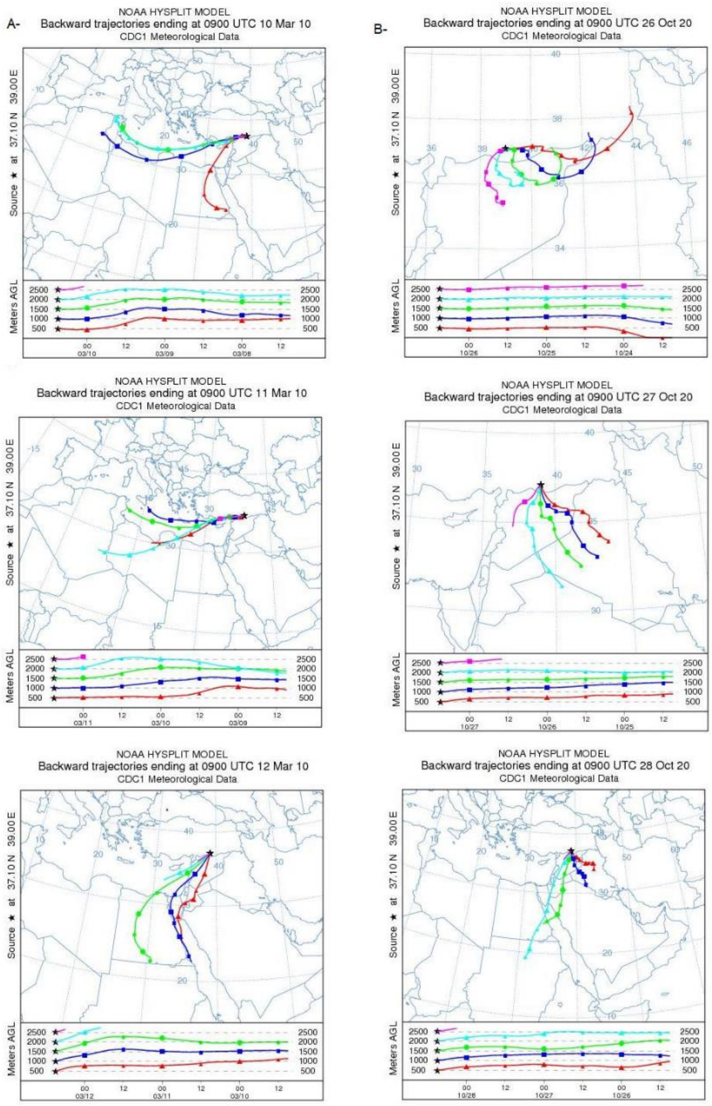

Figure 3. a. *HYSPLIT model of Sanliurfa province on 10-12 March 2010,* ***b.*** *HYSPLIT model of Sanliurfa province on 26-28 October 2020*

It is known that the anthropogenic source of SO_2 in the atmosphere is the burning of coal. SO_2 is considered the most common pollution that threatens the environment and human health and may lead to the increase in the number of cardiovascular and respiratory diseases (Landim et al., 2018).

In the study conducted over a seven-year period (2009–2015) in eastern Wielkopolska, Poland, PM_{10} was associated with sulfur dioxide, higher pollution levels in winter and PM_{10} concentrations exceeding the limit values. In addition, it was stated that the levels of pollutants such as sulfur dioxide, nitrogen dioxide and carbon monoxide increase in winter, but do not exceed the limit values (Cichowicz et al., 2017).

SO_2 concentrations values measured daily by air quality measurement station in SAR provinces were calculated as monthly average values. The monthly average SO_2 exposure according to the 24-hour average values within the scope of the air quality standards determined by the WHO is 20 μg/m^3 and this has been compared with the average SO_2 concentrations of the SAR provinces (WHO, 2006).

As can be seen in *Fig. 4*, the SO_2 concentration exceeded the WHO standards in Sirnak, one of the coldest provinces of the SAR, with values of November (102.58 µg/m^3), December (283.64 µg/m^3), January (326.05 µg/m^3), February (234.77 µg/m^3), March (116.90 µg/m^3) and April (63.87 µg/m^3) during 2010. Since the SO_2 concentration does not exceed the WHO standard during spring and summer in Sirnak, it can be understood that this high rate of SO_2 resulted from the use of poor-quality coal due to the lack of natural gas systems. Natural gas started to be used in Sirnak, except for the suburban areas, in 2020. SO_2 values measured in Sirnak for the year 2020 were November (57.11 µg/m^3), December (98.13 µg/m^3), January (104.01 µg/m^3), February (77.29 µg/m^3), March (38.25 µg/m^3) and April (22.32 µg/m^3). As seen in *Table 1*, although the population of Sirnak increased by 25.02% and the number of vehicles by 2.3% over a 10-year period, the decrease in SO_2 concentration was found to be the result of natural gas use.

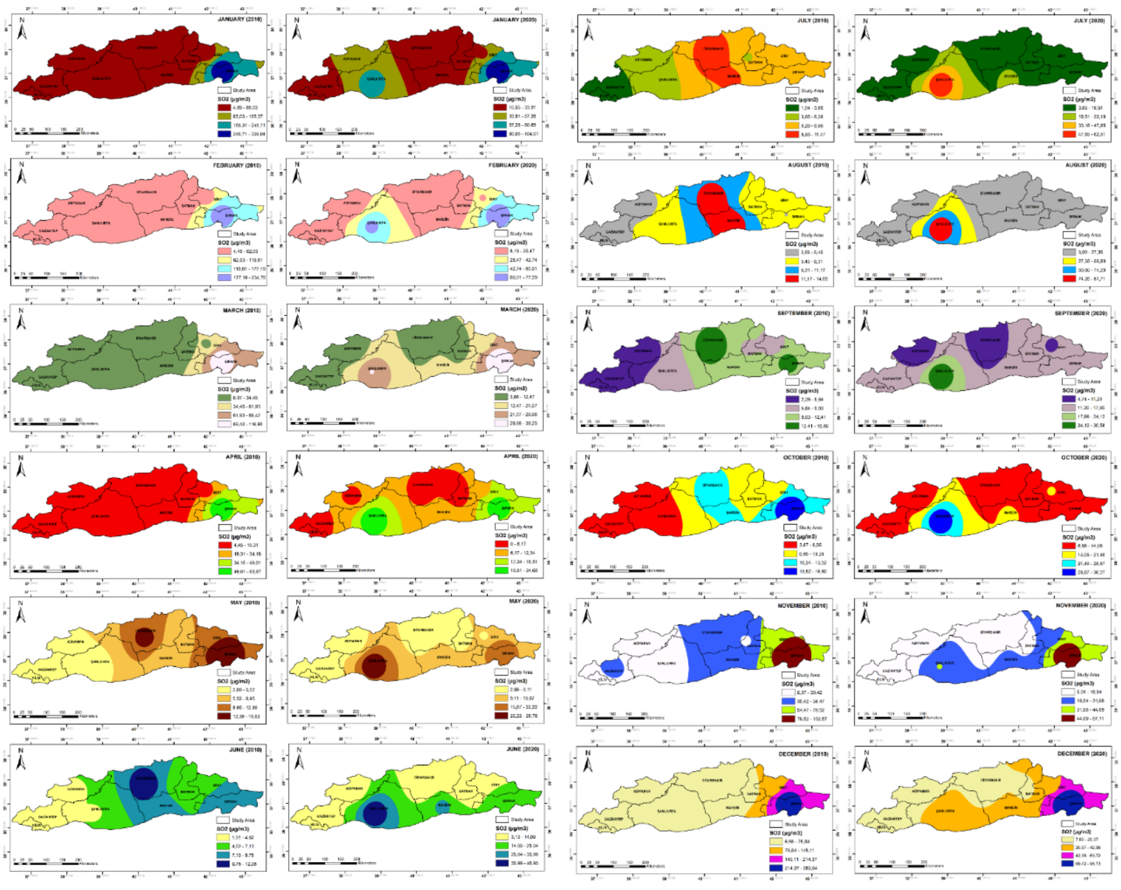

Figure 4. *Spatial distributions of SO_2 in 9 provinces of the SAR in 2010 and 2020 (12 months)*

Use of vehicles is increasing dramatically. This increase has a tremendous impact on the environment, including air pollution, particularly due to private vehicle users (Boedisantoso et al., 2019). In this study, when we examine the province of Kilis as in *Table 2*, while there were 28.457 motor vehicles in 2010, it was 110.430 in 2020 with an increase by 288.05%.

Coal is not burned for heating purposes in spring (March, April, May) and summer in Turkey, and natural gas is used instead of coal in 2020. However, when the spring and

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summer months of 2010 and 2020 in Kilis were considered as in *Fig. 4*, an increase in SO_2 concentration was found in April, May, June, July, August, September, and October. It is estimated that the only main source of this was the 288% increase in the number of vehicles.

Batman Oil Refinery, Turkey's first refinery, causes a significant decrease in the air quality of the province. As a result of the burning of fuels such as fuel oil and refinery gas in processes in refineries, emissions such as hydrocarbons, sulfur oxide, carbon dioxide, CO, dust, H_2S, VOC, heavy metals and nitrogen oxides occur (Batan, 2013). Waste gas emissions from the refinery cause air pollution on a local, regional, and global scale after being released into the atmosphere from the refinery. The main problem observed at the local scale is the deterioration of air quality due to SO and PM and its impact on public health (Zeydan, 2019). Batman province had the highest PM_{10} value in 2010 and 2020, which is considered to have resulted from waste gas emissions from the oil refineries.

Conclusions

Considerable differences in air quality were found among the SAR provinces over a 10-year period, which are among the fastest developing regions of Turkey in terms of both industry and population. In 2010, PM_{10} level was found to be high due to the burning of coal especially in winter (December-January-February) and autumn (September-October-November). Transition to natural gas as an alternative to burning coal for heating in 2020 has had a positive impact on the air quality of SAR provinces. However, in border provinces (Sanliurfa, Gaziantep, Mardin, Kilis, Sirnak), the amount of PM_{10} was found to be high in the spring (March-April-May) and autumn (September-October-November) both in 2010 and 2020. The reason for this was determined, using the HYSPLIT model, to be the transport of atmospheric aerosols from the deserts of Sahara, Syria, and Arabian Peninsula. Dogan et al. reported in their study conducted in Sanliurfa in 2020 that the maximum PM_{10} and $PM_{2.5}$ concentrations during the spring and autumn months were 150 and 250 $\mu g/m^3$, respectively (Dogan et al., 2020).

The highest SO_2 concentration was 326.05 $\mu g/m^3$ in January 2010 in Sirnak province. With the transition to natural gas in 2020, the positive consequences of not using coal for heating have been observed in Sirnak, and both PM_{10} and SO_2 concentrations have considerably decreased.

Exhaust gases from vehicles are known to be a serious SO_2 source. The highest increase in the number of vehicles between 2010 and 2020 (28.457 in 2010, 110.430 in 2020 with an increase by 288.05%) was in Kilis. While the SO_2 value was low in 2010 despite using coal for heating purposes, this value increased despite the use of natural gas for heating purposes in 2020. The reason for this increase can be attributed to the vehicles as the SO_2 value increased especially in the spring (March-April-May) and summer (June-July-August).

Batman was the province with the highest concentration of PM_{10} and had the lowest air quality in 2010 and 2020. This can be due to waste gas emissions from oil refineries. In SAR provinces, the highest value of PM_{10} was measured in Batman in November, 2010 as 260.28 $\mu g/m^3$ while the lowest value was measured in Mardin in September as 9.62 $\mu g/m^3$. On the other hand, the SO_2 concentration was measured at the maximum level of 326.05 $\mu g/m^3$ in Sirnak in January and at a minimum level of 1.04 $\mu g/m^3$ in Kilis in July. In 2020, PM_{10} concentration increased to a maximum level of 557 $\mu g/m^3$ in Sirnak

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in May and at a minimum level of 3.70 μg/m^3 in Mardin in August. The SO_2 concentration was measured at a max level of 104.01 μg/m^3 in Sirnak in January and at a minimum level of 2.55 μg/m^3 in Diyarbakır in May.

In conclusion, the transition from coal use for heating purposes to natural gas has decreased the PM_{10} concentration in all provinces during the winter months (December-January-February) in the 10-year period between 2010 and 2020. In 2020, the main source of air pollution in SAR provinces was the increase in the number of vehicles, the secondary reason was the increase in population, and the third reason was atmospheric aerosols transported from the deserts (Syria, Arabian Peninsula, Sahara). The concentrations of other gases (nitrous oxide, carbon dioxide, etc.) should be measured daily to maintain human health at the stations that automatically measure the air quality of the provinces. People should be warned not to go outside and to open windows on dates when PM_{10} and SO_2 concentrations are high. In order to prevent global warming in the world and for people to breathe cleaner air, the use of coal for heating should be abandoned, and transition to renewable energy sources should be the policy and goal of all countries.

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Data availability. NOAA-HYSPLIT trajectory and PM_{10} and SO_2 data are freely accessible from the data providers mentioned in "Material and methods" of the manuscript; NOAA-HYSPLIT: https://www.ready.noaa.gov/HYSPLIT_traj.php; PM_{10} and SO_2 data: www.havaizleme.gov.tr.

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