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RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

General Assessment of PM_{10} and SO_2 in Ağrı City Centre

Ağrı Şehir Merkezinde PM_{10} ve SO_2'nin Genel Değerlendirmesi

Yiğitalp KARA[1], Mehmet ÇİVİCİ[2], Uygar KARTUM[2], Rosa M. FLORES[3*]

[1]*Istanbul Technical University, Department of Meteorological Engineering, Faculty of Aeronautics and Astronautics, İstanbul, Turkey*
[2]*ITU Vocational and Technical Anatolian High School, İstanbul, Turkey*
[3]*Marmara University Department of Environmental Engineering, Engineering Faculty, Istanbul, Turkey*

Abstract
The emission of air pollutants has been increasing dramatically because of the high-energy consumption and usage of transportation systems triggered by the industrial revolution. In addition, the development of technology, high demand for conventional sources, unplanned urbanization, and rapid growth of population are some of the most important factors for the increase of particulate matter (PM) and sulfur dioxide (SO_2) in the last 20 years in Turkey. Ağrı, which is a rural province having more high plateau areas and agricultural lands than residential areas, is less affected by these factors compared to developed cities. In this work, variations of PM_{10} and SO_2 concentrations were evaluated from January to December of 2018. Overall, it was found that SO_2 concentrations were well below the regulations, and the majority of the air pollution in Ağrı was due to PM_{10}. Also, concentrations of PM_{10} were higher than expected due to the location of the station. Hourly PM_{10} and SO_2 concentrations ranged as 9.4-179.7 and 1.4-39.4 µg/m³, with average values of 52.1 and 8.3 µg/m³, respectively. According to the Turkish Aerosol Quality Index (AQI), daily PM_{10} concentrations were 51% in the "good" class, 44% in the "moderate" class, and 5% in the "sensitive" class. While SO_2 measurement values were 100% in the "good" class in 2018. According to the results obtained in this work, it is recommended that more efforts are done to decrease emissions of PM_{10} throughout the year, particularly during the heating season.
Keywords: Air Quality, Air Pollution, Diurnal Variation, Seasonal Variation, Rural Area, Turkey

Öz
Sanayi devriminin tetiklediği yüksek enerji tüketimi ve ulaşım sistemlerinin kullanımı nedeniyle hava kirleticilerinin miktarı önemli ölçüde artmaktadır. Ayrıca, teknolojinin gelişmesi, geleneksel kaynaklara olan yüksek talep, plansız kentleşme ve hızlı nüfus artışı, Türkiye'de son 20 yılda partikül maddenin (PM) ve sülfür dioksitin (SO2) artışının en önemli sebeplerinden bazılarıdır. Yerleşim alanlarına göre daha fazla kırsal alanı ve tarım arazisine sahip kırsal bir il olan Ağrı, gelişmiş illere göre bu faktörlerden daha az etkilenmektedir. Bu çalışmada, 2018 yılının Ocak-Aralık ayları arasında PM_{10} ve SO_2 konsantrasyonlarının değişimleri değerlendirilmiştir. Genel olarak, SO_2 konsantrasyonlarının yönetmeliklerin oldukça altında olduğu ve Ağrı'daki hava kirliliğinin büyük kısmının PM_{10}'dan kaynaklandığı tespit edilmiştir. Ayrıca, İstasyonun konumundan dolayı partiküler madde konsantrasyonları beklenenin üstünde çıkmıştır. Saatlik PM_{10} ve SO_2 konsantrasyonları 9,4-179,7 ve 1,4-39,4 µg/m³ arasında değişirken, ortalama değerler ise sırasıyla 52,1 ve 8,3 µg/m³ olarak tespit edilmiştir. Hava kalitesi indeksine (AQI) göre günlük PM_{10} konsantrasyonlarının %51'i "iyi", %44'ü "orta" ve %5'i "hassas" sınıfta bulunmuştur. 2018 yılında SO2 ölçüm değerleri% 100 "iyi" sınıfında yer alırken. Bu çalışmada elde edilen sonuçlara göre PM_{10} emisyonlarının azaltılması için yıl boyunca ve özellikle ısıtma mevsiminde daha fazla çaba harcanması önerilmektedir.
Anahtar Kelimeler: Air Quality, Air Pollution, Diurnal Variation, Seasonal Variation, Rural Area, Turkey

I. INTRODUCTION

Air pollution is considered as the most important environmental problem. It can be defined as organic and inorganic pollutants whose concentrations exceed air quality standards determined by various sources in a certain place. Pollutants causing a decrease in the air quality can be classified into two groups as aerosols and gases. Particulate matter (PM) consists of suspended solid- and liquid-phase substances in the air and poses the most significant threat to health [1]. Particles such as dust, pollen, or mold in the atmosphere with 10 microns or less in diameter are called PM_{10}. Particles which are formed as a result of combustion, organic compounds with 2.5 microns or less in diameter, are called $PM_{2.5}$. Besides the physical properties of particulate matter, its chemical composition is also very important for health. Particulate matter can contain heavy metals such as mercury, lead, cadmium, and carcinogenic chemicals, and pose a significant threat to health [2]. Also, Sulfur dioxide (SO_2) is an invisible gas with a strong odor and decreases air quality by creating toxicity for living creatures and the general ecosystem.

Corresponding Author: Rosa M. FLORES Tel:+90 0216 777 3608, e-posta: rflores@marmara.edu.tr
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Many countries around the world have prepared various regulations, restrictions, and emergency plans on pollutant concentrations to reduce their potential harm. In order to achieve this, data is provided in real-time from in-situ measurement stations installed in many locations. In the world, there are various thresholds and categorizations for gases and aerosols to find out whether the atmosphere is polluted or not. For example, the US-EPA Air quality index (AQI) which is adapted by most of the countries according to their own legislation is used for daily reporting of air quality (Table 1).

There are various sources of PM and SO_x. For example, volcanic activities, forest fires, organic decay, and dust transport are some examples of natural pollutant sources. Also, transportation (motor vehicles, aircraft, ships, etc.), fossil fuel usage, industrial processes, agricultural activities, solid waste storage areas can be examples of anthropogenic sources of these pollutants [4]. The existence and impact of the various pollution sources listed above vary depending on location and time. There are many environmental and biological effects of PM and SO_x. For example, decrease in incoming solar radiation and visibility, decrease in the efficiency of the various agricultural products caused by a decrease in sunlight, and negative effects on aquatic ecosystems due to air-water transfer are also important effects of PM and SO_x. Furthermore, long-range transport from desert dust and other urban areas affects the marine ecosystem, and human health such as respiratory issues and toxicity due to the complex chemical composition such as metals in inhalable particles [5][6].

In the world, there are many studies conducted in terms of finding out atmospheric pollution in cities. For example, In Tehran, AQI has been calculated for $PM_{2.5}$ and it was found that for 4 years consisting of the 2010-2013 period, the air quality exceeded the "good" class by falling in the category of "unhealthy for sensitive groups" [7]. Also, in China, it was found that the average API-derived PM_{10} concentrations have been declined continuously according to the daily air quality reports taken from 86 cities [8]. In India Kerala, six major sites have been studied in terms of the intensity of air pollution by applying AQI. It was found that most of the air pollution in those sites was caused by particulate matter and the most polluted district was Ernakulam due to the existence of both, residential and industrial areas [9].

In Turkey, there have been many studies conducted about SO_2 and PM_{10}. However, there is a limited number of articles in the literature that analyze or evaluate air pollution for the province of Ağrı. One of the most recent studies assesses the air quality of Turkey by extracting a general picture of PM_{10} distribution in the provinces of Turkey [10]. Another study uses GIS to create spatial distribution maps to determine spatial patterns of PM_{10} and SO_2 [11]. Also, there is a study examining the effects of meteorological parameters such as temperature, pressure, and wind on PM_{10} and SO_2 concentrations [12]. Another study is about analyzing daily PM_{10} data in 2014 in Eastern provinces statistically [13]. Lastly, Iğdır, which is one of the eastern provinces like Ağrı, the amount of particulate matter is high due to the heating season in which poor-quality fuel is used in the winter and due to the dust coming from the dirt roads in the summer according to 2014-2019 period [14]. It is clear that the studies investigating the particulate matter and sulfur dioxide for the province of Ağrı are not enough.

The first aim of this study is to examine and evaluate daily, monthly, and annual changes of PM_{10} and SO_2 concentrations measured in the city center of Ağrı. In addition, another aim is to provide a useful statistical analysis to evaluate the overall air pollution in Ağrı with respect to Air Quality Indices (AQI) and regulations.

Table 1. US-EPA AQI and breakpoints [3]

Air Quality Index	SO_2 ($\mu g/m^3$)		NO_2 ($\mu g/m^3$)	CO ($\mu g/m^3$)	O_3 ($\mu g/m^3$)		PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	
	1H Mean	24H Mean	1H Mean	8H Mean	8H Mean	1H Mean	24H Mean	24H Mean	
0-50	0-93		0-102	0-5,2	0-108		0-54	0.0-12,0	Good
51-100	94-200		103-192	5,3-11	109-248		55-154	12,1-35,4	Moderate
101-150	201-493		193-689	11,1-14,5		249-328	155-254	35,5-55,4	Sensitive
151-200	494-810		690-1242	14,6-18		329-408	255-354	55,5-150,4	Unhealthy
201-300		811-1609	1243-2380	18,1-35,5		409-808	355-424	150,5-250,4	Bad
301-400		1.610-2.141	2.381-3.145	35,6-47,1		809-1.008	425-504	250,5-350,4	Dangerous
401-500		2.142-2.674	3.146-3.910	47,2-58,8		1.009-1.208	505-604	350,5-500,4	Dangerous

II. MATERIALS AND METHODS

2.1. Study Area

Ağrı is located at 39.7191° North latitude and 43.0506° East longitude (Figure 1). The provincial center of Ağrı was established at an altitude of 1,640 meters above sea level. The province has gained importance due to its location on the road connecting Anatolia with Iran [15]. 46% of the lands of the province of Ağrı are mountains, 29% are plains, and 25% are plateaus. Many peaks are found in Ağrı whose heights exceed 3,000 meters, including 5,137 m (Büyük Ağrı Mountain) and 3,896 m (Küçük Ağrı Mountain) [16]. Ağrı Province with a total population of 551,177, ranks 38 of 81 cities in terms of the total population in Turkey. In 2013, Turkey's arithmetic population density was 85.97 km^{-2}, and the number of people per km^2 in Ağrı was 48.45 [17]. It is clear that settlement, transportation, and construction difficulties due to the complex topography cause a decrease in the socio-economic value of the region, which is strongly related to population.

Ağrı province has a severe terrestrial climate. In general, from West to East in the region, the continent is even more affected by the reduction of the sea effect and the increase of the altitude which causes a change in wind pattern. Under the influence of terrestrial polar air masses that come from Siberia, the winters tend to be harsh and long [18]. In addition, the climate in this region falls in the "Dsb" class defined as having continental climate: severe winter, dry, and cool summer, according to the Köppen-Geiger climate classification which is one of the most frequently used climate classification methods in the world [19].

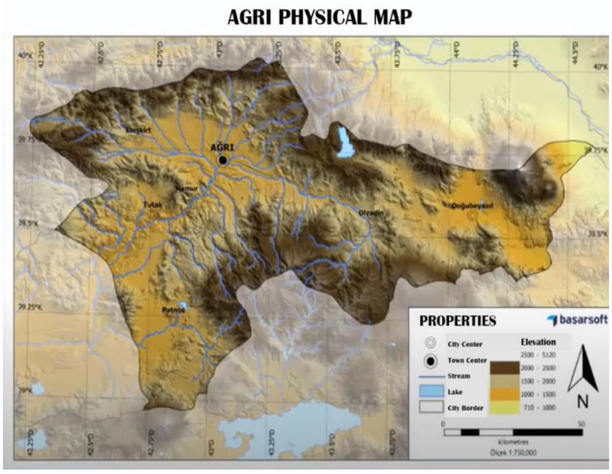

Figure 1. Ağrı topographic map [20]

2.2. Information About the Station's Location and Topography

Stad Street is located 10 meters east of the sampling station and Erzurum Boulevard is located 170 meters south. There are official institution buildings, workplaces, and residences heated by natural gas and coal after 40 meters of the station. Also, Ağrı Sugar Factory that uses natural gas as fuel is located 3.8 km northwest of the station. However, this factory is not subjected to the continuous emission measurement communique (SEÖS), which defines the principle of continuous measurement, monitoring, and transfer process the pollutant data to the ministry system by the local administrations. The location of the station in the middle of two-way single-lane dirt roads is particularly vulnerable to rising dust due to large vehicle crossings. In addition, there is a wall of the stadium to the east of the station. Also, there is an agricultural land in the north of the station, residential areas in the northeast, east, and south, and a construction area in the southwest direction (Figure 2).

In the province of Ağrı, the city center, which is around 200-250 meters lower than the surrounding elevations, follows the characteristics of a valley (Figure 3). Due to this geographical structure, the winds causing the dispersion of air pollution become difficult to enter the inner part of the city. In addition, the topography allows the formation of an inversion layer, especially at night when atmospheric stability is high.

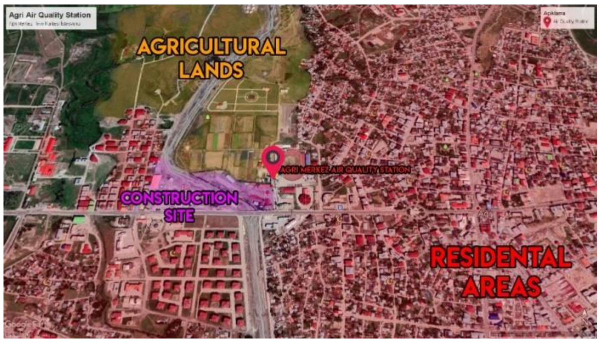

Figure 2. Ağrı Merkez AQI station (Google Earth)

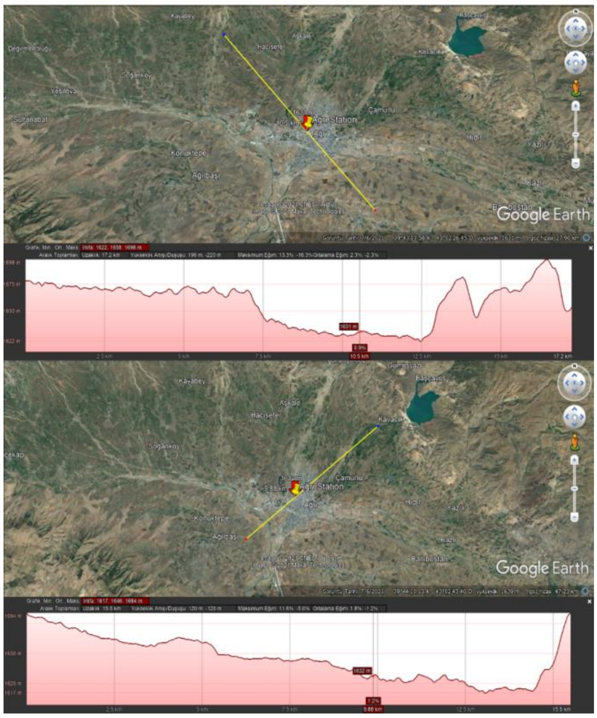

Figure 3. Air Quality Station Centered Topography and Elevation of Agri (Google Earth)

2.3. Data

In this study, hourly pollution data (PM_{10} and SO_2) were obtained from the Ministry of Environment and Urbanization of the Permanent Monitoring Center [21]. Also, hourly wind speed and direction data were gathered from the Turkish State Meteorological Service. The time period of this study was taken as 01.01.2018 - 31.12.2018.

2.4. Methodology

PM_{10} and SO_2 concentrations were obtained from the National Air Quality Monitoring Network (AQMN) in Turkey from January to December 2018 for the station in Ağrı (Merkez) (Latitude: 43.0402; Longitude: 39.7205; Altitude: 1,640 m) (Figure 2). The AQMN is operated and maintained by the Ministry of Environment and Urbanization of Turkey. The automatic PM_{10} and SO_2 measurements are performed according to EU regulations. For SO_2, the TSE - TS EN 14212 measurement method is a technique for the measurement of the concentration of sulfur dioxide by using ultraviolet fluorescence. According to equations (1) and (2) the fluorescent signal is directly proportional to the SO_2 concentration (Eq. 1, Eq. 2) [22].

$$\boldsymbol{I_f = \frac{K_f I_o \alpha \varphi [SO_2]}{K_f + K_d + K_q[M]}} \quad (1)$$

Since $\boldsymbol{K_f}$, $\boldsymbol{K_d}$, $\boldsymbol{K_q}$, [M], $\boldsymbol{I_o}$, and $\boldsymbol{\varphi}$ are constants, then:

$$\boldsymbol{I_f \infty [SO_2]} \quad (2)$$

Where the $\boldsymbol{I_f}$: intensity of florescence, $\boldsymbol{I_o}$: incident of light density, $\boldsymbol{\alpha}$: absorbtion coeff. Of SO_2, $\boldsymbol{\varphi}$: length of light path through sample, [SO_2]: Sulfur dioxide concentration, $\boldsymbol{K_f}$: rate constant, fluorescence, $\boldsymbol{K_d}$: rate constant, dissociation, $\boldsymbol{K_q}$: rate constant, quenching, [M]: concentration of quenching molecules.

For PM, the TSE - TS EN 14212 measurement method which is a technique about the determination of the concentration of suspended particles in the atmosphere by using gravimetric method (Eq. 3) [23]. Gravimetric method is a quantitative analysis method based on weighing the substance to be analyzed directly.

$$\boldsymbol{PM_{10\,a} = \frac{(W_f - W_i)(10^6)}{V_a}} \quad (3)$$

Where the W_i: Initial weight of filter collecting, PM_{10} particles (g), W_f: Final weight of filter collecting PM_{10} particles (g), $PM_{10\,a}$: Mass concentration of PM_{10} µg/m³, V_a: Total air sampled in ambient conditions volume units (local m^3)

All graphics were made with R programming language (RStudio Version 1.2.5033) and the Openair Package [24] which is commonly used in environmental studies. Also, the analysis was made with MS Excel. While the data was being graphed, 5% lower and upper parts of the dataset having outliers were discarded. Because outliers affect the mean and other statistical parameters in calculations in a way that detracts from the actual.

III. RESULTS

According to Fig. 4, for PM_{10}, there was a total of 11.8% missing data in March and July. For SO_2 there was a total of 11.5% missing data in March, July, and August. The reasons for this lack of data availability may be device replacement and maintenance that ensure high quality of the data. According to Table 2, the yearly average values of PM_{10} and SO_2 were measured as 52.1 and 8.3 µg/m³, respectively. Also, the extreme values corresponding to 75 percent were measured as 71.9 and 9.5 µg/m³, respectively.

As seen in Figure 5, roughly 25% of the measured hourly PM_{10} concentrations, were in the range of 50-90 µg/m³, which is the limit indicating medium air pollution according to the Common Air Quality Index (CAQI) used in European Cities [25]. According to the CAQI, high air pollution was observed 15% of the time in 2018 since hourly PM_{10} concentrations were in the range of 90-180 µg/m³. On the other hand, very high air pollution (> 180 µg/m³) was not observed in 2018. As shown in Fig. 4, the majority (75 %) of the hourly SO_2 concentrations were below 9.6 µg/m³, while 84% of the data was observed in the range of 1.4-16.5 µg/m³, where the density is highest.

Table 2. Descriptive statistics of hourly PM_{10} and SO_2 concentrations (µg/m³) in 2018

Variable	PM_{10}	SO_2
Number of Measurements	8719	8719
Percentage of Available Data	89	89
Minimum Value	9.4	1.4
1^{st} Quarter Value	23.8	3.3
Mean	52.1	8.3
Medium	41	4.6
3^{rd} Quarter Value	71.9	9.5
Maximum Value	179.7	39.4
Standard Deviation	36.5	8.2

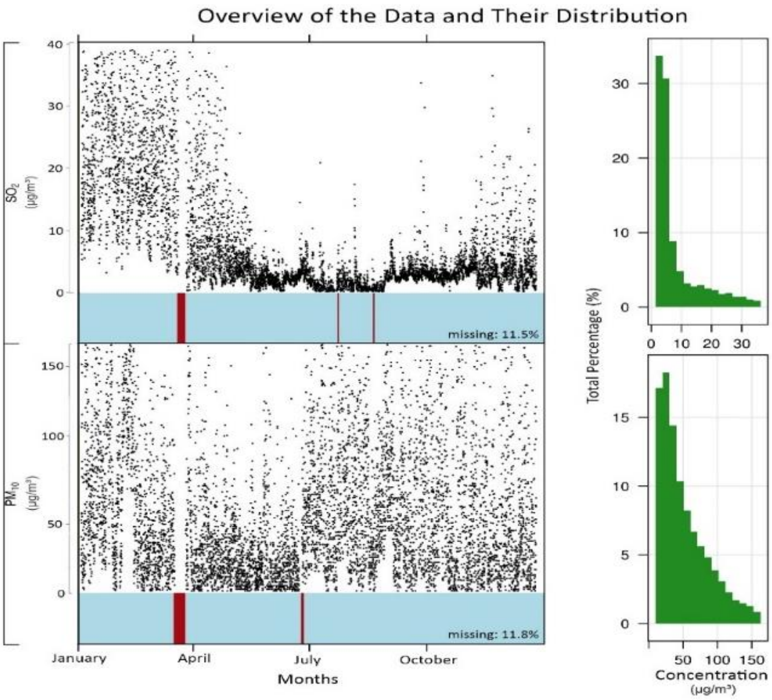

Figure 4. Overview PM_{10} and SO_2 concentrations and their distribution in 2018

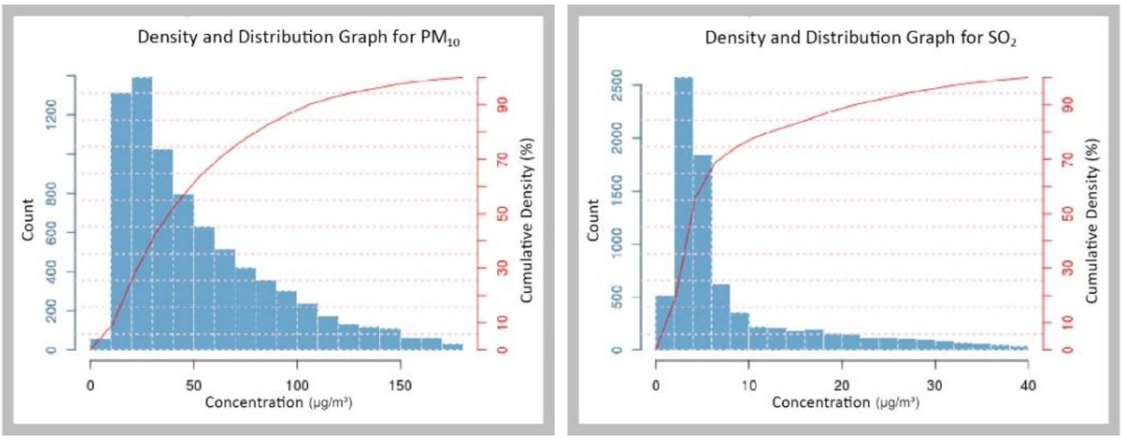

Figure 5. Density and distribution graphs of hourly-averaged pollutants

Figure 6 and Figure 7 show the time series of daily average of PM_{10} and hourly average of SO_2 in 2018. According to the figure, it is seen that although there is a decrease in the concentration of SO_2 over the middle of the year, all concentrations are well below the daily national air quality standard of 125 µg/m³ (Fig. 6). PM_{10} concentrations show greater interannual variations than SO_2 as various peaks are observed throughout the year. These variations may be due to changes in emission sources and mostly the location of the station. The extreme values observed are: The highest PM_{10} daily average of 142 µg/m³ was observed in winter on Monday Feb 05, 2018, while the lowest PM_{10} daily average of 16.1 µg/m³ was observed in summer on Saturday Jun 02, 2018 (Fig 6). The highest SO_2 hourly average of 39.4 µg/m³ was observed on March 15, 2018 23:00, while the lowest SO_2 hourly average of 1.4 µg/m³ was observed in 09.06.2018 10:00 (Table 2, Fig. 7). As it can be observed, for both, PM_{10} and SO_2, the maximum and minimum concentrations occur during the winter/heating season and summer seasons, respectively. The main reason for this is that the station is located right on the side of the dirt road, and dust is removed from the ground in any vehicle passage, especially in the summer and autumn seasons.

Figure 8 shows hourly, daily, and monthly variations of PM_{10} and SO_2 concentrations normalized by the yearly average concentrations of 52.1 µg/m³ and 8.3 µg/m³ respectively. When it is examined on a daily basis, there is not much difference in the average pollutant concentration between weekdays (Monday-Friday). However, slightly higher pollutant concentrations were found on Tuesday and Thursday compared to other days. The highest value for PM_{10} (179.7 µg/m³) was measured at 00:00 on 01.11.2018, while the highest value for SO_2 (39.4 µg/m³) was measured at 12:00 on 12.02.2018.

On a monthly scale, the atmosphere has more PM_{10} and SO_2 generally in winter months (Jan-Mar) because of heating from generally conventional resources. In addition, it was observed in the normalized graph that the sulfur dioxide concentration difference between winter and summer was much higher than the particulate matter concentration difference. This naturally shows that the need for residential heating decreases in the summer months. In other words, the source of the particulate matter in the atmosphere in Ağrı during the summer period mostly results from the transportation and location of the station.

Meteorological factors play a significant role on the levels of air pollution due to transport, transformation, and dispersion of air pollutants. Since Ağrı province has mountainous terrain around it, wind direction is determined by the effect of topography as mentioned in the previous section. According to the obtained wind data, the dominant wind direction was determined as north in different seasons in 2018, particularly in summer and winter (Figure 9).

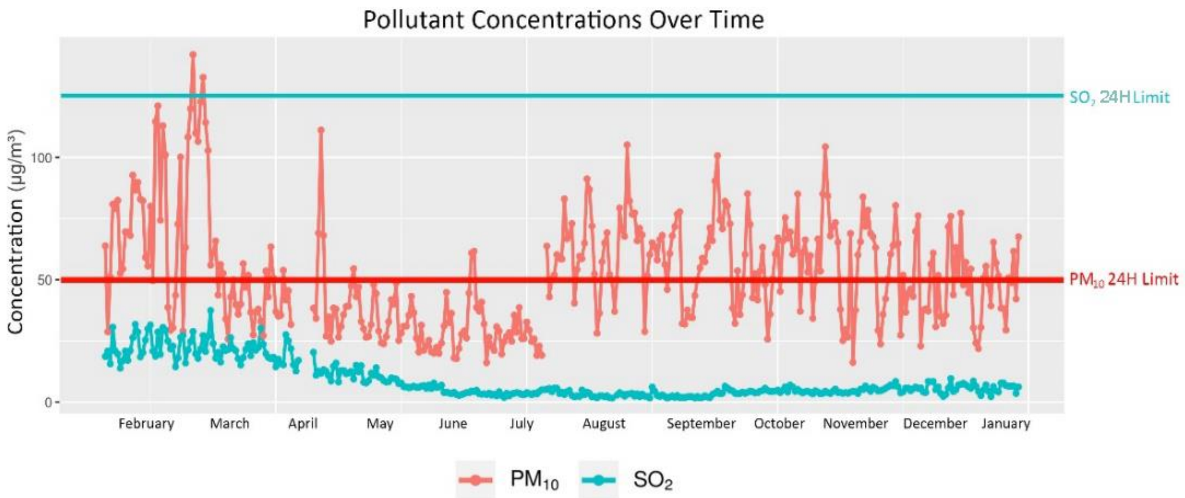

Figure 6. Time series of daily average concentrations of PM_{10} and SO_2 in 2018. The red line is an indicator for the Turkish limit of daily SO_2 (125 µg/m³) and PM_{10} (50 µg/m³)

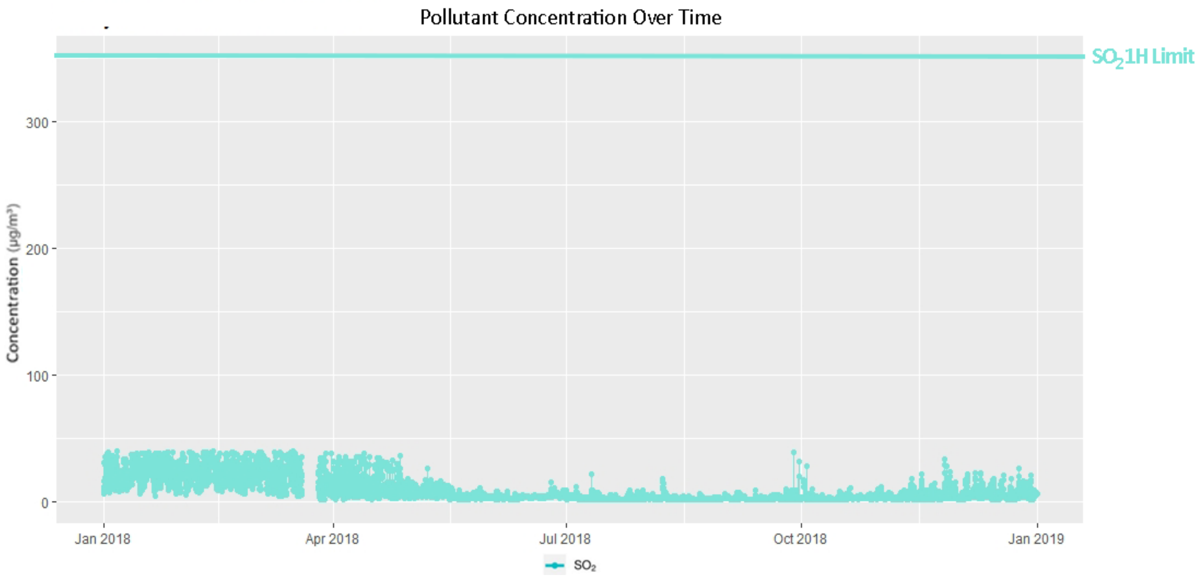

Figure 7. Time series of hourly concentrations of SO_2 in 2018. The blue line is an indicator for the Turkish limit of hourly SO_2 (350 µg/m³)

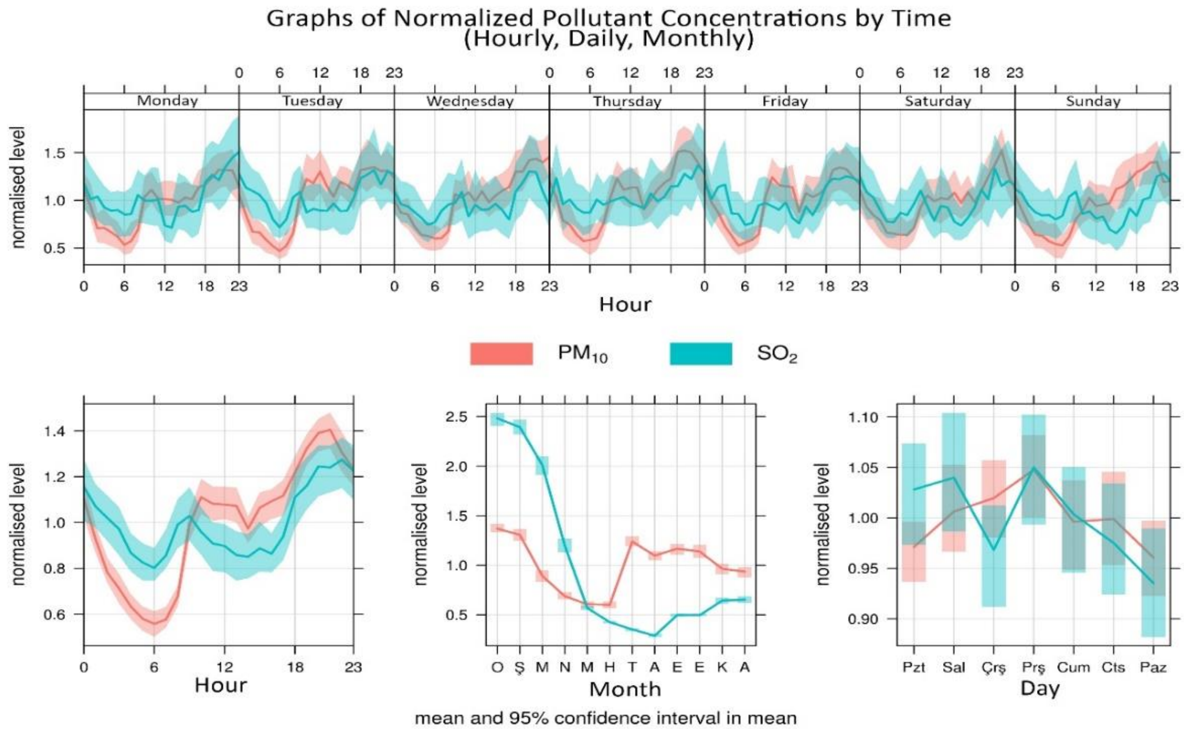

Figure 8. Normalized graphs of pollutants by time (hourly, daily, monthly)

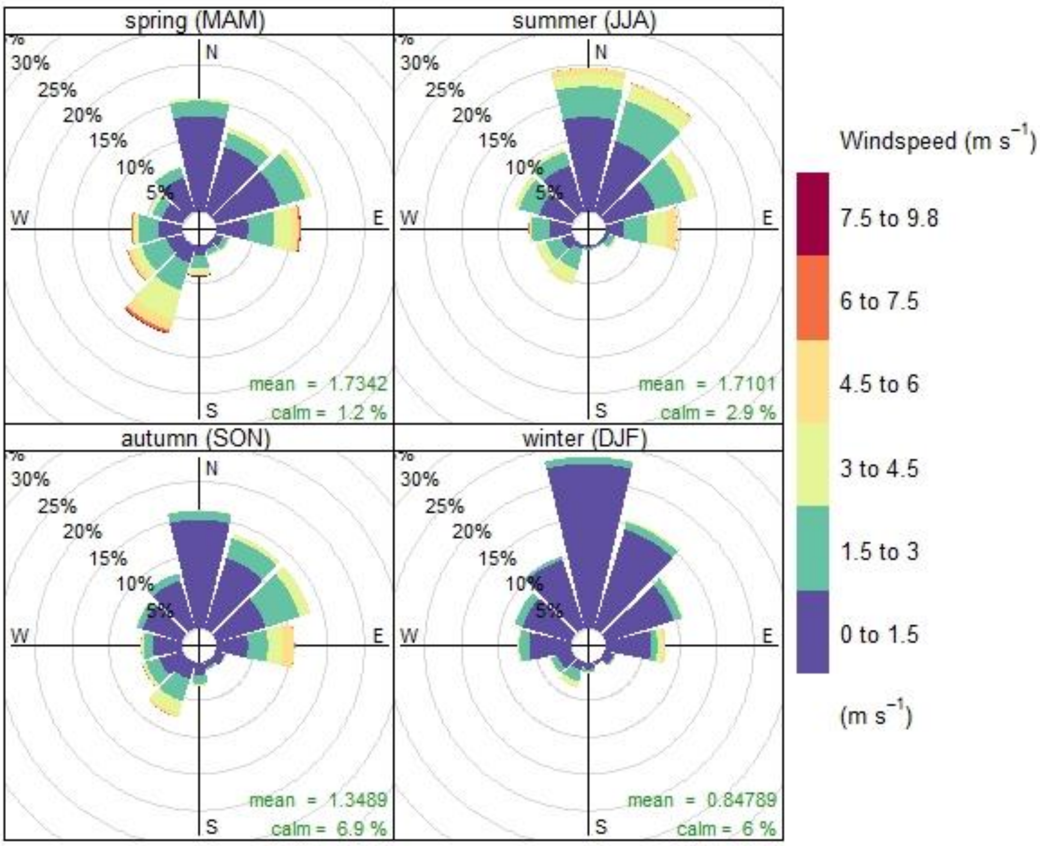

Figure 9. Seasonal wind rose of Agri in 2018

According to Figure 10 and Figure 11, it can be clearly seen that pollution forms from different directions during the year, and it intensifies especially around the station and in the East in winter because of low wind speed values (0 to 1.5 m/s). Considering that there are residential areas in the North and East of the station, the type of pollution may be considered to be residential, especially in the winter and spring months. In the spring, an increase in both PM_{10} and SO_2 concentrations was observed from the East and mostly from the southwest direction. Considering the wind speed, the pollution here is thought to be caused by the construction and from the southwestern settlements. Also, it can be seen that the construction area in the Southwest direction creates particulate pollution in various time periods.

The reason for the high amount of particulate matter, especially in summer, is a situation that occurs due to the location of the station. Since the location of the station is in the middle of the two lanes of dirt road, the vehicles passing over the road remove the dust on the ground. Therefore, the measured particulate matter concentrations in the summer and autumn months are found to be much higher than expected. In addition, this information was confirmed by the Ministry of Environment and Urbanization (Y. Kara, personal communication, March 29, 2021), which is the owner of the station.

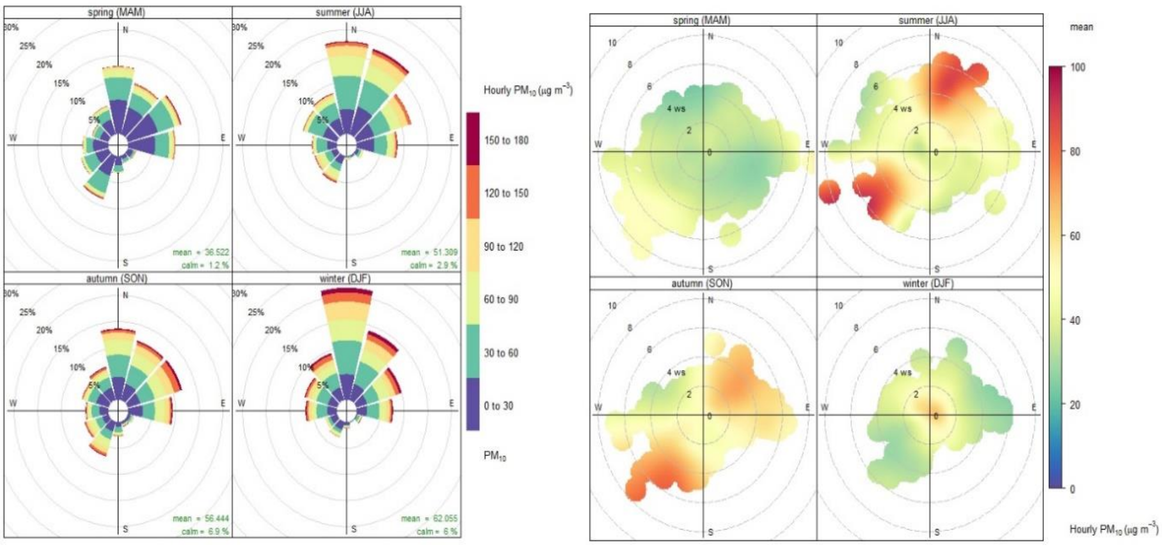

Figure 10. PM_{10} Pollution rose (left) and Polar plot (right) during various seasons

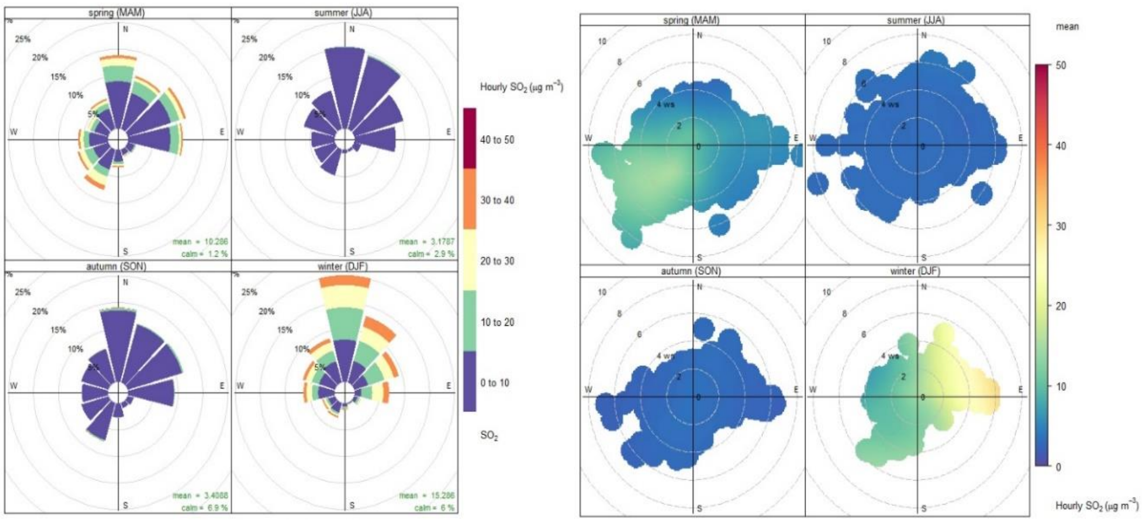

Figure 11. SO_2 Pollution rose (left) and Polar plot (right) during various seasons

Diurnal variations of PM_{10} and SO_2 during the weekdays and weekends are shown in Figures 12 and 13, respectively. On the hourly scale on weekdays (Figure 12), there is a decrease in the concentration of both PM_{10} and SO_2 between the hours 00:00 and 06:00 because of fewer anthropogenic activities. In addition, it is clearly seen that pollutant concentrations increase between 06:00 to 12:00 and 17:00 to 20:00 because of various activities such as mining, construction, heating, and driving due to commuting. The highest hourly average PM_{10} concentration observed on weekdays was 72.2 µg/m³ at 20:00 and the lowest value was 28.4 µg/m³ at 06:00. On the other hand, the highest hourly average SO_2 was 10.7 µg/m³ at 22:00 and the lowest value 6.5 µg/m³ at 06:00. In addition, on hourly scale on weekends (Figure 13), the variation of both pollutants is similar to weekdays. However, at 14:00 there is a decrease in the concentration of PM_{10} which is not observed on weekdays. Also, a slightly stronger diurnal cycle is observed during the weekends, with concentrations increasing rapidly at 8:00 and remaining relatively constant and high until 17:00 when they continue to increase. During the weekends, the highest average hourly PM_{10} concentration was observed as 75.9 µg/m³ at 21:00 and the lowest as 30 µg/m³ at 07:00. The highest hourly average value of SO_2 was observed as 10.3 µg/m³ at 22:00 and the lowest value as 5.8 µg/m³ at 15:00. Also, the particulate matter and sulfur oxide gas concentrations do not likely increase depending on each other and thus may have different sources. According to the diurnal variations observed in Figs. 12 and 13, it is possible that the primary factor causing the increase of air pollution due to atmospheric particles is vehicle emissions using conventional energy sources, while the use of coal may be the main cause for sulfur dioxide emission, in addition to particulate matter.

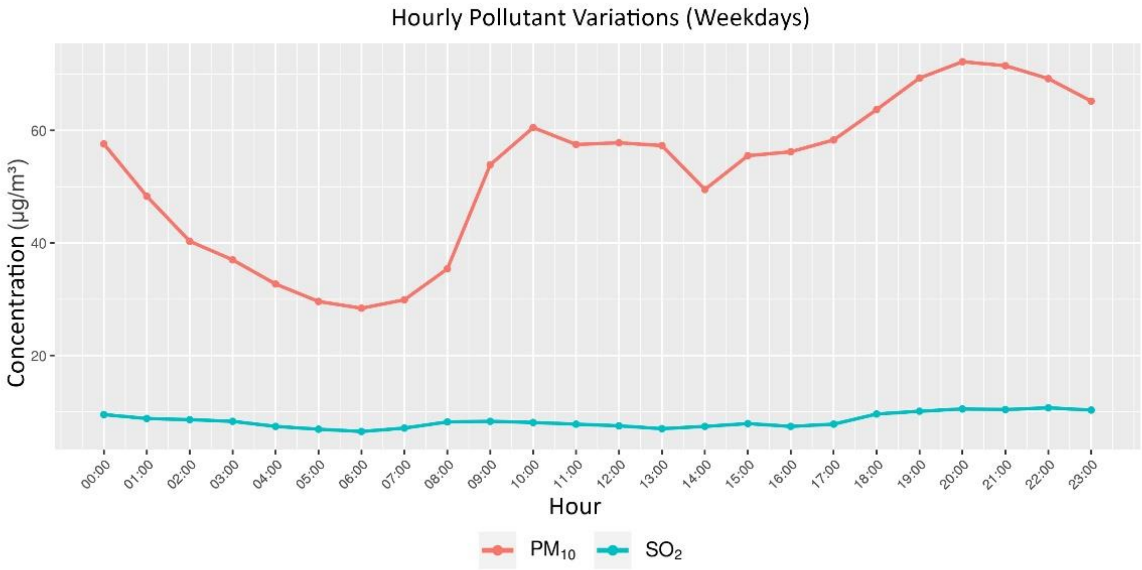

Figure 12. Diurnal variations of PM_{10} and SO_2 during the weekdays (Mon-Fri)

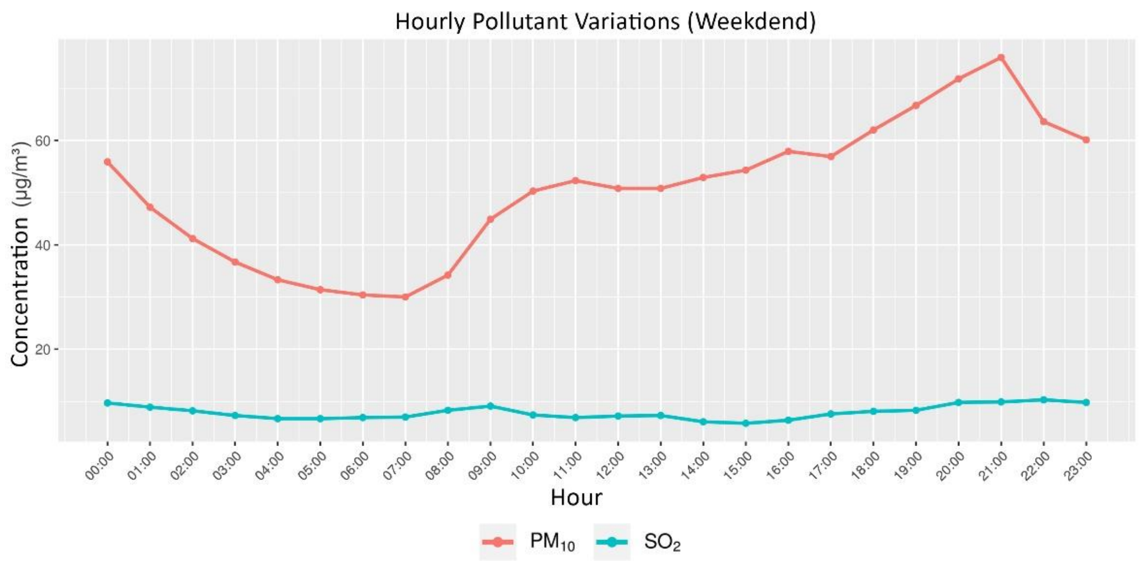

Figure 13. Diurnal variations of PM_{10} and SO_2 during the weekends (Sat-Sun)

IV. DISCUSSION

4.1. National Air Quality Index (NAQI)

The National Air Quality Index was created by adapting the EPA Air Quality Index to our national legislation and limit values. The NAQI is calculated for 5 basic pollutants which are particulate matter (PM_{10}), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3). The ranges of the air quality index applied in Turkey are shown in Table 3.

In order to find the daily concentrations of pollutants, the 24-hour average of the data was calculated. These calculated values were compared with the PM_{10} (daily) and SO_2 (hourly) concentration thresholds in the National Air Quality Index (Table 3) in order to determine how many days, the atmosphere was polluted on a yearly and seasonal basis. The seasonal analysis showed that the most decrease in the air quality was observed during the winter (64%) and autumn (60%) according to Table 4. Also, it was found that the cleanest season in 2018 was spring and the most polluted season was winter.

Figure 14 shows the AQI applied to both pollutants during the calendar year of 2018. According to the AQI, it was found that for PM_{10} 51% were observed in the "good" class, 44% in the "moderate" class and 5% in the "sensitive" class in terms of 24h mean value. When SO_2 measurement values were analyzed as a percentage, it was observed that 100% of the data were in the "good" class in terms of 1-h mean value in Ağrı. According to the results, air pollution in Ağrı mostly results from particulate pollution. In addition, the concentrations of sulfur dioxide gases resulting from the sources used for heating are very low. Considering that the station is located near one of the crowded boulevards of Ağrı, it is seen that the source of pollution is linear-based pollutant rather than areal pollution source.

Table 3. National Air Quality Index [26]

Index	AQI	SO_2 [µg/m³]	NO_2 [µg/m³]	CO [µg/m³]	O_3 [µg/m³]	PM_{10} [µg/m³]
		1 H. Mean	1 H. Mean	8 H. Mean	8 H. Mean	24 H. Mean
Good	0 – 50	0-100	0-100	0-5500	0-120	0-50
Moderate	51 – 100	101-250	101-200	5501-10000	121-160	51-100
Sensitive	101 – 150	251-500	201-500	10001-16000	161-180	101-260
Unhealthy	151 – 200	501-850	501-1000	16001-24000	181-240	261-400
Bad	201 – 300	851-1100	1001-2000	24001-32000	241-700	401-520
Dangerous	301 – 500	>1101	>2001	>32001	>701	>521

Table 4. Descriptive statistics of 24-h and 1-h average pollutants according to season

	PM_{10} (µg/m³) (24-h)				SO_2 (µg/m³) (1-h)			
Months	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
1st Quarter	18.21	24.99	25.30	26.64	4.19	2.10	2.09	5.68
Median	28.00	43.98	45.94	46.80	6.71	2.88	2.73	13.94
Mean	34.44	51.28	53.69	55.37	10.29	3.14	3.43	15.27
3rd Quarter	42.55	71.98	76.88	79.46	13.69	3.74	3.73	22.24
Polluted Days (%)	10	56	60	64	0	0	0	0

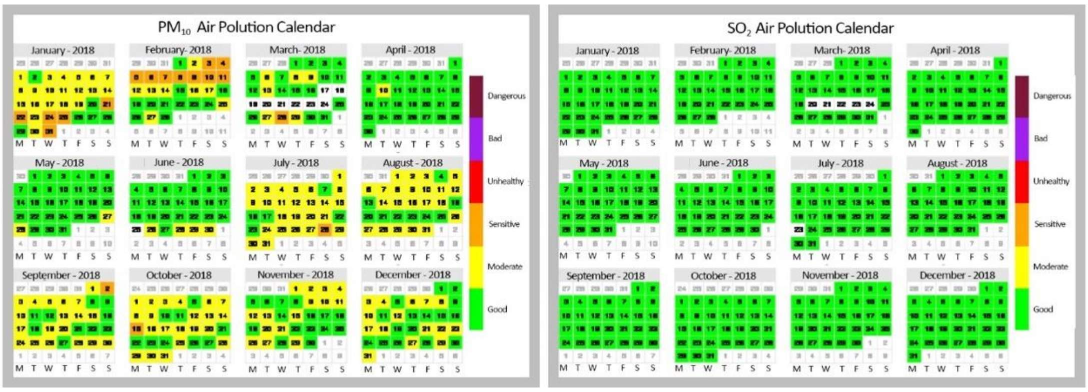

Figure 14. Pollution calendars for both pollutants

V. CONCLUSIONS

In this work, PM_{10} and SO_2 concentrations were investigated in the rural area of Ağrı in 2018. Their hourly, daily, and seasonal variations were discussed and the concentrations were compared to regulations and recommendations in order to evaluate the overall air quality of Ağrı during the whole year. Overall, it was found that SO_2 concentrations were well below the regulations, and the majority of the air pollution in Ağrı was due to PM_{10}. Hourly PM_{10} and SO_2 concentrations ranged as 9.4-179.7 and 1.4-39.4 µg/m³, with average values of 52.1 and 8.3 µg/m³, respectively. Hourly concentrations are a better indicator of air quality than daily-averaged concentrations. According to the Common Air Quality Index (CAQI) applied to hourly PM_{10} concentrations, the population in Ağrı was exposed to medium and high air pollution 25 and 15% of the time in 2018, respectively. While averaged-daily SO_2 concentrations were well below the Turkish limit of 125 µg/m³, PM_{10} concentrations exceeded the daily limit of 50 µg/m³ at all months, except in Apr-Jun, 2018. As commonly observed in other residential sites, both, PM_{10} and SO_2, showed the maximum and minimum concentrations during the winter and summer seasons, respectively. This behavior may be due to a combination of emission sources and meteorology, particularly the use of coal for residential heating and transportation, and most importantly due to the location of the air quality station. Since the station is in the middle of dirt roads, dust resuspension may be partly responsible for concentrations observed in the summer and autumn months.

The statistical analysis showed that 56-60% of the days in 2018 were classified as polluted in summer, autumn, and winter. According to the Air Quality Index of Turkey, using daily-averaged PM_{10} concentrations as indicators, the air quality in Agri was classified as good, moderate, and sensitive 51, 44, and 5 % of the time in 2018, respectively. According to the results obtained in this work, it is recommended that more efforts are done to decrease emissions of PM_{10} throughout the year and to change the location of the station. In future studies, the time period should be expanded to obtain a long-term perspective.

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