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Seasonal analysis and mapping of air pollution (PM10 and SO_2) during Covid-19 lockdown in Kocaeli (Türkiye)

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Abstract

The Covid-19 epidemic has adversely affected the world in terms of health, education, economic, tourism, social and psychological. During to the epidemic, different measures were taken to prevent the epidemic, such as travel bans, curfews, stopping in production. These measures have reduced and improved air pollution. Within the scope of this study, the change in air pollution in Kocaeli between 2019 and 2021 was examined monthly. PM10 and SO2 maps were created with inverse distance weighted (IDW) technique using geographic information systems technology (GIS). The year 2020, when Covid-19 measures were taken, was compared with 2019 and 2021. Change maps were created by taking the difference between 2020-2019 and 2021-2020 with GIS technology. As a result of the research, it was determined that the level of air pollution decreased in 2020. On the contrary, in 2021, an increase in air pollution levels was observed. In the study, a decrease was observed in PM10 concentration during the Covid-19 lockdowns, however a decrease was not observed for SO_2.

1. Introduction

In the last days of December 2019, it was reported that the novel coronavirus (2019-nCoV, or COVID-19) epidemic first broke out in Wuhan and has been spreading in whole China and the world. It was declared a pandemic by the WHO for the disease spread rapidly and turned into a global epidemic [1]. First, measures were taken by governments, such as personal hygiene, restrictions on human mobility, and social isolation. Within this scope, restrictions were imposed on public gatherings (entertainment, religious, political, business, sports, education), public transportation, some production facilities, and international and local travel around the world [2].

As Covid-19 cases started to be identified in Turkey's border neighboring countries (Iran, Iraq, Greece, Bulgaria), measures have started to be increased in Turkey. General information about the disease and the pandemic was published, and the public was informed with videos and posters. Hospitals that provide certain conditions in the country were defined as pandemic hospitals. The first coronavirus case in Turkey was detected on 10 March 2020 and the public was informed on 11 March. Since this date, restrictions include suspending education, bans on travel, stopping activities in places where people spend time together, switching flexible shift systems, banning risk group people from going out, and the lockdown has been taken. With the spread of the disease, restrictions continued [3-4].

Social isolation measures taken to prevent the spread of the virus did not only provide its progress but also affects the environment positively [2]. The isolation measures taken due to the Covid-19 epidemic adversely affected the country's economies and human activities. On the contrary, it has had a positive effect on the improvement of air quality thanks to reduced human activities and reduced pollutant emissions [5]. It is said that there are significant changes in air pollution within the scope of the measures taken due to the Covid-19 epidemic [6].

Urbanization with industrialization causes the population and the number of vehicles to increase in the world. One of these environmental problems is air pollution [7-8]. The primary pollutants in the atmosphere list as follows: particulate matter (PM), sulfur dioxide (SO_2), carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), nitrogen dioxide (NO_2), nitrogen oxides (NO_X). WHO considers that using PM_{10} and SO_2 to measure air quality is enough [9]. World

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Health Organization list premature deaths, lung cancer deaths, acute respiratory infections, strokes, and chronic obstructive pulmonary disease as the deaths caused by air pollution [10].

It is aimed to examine the effect of the restrictions taken during the Covid-19 period on air pollution by examining the change in air pollution in Kocaeli, one of the important industrial cities of Turkey in this study.

1.1. Covid-19 and Air Pollution

Measures such as reducing human activities and reducing pollutant emissions taken to control the pandemic are important in terms of improving air quality. Studies within the scope of this purpose were examined in the literature. Sahrei et al. [11] determined that there was a 90% diminished in the use of public transport during the Covid-19 quarantine period. They confirmed reductions in air pollutants at the same time. Vega et al. [12] conducted research in Mexico City, London, and Delhi 2021. They confirm that Covid-19 restrictions reduced traffic in the urban area and improved air quality. Gouda et al. [1] study for the city of Bangalore, confirmed reductions in air pollutant concentrations during the Covid-19 quarantine period compared to the previous year. In their study conducted in many parts of India in 2022, Marwah and Agrawala confirm that air pollutants reduce according to 2019 data [2]. In another study conducted in India, it was concluded that $PM_{2,5}$, PM_{10}, and NO_2 decreased within the scope of Covid-19 measures. It was concluded that the air quality has improved significantly in the city of Delhi [6]. They observed the effect of air pollution. They examined the quarantine period that they divided into 6 parts in Iraq. In this study, they found that the air quality improved as a result of the reduction in human activities in Iraq [5]. Yang et al. [13] conducted research within the scope of Covid-19. They ascertained a decrease in $PM_{2,5}$, PM_{10}, NO_2, and CO levels as a result of studies carried out in different parts of the world. They found that no improvement could be detected in SO_2 and O_3 levels. They examined $PM_{2.5}$ changes during Covid-19. As a result of the study, it was determined that the highest decrease was in America, Asia, and Africa. The highest decrease was found in Bogotá, Colombia with 57% [14]. Özel et al. [15] studied in the Çernezköy organized industrial zone in 2021. The temporal variation of the air quality index was examined in the study. It was observed that the air quality index was at a good level compared to previous years at the time of the restrictions due to the pandemic. Collivignarelli et al. studied air quality during the Covid-19 quarantine period in Milan. They detected a decrease in the concentration of most pollutants such as PM_{10}, $PM_{2,5}$, and CO. But they did not see a decrease in SO_2 [16]. Kumari and Toshniwal researched Beijing, Bengaluru, Delhi, Las Vegas, Lima, London, Madrid, Moscow, Mumbai, Rome, Sao Paulo, and Wuhan in 2020. They found that $PM_{2.5}$, PM_{10}, and NO_2 parameters decreased during the Covid-19 lockdowns. They did not find a regular change in SO_2 and O_3 parameters [17]. Lian et al. [18] in their study in Wuhan, found that the air quality index decreased significantly. Adams [19] researched it in Ontario, Canada in 2020. Adams [19] studied air pollution during the Covid-19 state of emergency. As a result of the study, Adams [19] observed that NO_2 and NO parameters decreased.

2. Method

2.1. Study area

Kocaeli city is located in Marmara Region. Figure 1 shows the location of Kocaeli city. It is the 10th most populous city in Turkey and the 2nd city in terms of population density. According to 2021 TUIK data, it has a population of 2.033.441 people according to the data of 2021 and an area of 3397 km² [20].

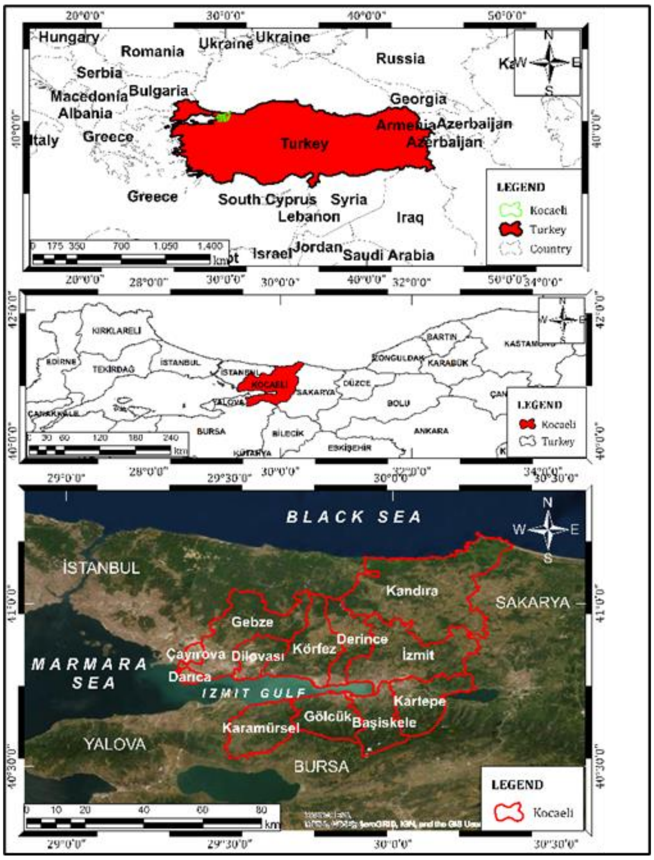

Figure 1. Kocaeli location map

It is among the important industrial cities of Turkey. There are sectors such as the automotive industry, iron-steel, chemistry, and plastics in the city. It is at a crossroads between the Asian and European continents. It has a busy sea route with the Körfez Port, which is a natural port. Kocaeli has research-development and innovation centers and ranks 2nd in Türkiye.

2.2. Data set

Data used in the study were obtained from the National Air Quality Monitoring Network. PM_{10} and SO_2 concentration data, which are pollution parameters, were provided daily for the years 2019-2021 [21]. The monthly averages of the pollution parameters were calculated from 10 stations (Figure 2).

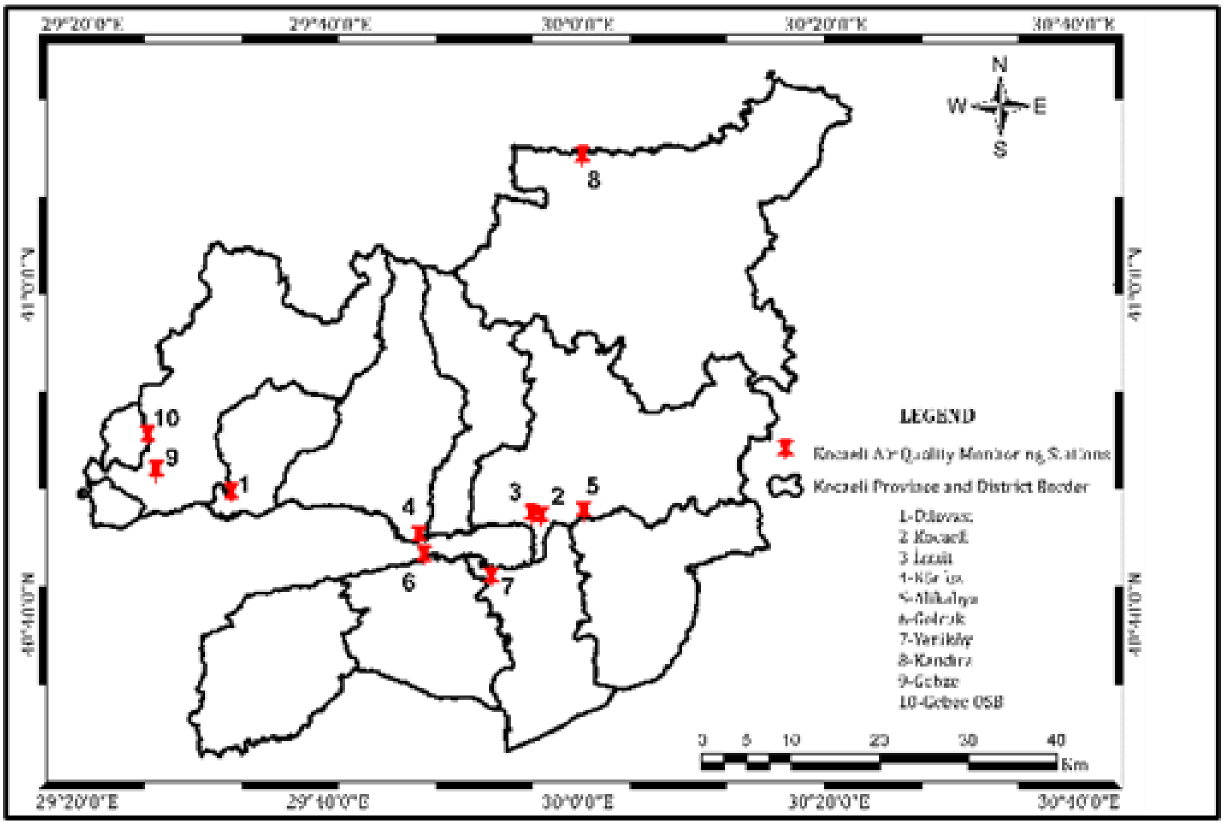

Figure 2. Kocaeli air quality monitoring stations

The monthly average PM_{10} and SO_2 concentration data between 2019 and 2021 are shown in Table 1.

Table 1. Monthly average concentration values

Months	Polluting	2019	2020	2021
January	PM_{10}	40.03	35.48	45.65
	SO_2	8.64	9.66	11.72
February	PM_{10}	45.73	36.23	51.89
	SO_2	8.60	11.21	12.30
March	PM_{10}	47.53	41.36	42.36
	SO_2	9.67	11.09	15.46
April	PM_{10}	41.84	31.73	43.19
	SO_2	6.61	10.65	14.09
May	PM_{10}	41.25	29.71	38.92
	SO_2	9.08	10.02	11.74
June	PM_{10}	33.77	28.64	35.10
	SO_2	5.04	6.18	11.79
July	PM_{10}	26.90	25.60	34.21
	SO_2	4.29	4.50	6.29
August	PM_{10}	27.47	27.71	36.05
	SO_2	4.11	7.88	6.34
September	PM_{10}	30.05	37.28	29.15
	SO_2	5.32	7.73	7.26
October	PM_{10}	38.49	52.61	34.14
	SO_2	6.81	11.52	10.42
November	PM_{10}	50.28	43.24	59.94
	SO_2	10.89	7.64	16.34
December	PM_{10}	43.96	45.88	37.48
	SO_2	10.81	11.62	14.11

2.3. Inverse Distance Weighted (IDW)

Inverse distance weighted (IDW) is one of the interpolation methods. This method aims to generate data by interpolation using sample points. This technique is based on over-weighting the nearby sampling points on the surface to be interpolated. The weight decreases as the sample point get farther away. It performs surface interpolation by taking the weighted average of the sample points with this method [22-23].

The IDW method is said to be more suitable for interpolating air pollution parameters. Jumaah et al. [24] studied the estimation of the air quality index. The IDW technique was used for the interpolation of the parameters for this study. Vorapracha et al. [25] studied interpolation methods. In the study, they produced values for PM_{10} by interpolation. They found that the best interpolation result was IDW [25].

Geographic information systems (GIS) are important for decision-makers to better interpret and visualize events and data [26-30]. It is also said that GIS is an important technology for air pollution [31-33] and natural disaster studies [34-36].

3. Results

3.1. Mapping of Air Pollution

Air pollution was mapped using the data of the measuring stations for Kocaeli province. Pollution was mapped using the IDW technique within ArcGIS 10.6.1. software.

Monthly maps of air pollution (PM_{10} and SO_2) between 2019 and 2021 were created and it was aimed to compare the months in terms of air pollution.

PM_{10} concentration maps for December, January, and February are shown in Figure 3.

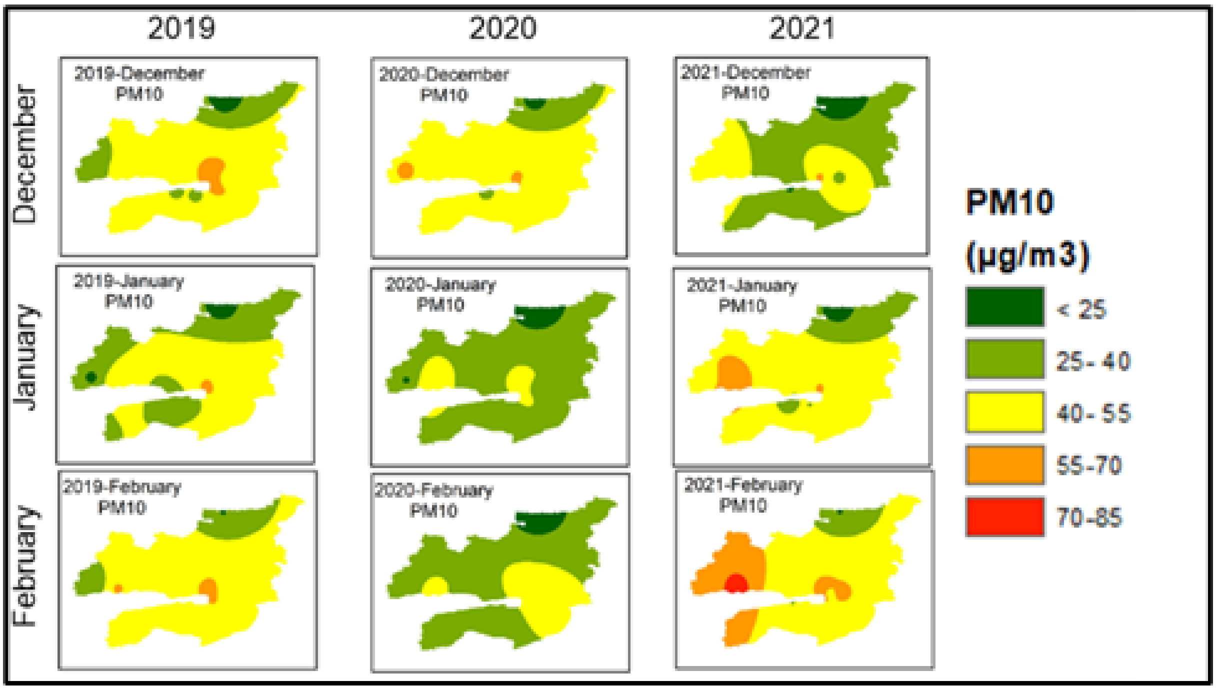

Figure 3. PM_{10} concentrations for winter

Winter term PM_{10} maps demonstrate a decrease in PM_{10} concentration in December 2021 compared to December 2019 and 2020. A decrease in PM_{10} concentration was observed in January and February 2020 compared 2019. On the contrary, PM_{10} concentration increased in January and February 2021 in the whole city and especially in the western part of Kocaeli. In addition, there is a lot of industrial density in this area. Therefore, it is a factor in the rise in pollutant concentrations. This can be considered as an indication that the covid measures are held more tightly in 2020 than in 2021. SO_2 concentration maps for December, January, and February are presented in Figure 4.

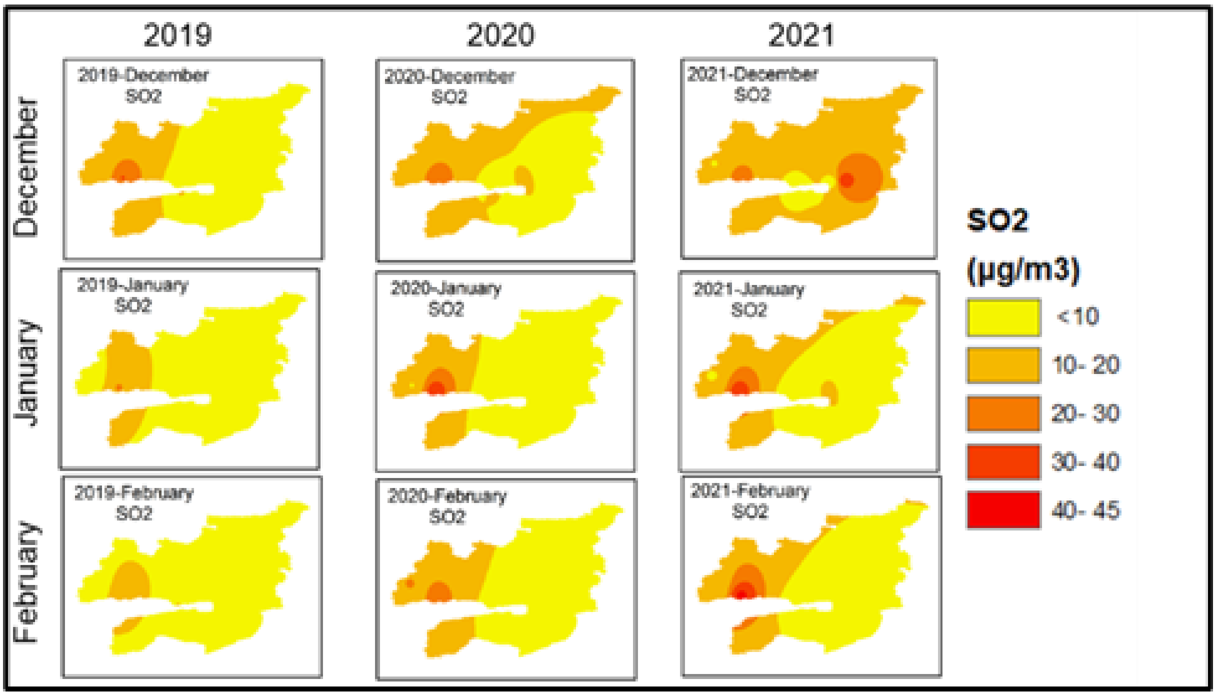

Figure 4. SO_2 concentrations for winter

The winter term SO_2 parameter concentration increased continuously from 2019 to 2021 in December, January, and February in western part of Kocaeli. In December 2021, it is observed that the SO_2 parameter values increased especially in the İzmit Kocaeli Bay end region. In addition, it can be said that this value has increased in an industrialized region Dilovası, in January and February of 2020 and 2021.

PM_{10} concentration maps for March, April and May are shown in Figure 5.

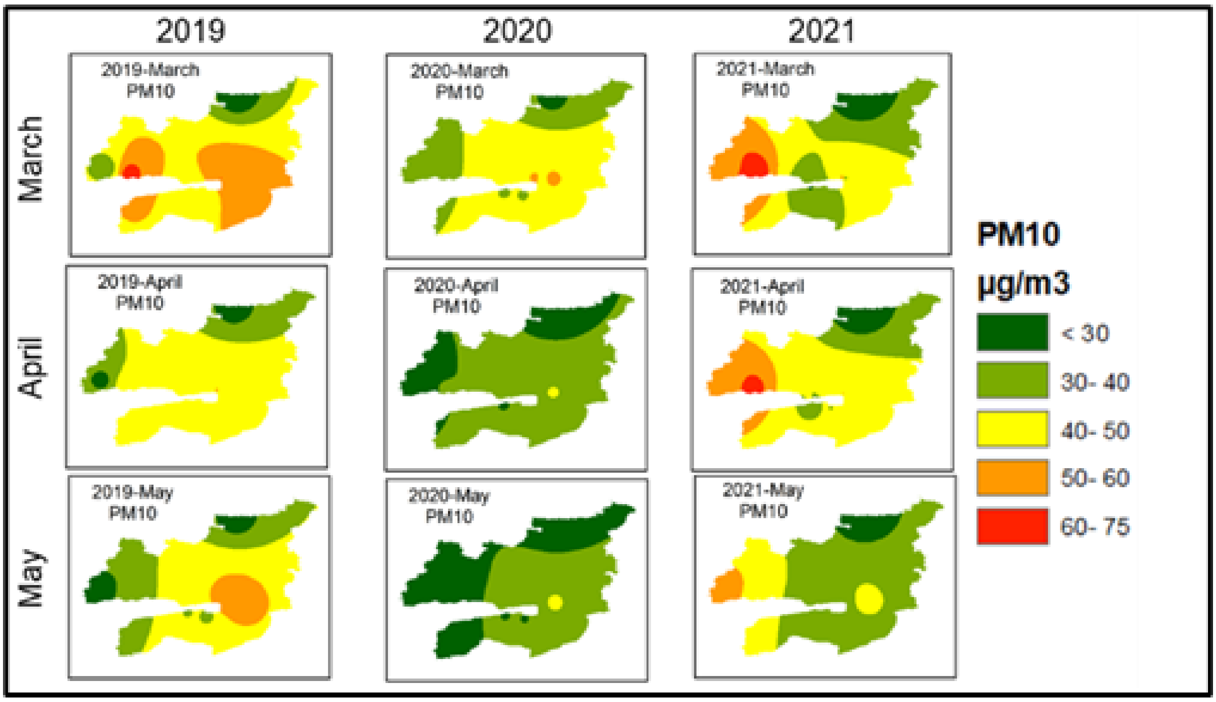

Figure 5. PM_{10} concentrations for spring

A notable reduction in PM_{10} concentration was observed in the spring season of 2020 compared to 2019. On the other hand, the PM_{10} concentration increased in 2021. March, April, and May of 2020 are the months with the most Covid-19 restrictions occurred. Under this case: It can be said that the reason for the PM_{10} decreases in 2020 might be Covid-19 restrictions.

SO_2 concentration maps for March, April, and May are shown in Figure 6.

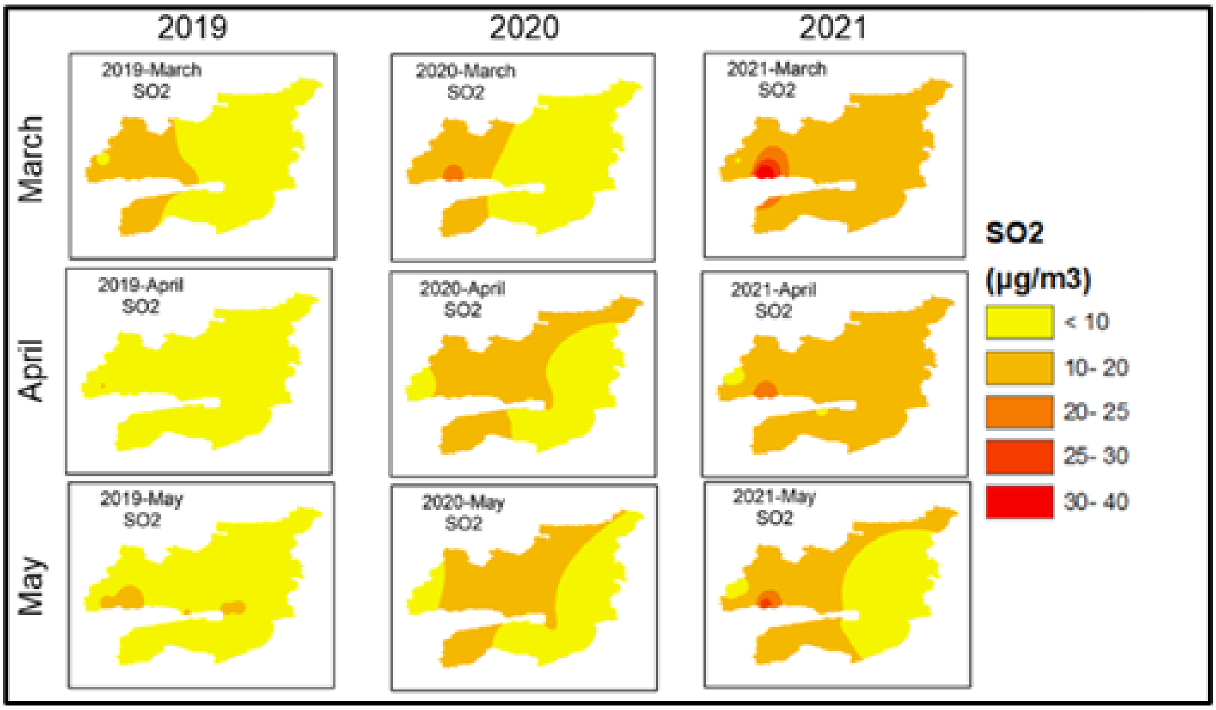

Figure 6. SO_2 concentrations for spring

The SO_2 parameter in the spring term increased continuously from 2019 to 2021. March is the month where the most SO_2 spread in the whole city especially in Dilovası.

PM_{10} concentration maps for June, July, and August are presented in Figure 7.

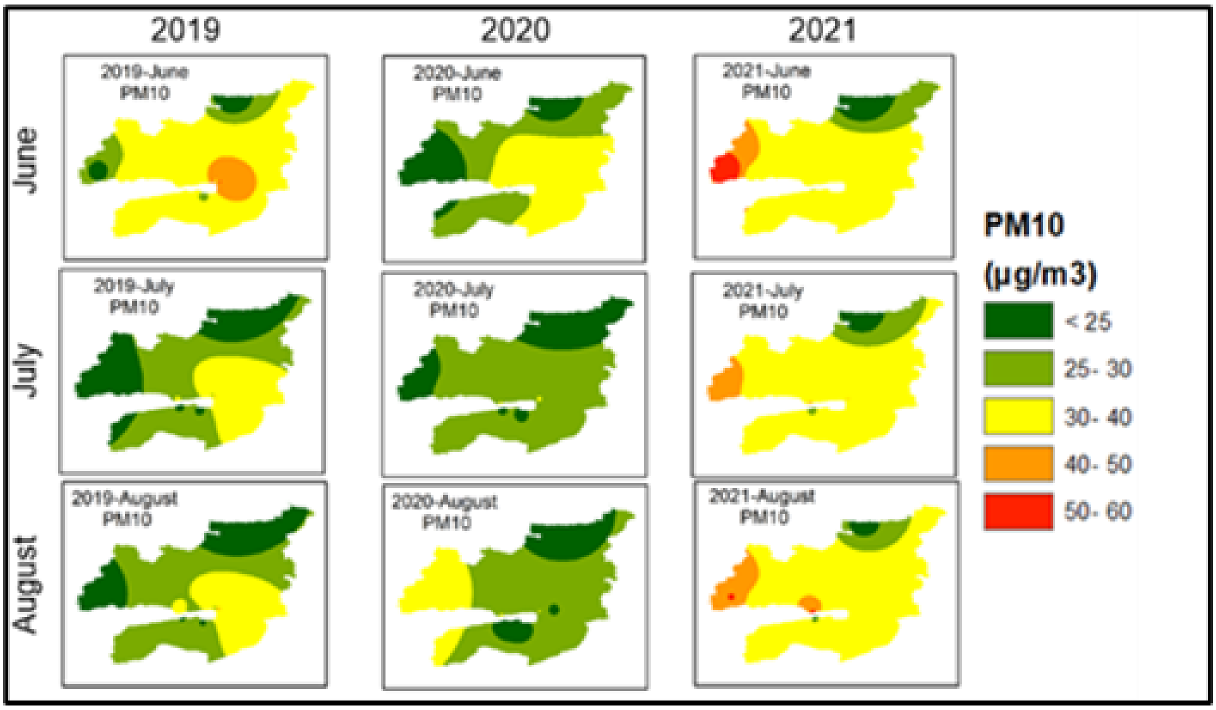

Figure 7. PM_{10} concentrations for summer

A significant decline in PM_{10} concentration in June, July 2020 compared to 2019 was observed in the whole city. There was no change in August 2019 compared to July 2019. Also, PM_{10} concentration increased in summer term in 2021 compared to 2020.

SO_2 concentration maps for June, July, and August are shown in Figure 8.

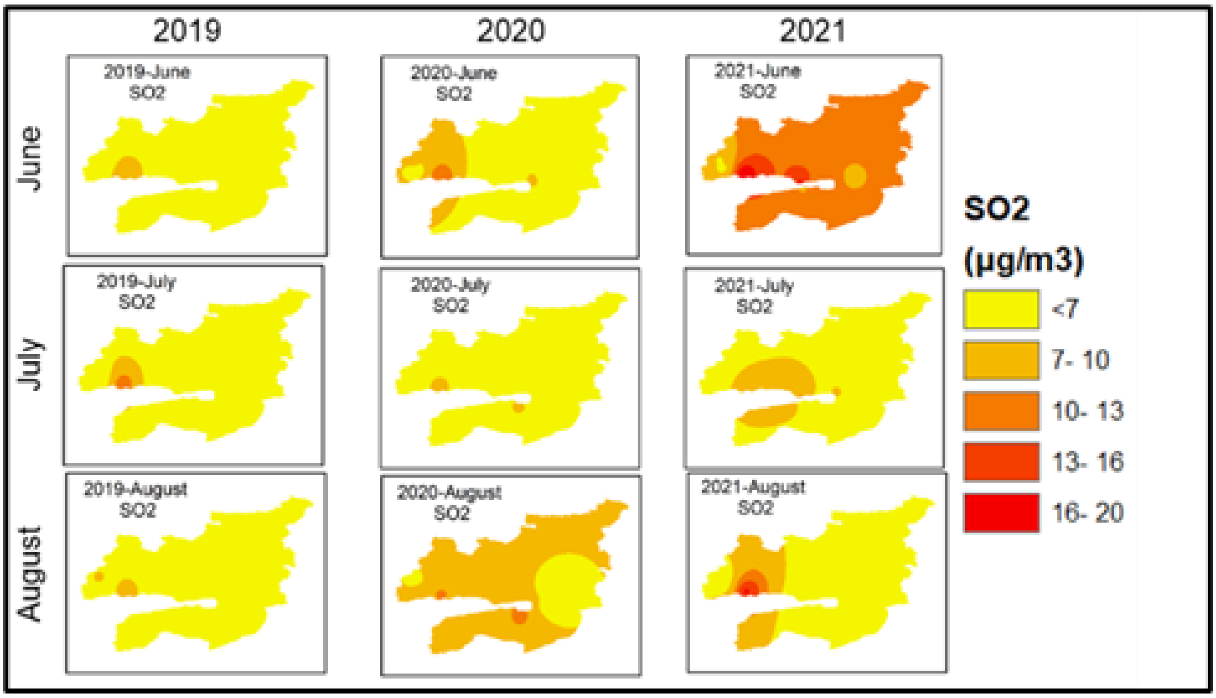

Figure 8. SO_2 concentrations for summer

The SO_2 parameter increased continuously from 2019 to 2021 in summer term, except for August. June 2021 was the month where highest SO_2 concentration was observed in the whole city. This might be due to reducing the covid restrictions in the beginning period of summer.

PM_{10} concentration maps for September, October, and November are shown in Figure 9.

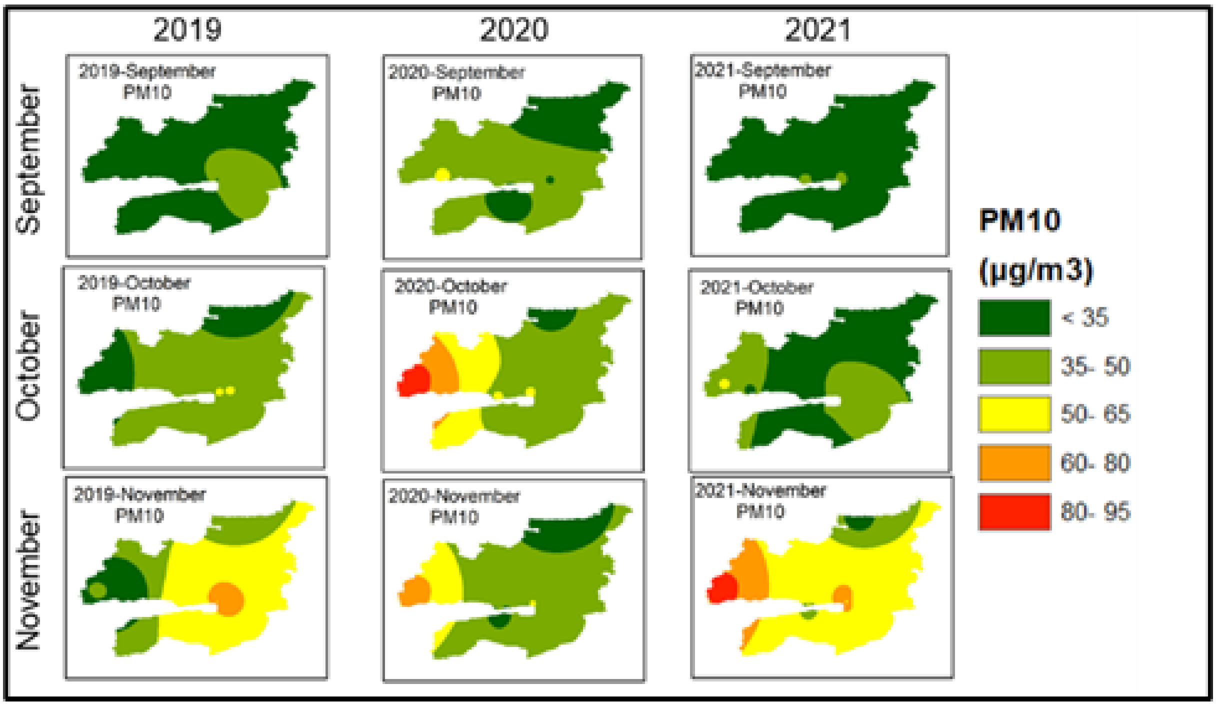

Figure 9. PM_{10} concentrations for autumn

The autumn term PM_{10} concentration for 2019, 2020, and 2021 was observed. An increase was identified in September and October 2020 compared to 2019 however, a decrease in PM_{10} concentration was founded in November 2020 compared to 2019. September 2021 is the month with the lowest PM_{10} spread throughout the city. September 2021, on the other hand, is the month with the lowest PM_{10} Emission throughout the city, however, in November, this value showed a gradual increase in the Gulf and its environs.

SO_2 concentration maps for September, October, and November are shown in Figure 10.

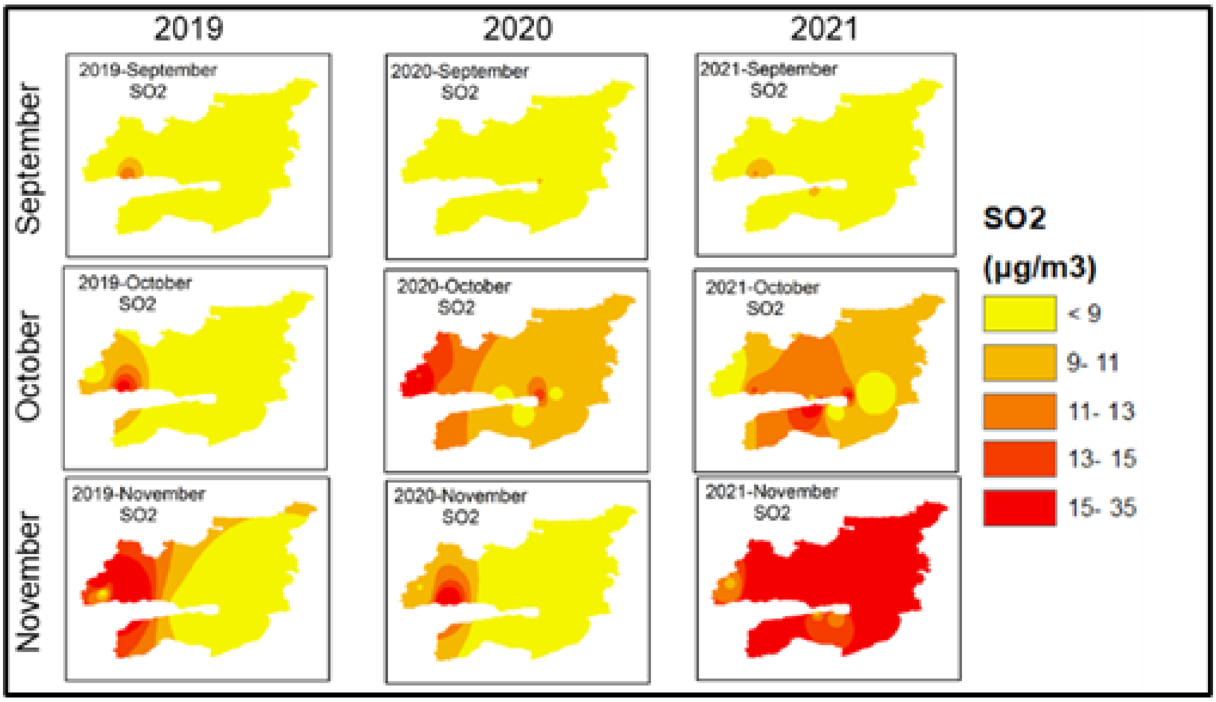

Figure 10. SO_2 concentrations for autumn

SO_2 concentration spread over Kocaeli was observed for 2019, 2020, and 2021 for the autumn term. An increase in SO_2 concentration in October 2020 and 2021 was observed compared to October 2019. A decrease in November 2020 compared to November 2019 was also identified in the eastern parts of the city. SO_2 concentrations reach highest values in the entire city surroundings in November 2021.

Temporal change maps will be more effective in visualizing concentration differences between months. These maps provide spatially the locations of decreases and increases of concentration.

3.2. Temporal Change Maps

The increase and decrease of PM_{10} and SO_2 concentration parameters obtained as a result of the study by months are show in Table 2 and Table 3 as percentages. The year 2020 has been compared with the data of 2019. Likewise, the year 2021 is compared with the data of 2020.

The maximum decrease in PM_{10} parameter in 2020 compared to 2019 was 27.97% in May. The maximum increase in PM_{10} parameter in 2020 compared to 2019 was obtained in October with 36.68%. The maximum decrease in PM_{10} parameter in 2021 compared to 2020 was seen in October with 35.11%. The maximum increase in PM_{10} parameter in 2021 compared to 2020 was seen in February with 43.23%.

In general, while decreases were observed in 2020 compared to 2019 for the PM_{10} parameter, there was an increase in the amount of concentration in 2021 compared to 2020.

The maximum decrease in SO_2 parameter in 2020 compared to 2019 was 29.85% in November. The maximum increase in SO_2 parameter in 2020 compared to 2019 was seen in August with 91.76%. The maximum decrease in SO_2 parameter in 2021 compared to 2020 was seen in August with 19.56%. The maximum increase in SO_2 parameter in 2021 compared to 2020 was seen in November with 114.03%. It was observed that there was a general upward trend for SO_2.

Overlay analysis was used for temporal change maps. As a result, raster maps were subtracted from each other, and change maps were obtained. The map of 2019 was subtracted from the 2020 map. Likewise, the map of 2020 was subtracted from the 2021 map. At the end of the proses, 2 new change maps were obtained. The negative values on the maps show the areas where the concentration value decreased compared to the previous year, while the positive values show the areas where the concentration value increased compared to the previous year. The temporal chance Figures also includes the PM10 or SO_2 concentration for the whole months.

The temporal change maps for PM_{10} concentration between 2019-2020 and 2020-2021 for December, January, and February are shown in Figure 11.

Figure 11 presents the concentration of change by years and the trend of change for each month of the years. When the spatial change maps are examined, it is observed that the decrease from December to February from 2019 to 2020 spread gradually to the city. In February, it is observed that the PM_{10} value has decreased all around the city. On the other hand, when the difference in the concentration distributions of 2020 and 2021 is analyzed spatially, a decrease was observed in the whole city in November, but this difference turned into an increase in January and February. Graphically, PM_{10} 2019 and 2020 tend to decrease from January to August. In this period, 2020 values are lower than 2019. After August, the values of 2020 and 2019 have returned to an increasing trend and 2020 shows this increasing trend more rapidly. Similarly, the PM_{10} value observed between months in 2020 and 2021 shows a downward trend until September, and the values for 2020 are lower than 2021. It has returned to an increasing trend since August 2020 and September 2021. After these months, the values turned to a rapidly increasing trend and decreased in December.

The temporal change maps and change trends over months for SO_2 concentration between 2019-2020 and 2020-2021 for December, January and February are shown in Figure 12.

Figure 12 presents the decreasing concentration mostly on the eastern part of the city in January (2020-2019). However, the SO_2 concentration tends to increase on winter term of 2021-2020 terms. The increasing trend also may be observer from the graphics of SO_2 between 2021-2020.

The temporal change maps and change trends over months for PM_{10} concentration between 2019-2020 and 2020-2021 for Marc, April, and May is shown in Figure 13.

Table 2. PM_{10} concentration difference

	PM_{10} (%)	
Month	2020-2019	2021-2020
January	-11.38	28.69
February	-20.78	**43.23**
March	-12.97	2.43
April	-24.16	36.14
May	**-27.97**	30.97
June	-15.19	22.53
July	-4.86	33.64
August	0.89	30.07
September	24.07	-21.80
October	**36.68**	**-35.11**
November	-14.01	38.63
December	4.36	-18.32

Table 3. SO_2 concentration difference

	SO_2 (%)	
Month	2020-2019	2021-2020
January	11.87	21.25
February	30.32	9.76
March	14.75	39.36
April	61.08	32.29
May	10.31	17.13
June	22.68	90.73
July	4.86	39.97
August	**91.76**	**-19.56**
September	45.30	-6.05
October	69.12	-9.57
November	**-29.85**	**114.03**
December	7.54	21.39

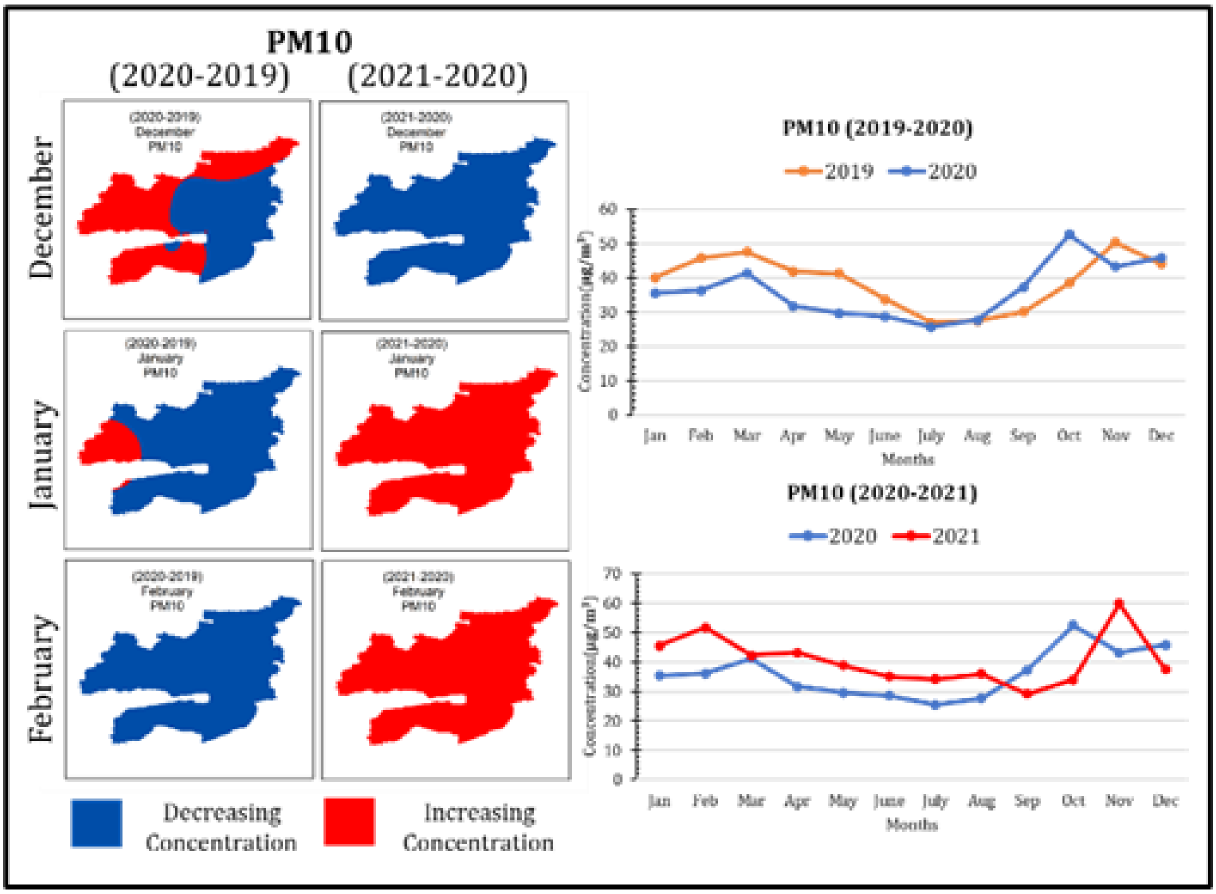

Figure 11. PM_{10} winter concentration temporal change map and trend over months

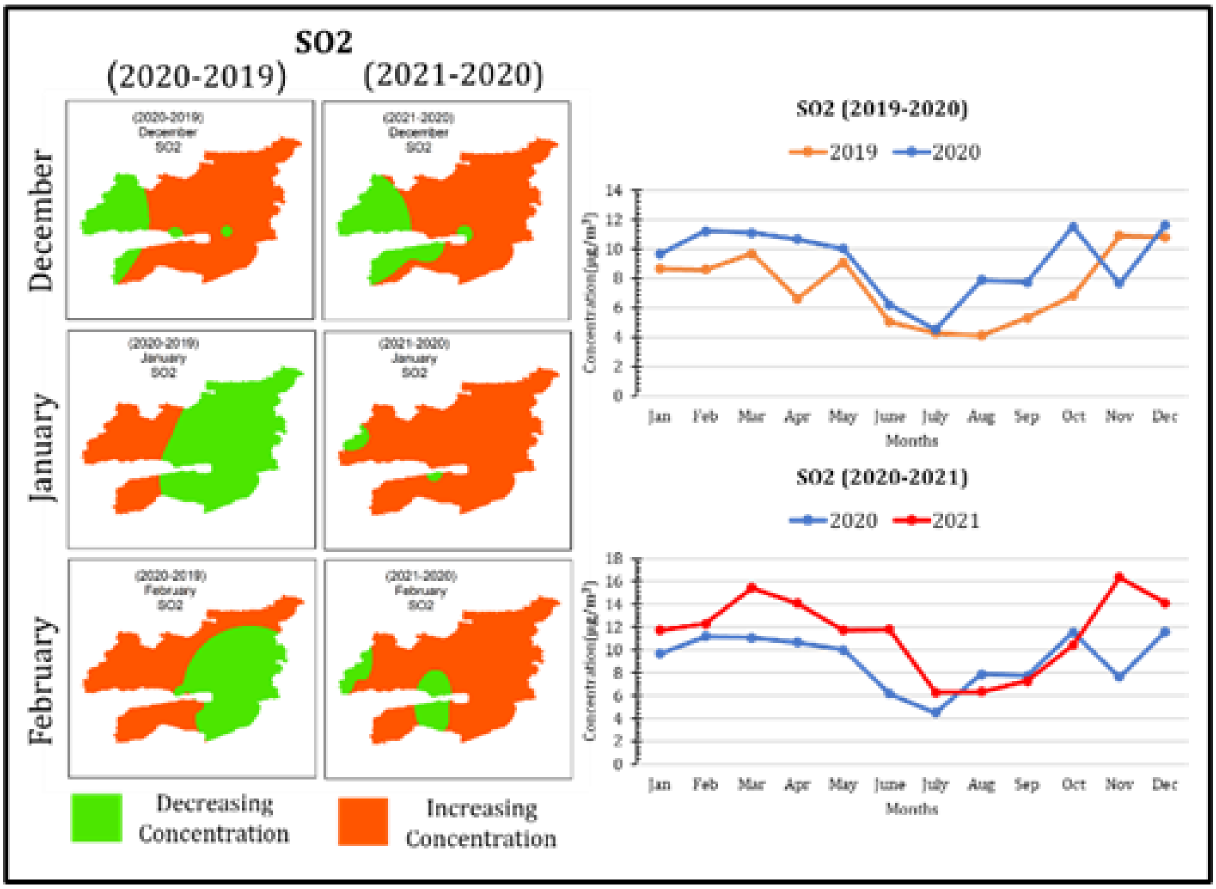

Figure 12. SO_2 Concentration winter temporal change map and trend over months

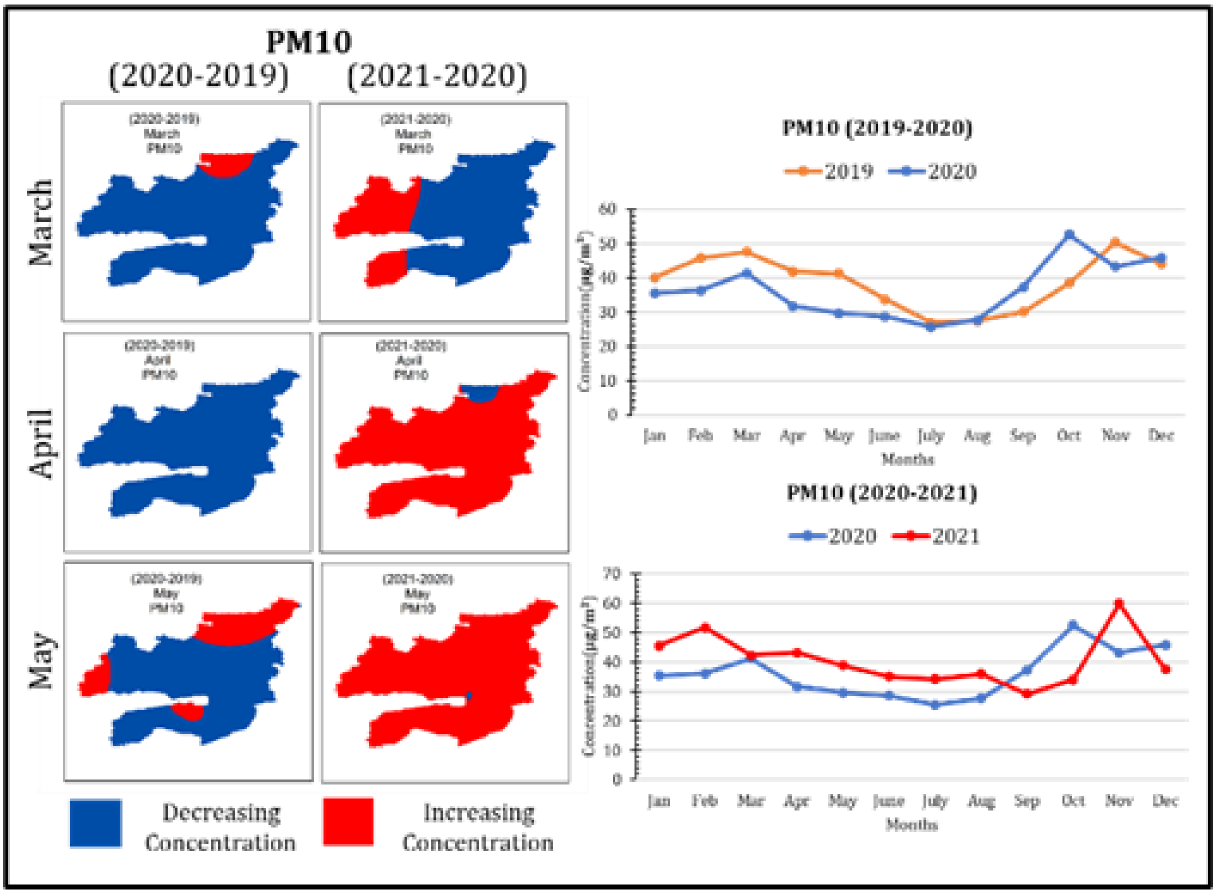

Figure 13. PM_{10} spring concentration temporal change map and trend over months

The spring term indicates a decrease of PM_{10} all over the city especially in April between 2020-2019. Similarly, in March and May it tend to decrease in the city center and regions around the gulf. The difference map 2020-2021 indicates that the PM_{10} tend to increase all over the city in April and May. However, in March, it represents a decrease of PM_{10} especially on eastern part of the city. The Graphics indicates a decreasing trend for all years in spring term. The spring term 2019 and 2021 have a higher concentration of PM_{10} values compared to 2020.

The temporal change maps and change trends over months for SO_2 concentration between 2019-2020 and 2020-2021 for March, April, and May are shown in Figure 14.

The spring term indicates an increase of SO_2 all over the city between 2020-2019 and 2021-2020 change maps. In March (2020-2019) and May (2021-2020) it tends to decrease in the city center and regions around the gulf. The Graphics indicates higher concentrations of SO_2 in 2021 compared to other years.

The temporal change maps and change trends over months for PM_{10} concentration between 2019-2020 and 2020-2021 for June, July, and August is shown in Figure 15.

Figure 15 presents the concentration of change for the summer term by years and the trend of change for each month of the 2019, 2020 and 2021 years. The spatial change maps are examined, it is observed that the PM10 concentration tend to decrease for 2020-2019 change maps, on the contrary it tends to increase on 2021-2020 change maps. It was observed that the PM10 concentrations in the summer period did not show much change in the graphics compared to the other seasons and were stable.

The temporal change maps and change trends over months for SO_2 concentration between 2019-2020 and 2020-2021 for June, July, and August is shown in Figure 16.

The summer term indicates an increase of SO_2 all over the city between 2020-2019 and 2021-2020 change maps except August 2021-2020. In August (2021-2020) it is observed that it is worth falling in almost the entire city. The increase trend of summer term can also be observed from the graphics for all years.

The temporal change maps and change trends over months for PM_{10} concentration between 2019-2020 and 2020-2021 for September, October, and November is shown in Figure 17.

The autumn term indicates an increase of PM_{10} all over the city except eastern regions of gulf especially in September and October between 2020-2019. On the contrary, it tends to decrease in all over the city between 2021-2020 change maps on these months. The difference map of November 2020-2019 indicates that the PM_{10} tend to decrease especially on eastern parts of the region, however it increased all over the city at 2021-2020 on November. The Graphics indicates a sudden trend of increase for all years on autumn term. 2020 have a higher concentration of PM_{10} values compared to 2019 and 2021 for autumn term.

The temporal change maps and change trends over months for SO_2 concentration between 2019-2020 and 2020-2021 for September, October and November is show in Figure 18.

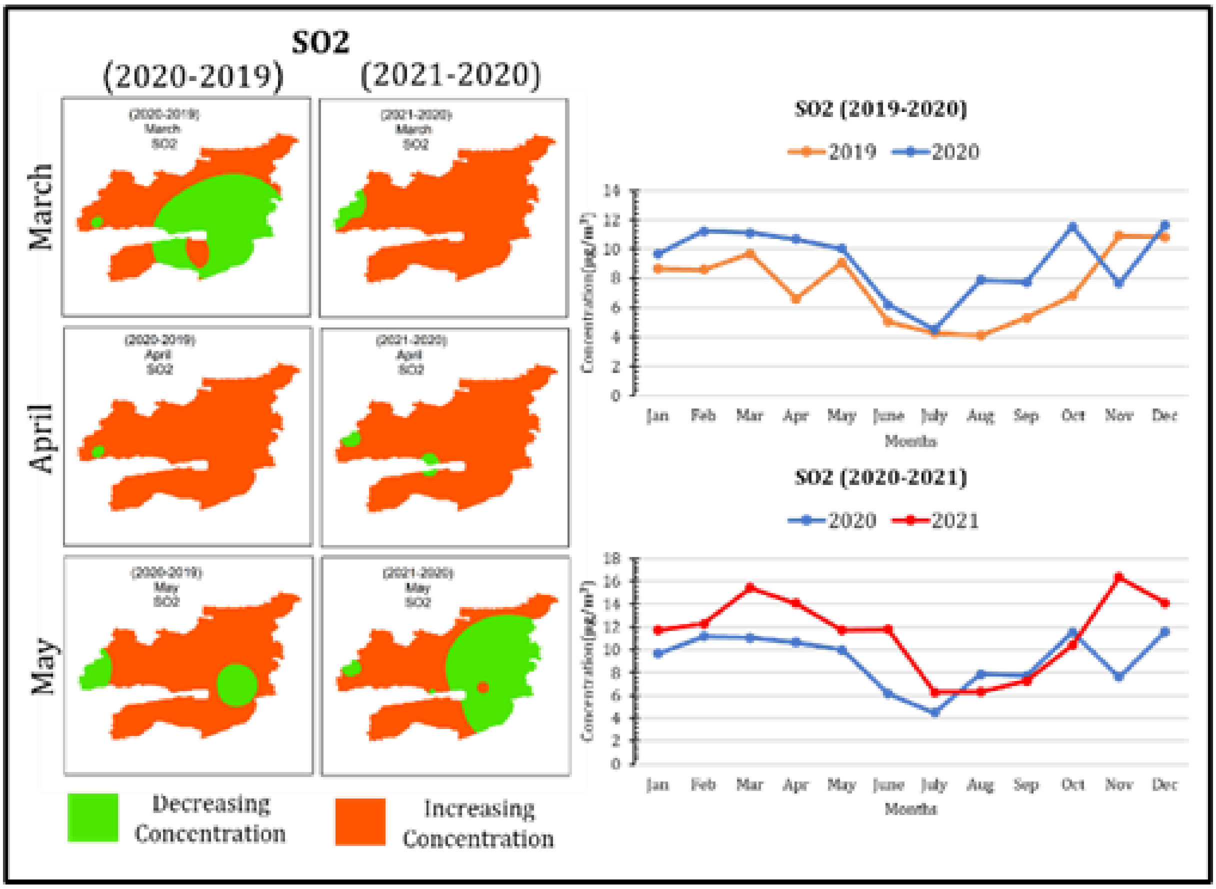

Figure 14. SO_2 Concentration spring temporal change map and trend over months

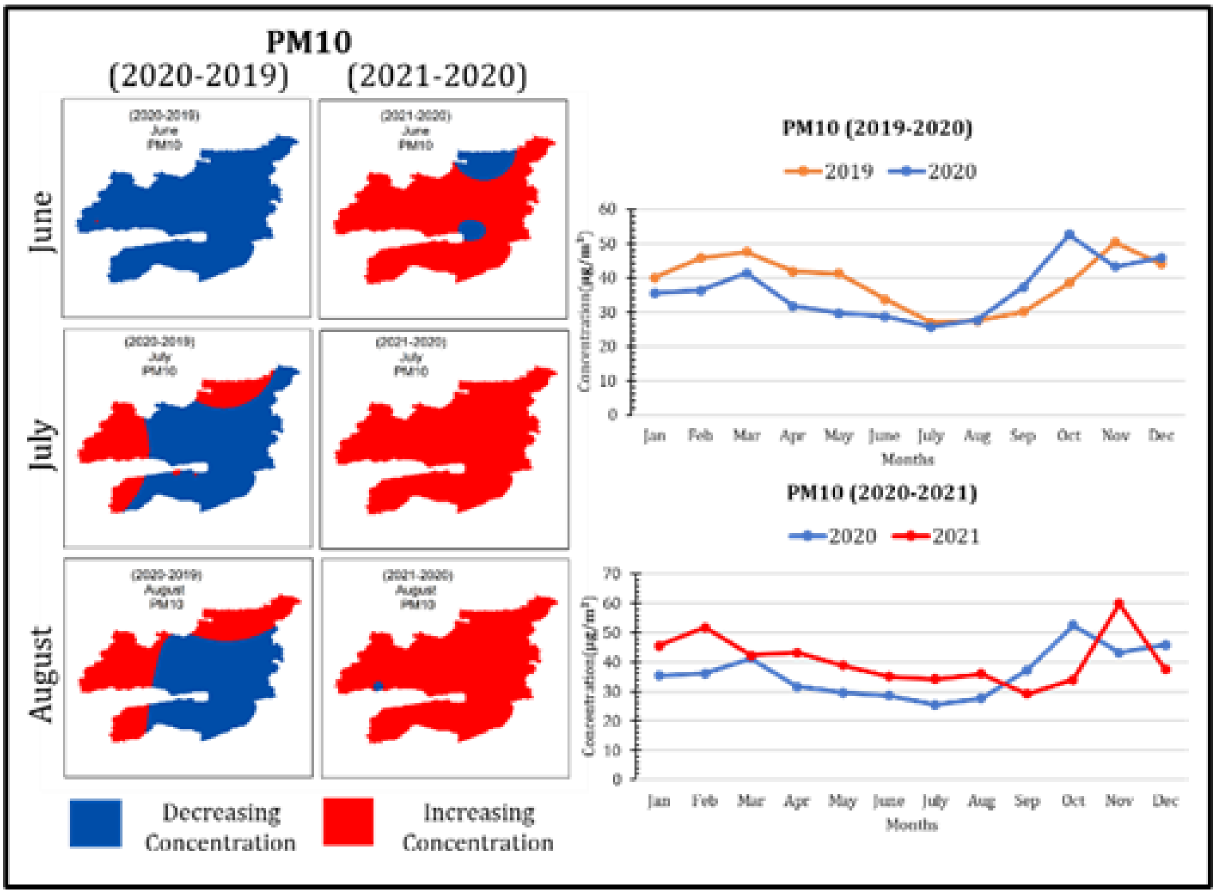

Figure 15. PM_{10} Concentration summer temporal change map and trend over months

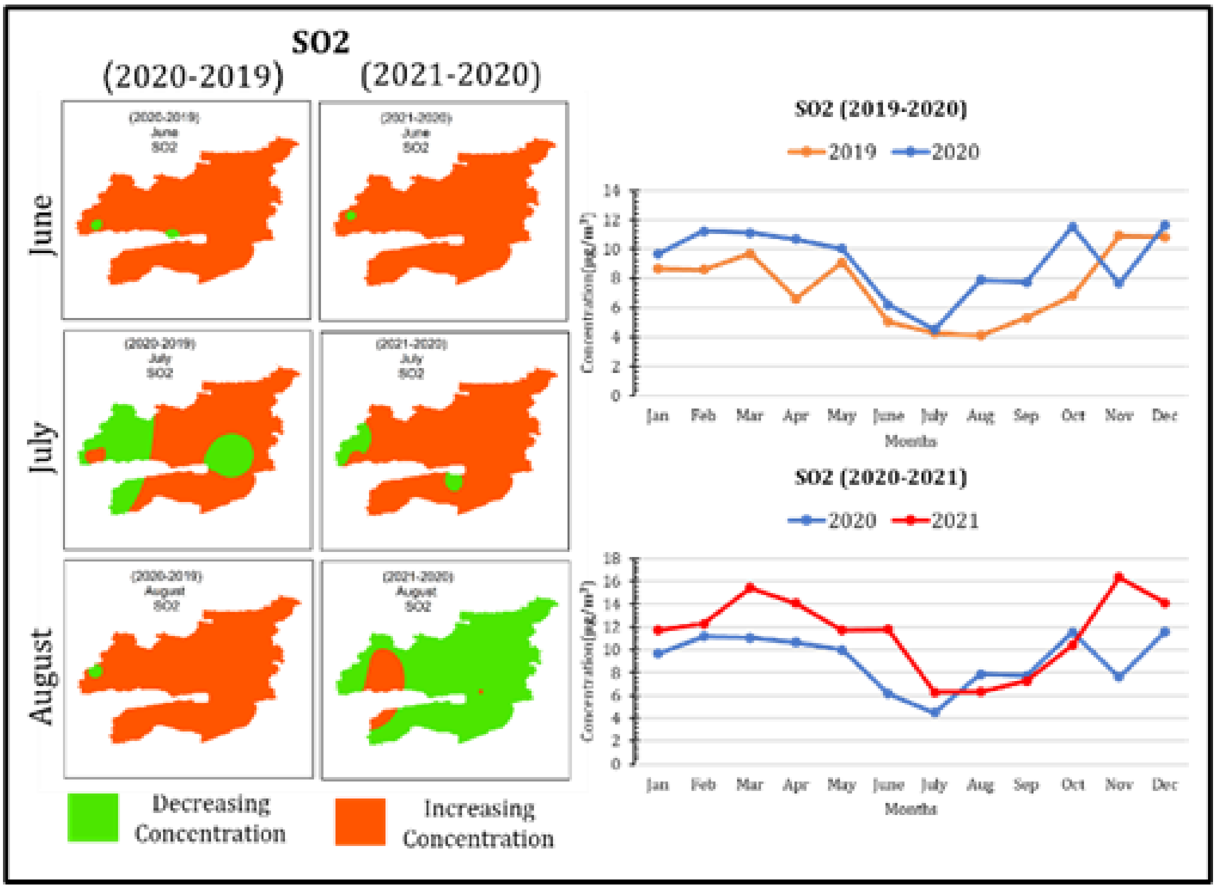

Figure 16. SO_2 Concentration summer temporal change map

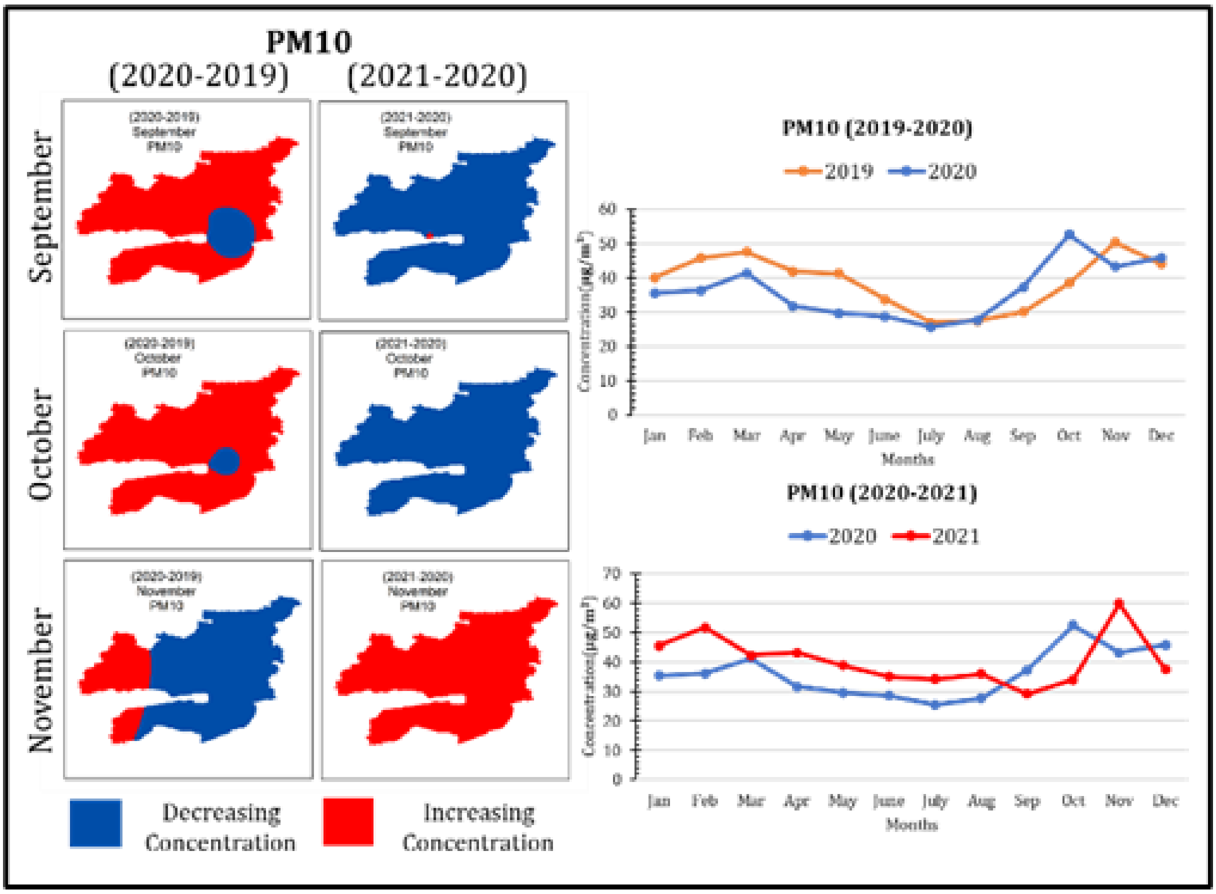

Figure 17. PM_{10} Concentration autumn temporal change map

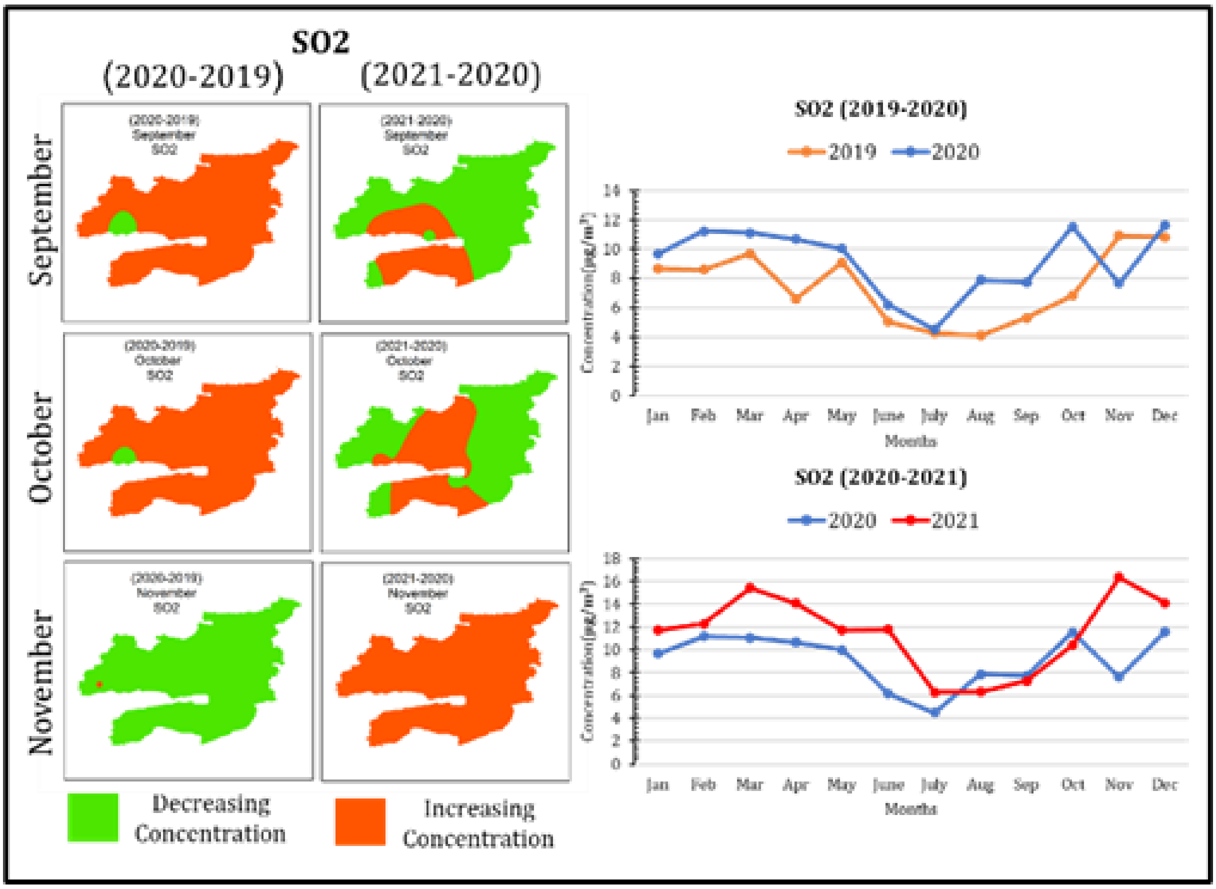

Figure 18. SO_2 Concentration autumn temporal change map

The autumn term indicates an increase of SO_2 all over the city between 2020-2019 change maps except November. In November (2020-2019) it is observed that it is worth falling in almost the entire city. 2021-2020 change maps for September and October indicate an increase of SO_2 mostly on the mid parts of the city. And it indicates an increasing concentration in November all over the city. The increase trend of autumn term can also be observed from the graphics for all years.

4. Discussion

The results of the study showed that the PM_{10} concentration, which is one of the air pollution parameters, decreased during the Covid-19 lockdown. As a result of this study, it is seen that the lockdown, restrictions on population mobility, curfews the pandemic have a positive effect on air pollution. Considering the results of the study, it was observed that the PM_{10} parameter showed serious decreases especially in March, April and May of 2020, when the measures were taken. In addition, no decrease in SO_2 concentration was detected during the Covid-19 lockdowns. These results support other studies as well. In these studies researchers conducted studies that proved that air pollution decreased and the amount of PM_{10} concentration decreased during the Covid-19 lockdowns [1,2,5,6,11,12,14,15,18,19]. In addition, [13,16,17] reported that air pollution decreased during the Covid-19 lockdowns, while PM_{10} concentration decreased, but they did not observe a decrease in SO_2 concentration.

The study reveals pollution maps in 2021. From this point of view, it is seen that Kocaeli air pollution has increased gradually compared to 2019 and 2020. Local governments should work to prevent air pollution.

The usability of GIS technology is also effective in terms of assessing the situation of air pollution, mapping it and interpreting it by visualizing it.

In terms of developing and improving this study, due to the uneven distribution of the current stations, it is believed that high-quality data will be collected by expanding the number of stations in a limited number and adding stations that appropriately reflect the research region. In recent years, satellite data and remote sensing technology have made it possible to continuously collect data on air pollution. These studies, which are based on data from the stations, may be contrasted with data on air pollution obtained through the use of satellite data and the study's findings. In addition, the study can be improved by making comparisons with different interpolation methods in future studies. By working on modeling of air pollution, it can be facilitated to control pollution with estimation of air pollution for the future.

5. Conclusion

In this study, it was aimed to examine the temporal change of air pollution during the Covid-19 lockdown period of Kocaeli province. In this context, pollution maps and temporal change maps were produced using

GIS technology. Data were obtained from 10 stations in the study area. Outliers in the data were eliminated. Pollution maps were created using the IDW technique from monthly data. Temporal change maps were created by overlay analyses. In this context, maps are important in terms of visualization of pollution and easy interpretation by decision makers. It is important in terms of evaluating air pollution and providing information about the progress of pollution.

The study's findings indicate that May of 2020 had the greatest decline in the PM10 concentration when compared to 2019 at 27.97%. The PM10 measure showed the greatest rise in 2021 compared to 2020 in February, at 43.23%. The SO2 concentration decreased by a high of 29.85% November 2020 compared to November 2019. The highest rise in the SO2 concentration in 2021 over 2020 was detected in November to be 114.03%. When the PM10 concentration is examined seasonally, it can be seen that the spring of 2020 sees a significant decline in comparison to other seasons. At the same time, increases in PM10 concentrations are noticeable when spring season values from 2021 were examined. One of the elements contributing to the declines in PM10 concentration is the fact that the lockdowns during this time were significantly more stringent because of the pandemic in the spring of 2020.

Covid-19 pandemic restrictions seen to improve air quality. These and other studies lockdown are show that a solution to can be produced as an emergency action plan when air pollution gives a red alarm.

Author contributions

Burak Kotan*:* Conceptualization, Methodology, Software, Data curation, Writing-Original Draft Preparation, Validation. Visualization
Arzu Erener: Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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