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Did Turkey Experience Reductions in Air Pollution During The Covid-19 Lockdown and Partial Lockdown?

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Abstract

Air pollution, one of humanity's essential environmental problems due to the increasing population and urbanization, negatively affects the ecosystem and public health. During reduced human activity, such as martial law, war, and pandemics like COVID-19, improvements in air quality may be observed due to diminished anthropogenic impact. The novel coronavirus, COVID-19, has caused widespread illness and fatalities. The World Health Organization (WHO) declared a state of emergency at the end of December 2019 following the first recognition of the virus in Wuhan. The Turkish government declared this state on March 11, 2020, and implemented some measures, including a lockdown (LD) and a partial lockdown (PLD), to protect public and human health. The present study aims to determine the impact of LD and PLD on the air quality of fourteen selected cities in Turkey that participated in all LDs during the state of emergency on weekends and national and religious holidays. The hourly air quality data used in the study were collected from 105 air monitoring stations in fourteen cities. The non-parametric Kruskal Wallis test, followed by the Dunn's Bonferroni test for pairwise comparison, was employed to determine the differences in air quality between years. The findings indicated significant reductions in air pollution during LD and PLD: 21.1-40.3% and 8.9-29.8% in PM_{10}, respectively, and 30.2-50.8% and 2.6-22.4% in NO_x, respectively. SO_2 and CO also varied significantly. While the changes in SO_2 during LD and PLD went from 0.0% to 5.7% and -2.4% to 1.2%, respectively, those in CO ranged from -6.6% to 29.6% and 1.3% to 33.2%, respectively.

Keywords
Pandemic, COVID-19, Air Quality, Lockdown, Air Pollutants

Türkiye, Covid-19 Kapanma ve Kısmi Kapanma Dönemlerinde Hava Kirliliğinde Azalmalar Yaşadı Mı?

Özet

Artan nüfus ve kentleşmeye bağlı olarak ortaya çıkan ve insanlığın temel sorunlarından biri olan hava kirliliği ekosistem ve halk sağlığını olumsuz etkilemektedir. Sıkıyönetim, savaş, COVID-19 gibi salgın hastalıkların yarattığı bazı koşullarda insanların çevre üzerindeki olumsuz etkisinin azalması nedeniyle hava kalitesinde de iyileşmeler görülebilmektedir. Yeni keşfedilen korona virüsün neden olduğu COVID-19 dünya çapında bir çok insanın hastalanmasına ve ölümüne neden olmuştur. Dünya Sağlık Örgütü (WHO), virüsün ilk kez Wuhan'da tanınmasının ardından Aralık 2019'un sonunda olağanüstü hal ilan etmiştir. Türkiye ise bu durumu 11 Mart 2020'de ilan etti ve ardından halk ve insan sağlığını korumak için karantina (LD) ve kısmi karantina (PLD) dahil olmak üzere bazı önlemler aldı. Bu çalışma, LD ve PLD'nin hafta sonları ile ulusal ve dini bayramlardaki olağanüstü hal sırasında LD'lere dahil olan on dört ilde hava kalitesi üzerindeki etkisini belirlemeyi amaçlamaktadır. Çalışmada kullanılan saatlik hava kalitesi verileri, on dört ildeki 105 hava izleme istasyonundan toplanmıştır. Yıllar arasında hava kalitesindeki farklılıkları belirlemek için parametrik olmayan Kruskal Wallis testi ve ardından ikili karşılaştırma için Dunn's Bonferroni testi kullanılmıştır. Bulgular, LD ve PLD sırasında hava kirliliğinde önemli azalmalar olduğunu göstermiştir: LD ve PLD için sırasıyla PM10'da %21,1-40,3 ile %8,9-29,8 ve NO_x'te %30,2-50,8 ile %2,6-22,4 şeklinde değişimler gözlenirken SO_2 ve CO konsantrasyonlarında da anlamlı değişiklikler tespit edilmiştir. Bu değişimler LD ve PLD için sırasıyla SO_2'de %0,0 ile %5,7, %-2,4 ile %1,2 arasında değişirken, CO'de %-6,6 ile %29,6 ve %1,3 ile %33,2 arasında ortaya çıkmıştır.

Anahtar Sözcükler
Pandemi, COVID-19, Hava Kalitesi, Karantina, Hava Kirleticileri

1. Introduction

Human activity has adversely affected air quality. As industrial, technological, and urban development has progressed, the negative pressure on environmental resources has increased. Suspended particles ($PM_{2.5}$ and PM_{10}) and gases such as carbon monoxide, sulfur dioxide, nitrogen oxide, and ozone emitted into the atmosphere by various sources comprise air pollution (Liu et al., 2019). All these changes and adverse effects on air quality are based on an increasing population.

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Most countries around the world suffer from air pollution and related diseases. New air-pollution-based respiratory diseases have emerged daily, and poor air quality is a globally important mortality risk factor (Heft-Neal et al., 2018). Therefore, the public and governments have noticed air pollution threatening the environment and human health. Many people die yearly from this problem, including seven million premature deaths (Plaia and Ruggieri, 2011; World Health Organization, 2020a). Furthermore, Vohra et al., (2021) estimated premature deaths worldwide as 10.2 million people yearly. While Burnett et al., (2018) attributed 4 million deaths in 2015 to increased $PM_{2.5}$ concentrations, Heft-Neal et al. (2018) reported that this pollutant is responsible for 9 to 22% of infant mortality. Increased air pollution in Istanbul, Turkey, was found to be correlated with both increased respiratory-related hospital admissions (Çapraz et al., 2017) and higher mortality rates from cardiovascular, respiratory, and non-accidental diseases (Çapraz et al., 2016).

The increasing population has caused air pollution through rapid industrial and urban development, increasing motor vehicle use, and fossil fuel consumption (Mamtimin & Meixner, 2011). The removal of one or more factors causing air pollution could enhance the quality of air. An air policy implemented during an Olympics, an economic recession, or a lockdown (LD) due to a situation such as martial law, war, or a pandemic could improve air quality (Agrawala et al., 2020). COVID-19, an epidemic and one of the mentioned situations, is an infectious disease caused by a newly discovered coronavirus. Most people experiencing this illness have mild to moderate respiratory symptoms and recover without special treatment. People with medical issues, such as cardiovascular disease, diabetes, chronic respiratory disease, or cancer, are more likely to develop severe illnesses (World Health Organization, 2020b).

The state of emergency due to COVID-19 was declared by the World Health Organization (WHO) at the end of December 2019 after the virus was first recognized in Wuhan, China. Then, the pandemic spread to a few countries outside China (Sahin, 2020). As of September 29, WHO (World Health Organization, 2020b) reported the number of confirmed cases of COVID-19 and deaths as 33,206,004 and 999,239 in the world, and 314,239 and 7997 in Turkey. The Ministry of Health in Turkey declared a state of emergency on March 11, 2020. After this date, the Turkish government took some economic and social precautions, as most countries have done, to protect public and human health, including LD and partial lockdown (PLD). The LD enforces rigorous measures, such as closing non-essential businesses, restricting movements, and issuing stay-at-home orders to curb social activities and movement. In contrast, the PLD permits a limited range of actions, enabling some economic and social activities to proceed while imposing restrictions in certain areas.

Regulation of working hours of banks and other associations, a curfew for those over 65, flight bans, restrictions on restaurants, barbers and beauty centers, entertainment, art, culture, and social activities, and closure of schools and universities are also among the precautions declared by the government (Kanat et al., 2020). In addition to a curfew for those over 65, the government ordered an LD for everyone on weekends and national and religious holidays. This period lasted from April 11 to May 31. Starting June 1, the LD and PLD ended, except for older individuals (Ministry of Interior, 2020).

During the COVID-19 period, some studies regarding the effect of COVID-19 on air quality were performed. Institutions such as NASA and the ESA reported NO_2 reductions of about 30% in China for the LD period (Arafat et al., 2020). The decline in air pollution was observed not only in China but also all over the world. For example, with the COVID-19 period measures, air pollution levels dropped by 50% in New York (Saadat et al., 2020). Significant contaminant reductions have also been observed in water and the environment (Arora et al., 2020; Zambrano-Monserrate et al., 2020).

The present study aims to determine the impact of the LD and PLD implemented by the Turkish government to protect the public and human health on air quality in fourteen cities in Turkey, considering meteorological parameters.

2. Material and Method

2.1. Study Area

This study was performed in fourteen cities in Turkey, located between Asia and Europe continents. The study area was situated from 36°-42° N and 26°-45° E, covering an area of 777,000 km^2 (Figure 1). The population of Turkey was 83,154,997 in 2019 (Turkish Statistical Institute, 2020). The climate in the country varies among regions. While the dry summer subtropical Mediterranean climate is dominant in the country's southern and western parts, with mid-to-high drought risk, the Black Sea region, with low drought risk, experiences a mid-latitude temperate climate (Turkes, 2020).

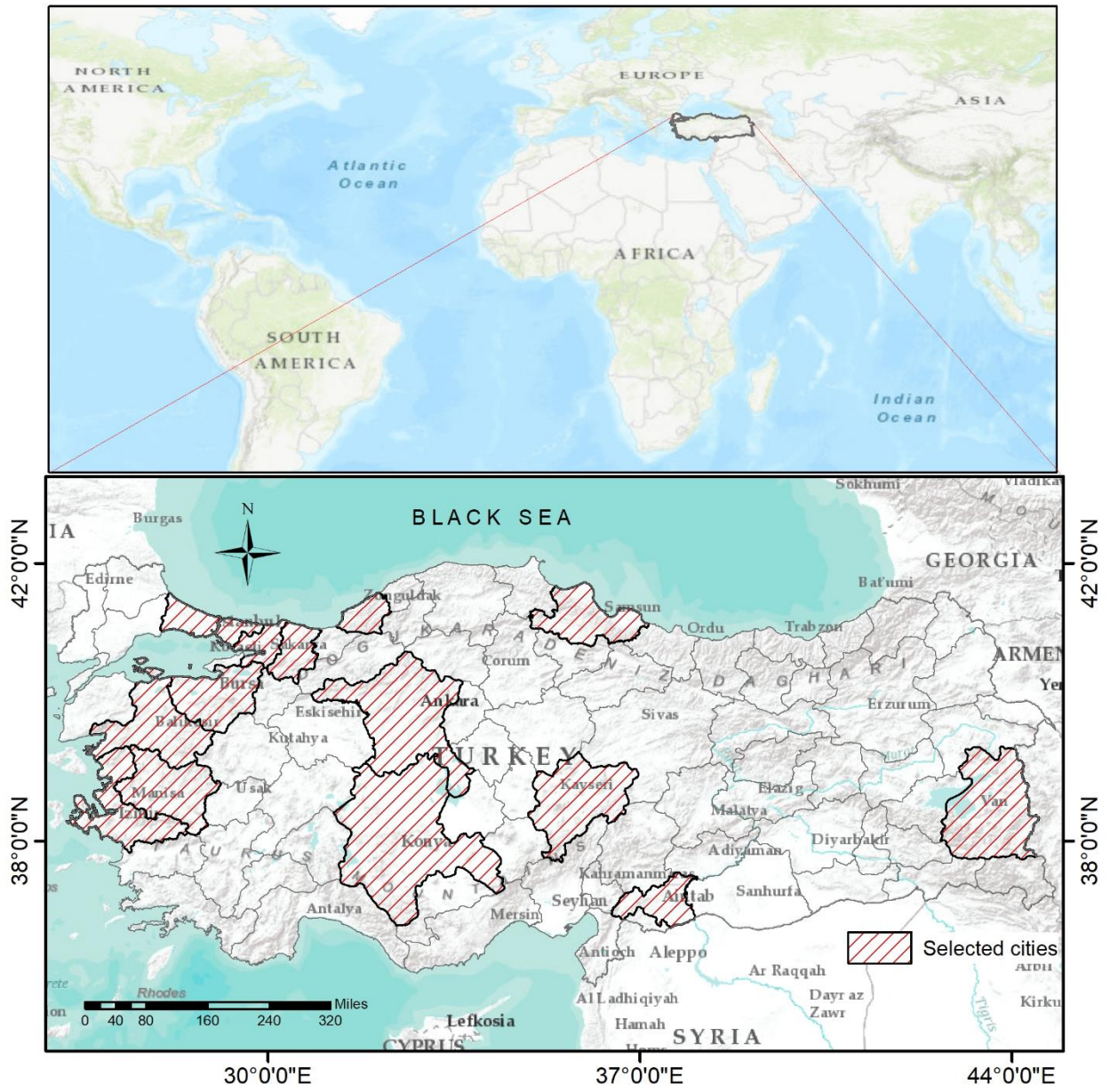

Figure 1: Location of selected cities with full lockdown in Turkey

2.2. Data and Methodology

Thirteen large cities and Zonguldak, included in all full LDs declared by the government between April 11 and May 31, 2020, were selected due to more confirmed cases of COVID-19 and more deaths in direct proportion to their population. (Full) LDs covered only weekends and national and religious holidays in a given period. Turkish Ministry of Health reported the highest number of confirmed cases in Istanbul, with 807.1 per 100,000 people, which is 40% of the total cases in the country (Ahsan & Sadak, 2021). It was followed by 436 cases in western Anatolia, 391 cases in southeastern Anatolia, 353 cases in eastern Marmara, and 310 cases in central Anatolia (Özvarış et al., 2020). Some selected provinces were among the most densely populated and significant industrialized cities (Goren et al., 2021).

Data from Eskisehir, another large city, could not be used because they were insufficient. Air quality data such as particulate matter ≤ 10 microns (PM_{10}), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and carbon monoxide (CO) were derived from 105 air quality stations monitored by the Turkish Ministry of Environment, Urbanization and Climate Change (http://www.havaizleme.gov.tr/hava.html). The amount of hourly air pollutant data used in the study were 519,553, 472,321, 236,161, and 226,321 for PM_{10}, SO_2, NO_x, and CO. According to the EPA, the following methods have been used: Beta-Attenuation Control for particulate matter (PM10), UV fluorescence for SO_2, Non-Dispersive Infrared Photometry for CO, and Gas-Phase Chemiluminescence for NOx (Gilliam & Hall, 2016).

In this study, meteorological data regarding mean temperature, precipitation, relative humidity, air pressure, and wind speed over given periods were gathered from NASA (https://power.larc.nasa.gov/data-access-viewer/). These data were used to assess air quality to decide whether restrictions imposed in lockdown and partial lockdown were the only factors affecting air quality. The air quality data in LD and PLD were compared to those in 2018 and 2019. One-way ANOVA and Kruskal Wallis analyses followed by Tukey and Dunn's Bonferroni tests were performed using SPSS version 20.0 (IBM Corp., 2011) to determine the differences in meteorological variables and air pollutants, respectively, among years (Leech et al., 2005).

3. Result and Discussion

This study compared and assessed air quality data for fourteen selected cities in Turkey during the LD and PLD periods.

3.1. Effect of lockdown and partial lockdown on air quality

PM_{10}, SO_2, NO_x, and CO concentrations constituted air quality data regarding the LD and PLD periods in the fourteen selected cities in Turkey. We presented some descriptive statistics related to air quality data during LD and PLD in Tables 1 and 2, respectively.

The average PM_{10} concentrations during the LD period for selected cities were 53.3±0.3, 40.3±0.3, and 31.8±0.3 µg/m3 in 2018, 2019, and 2020, respectively. The PM_{10} concentrations for the PLD period were 52.7±0.1, 40.6±0.1, and 37.0±1.1 µg/m3.

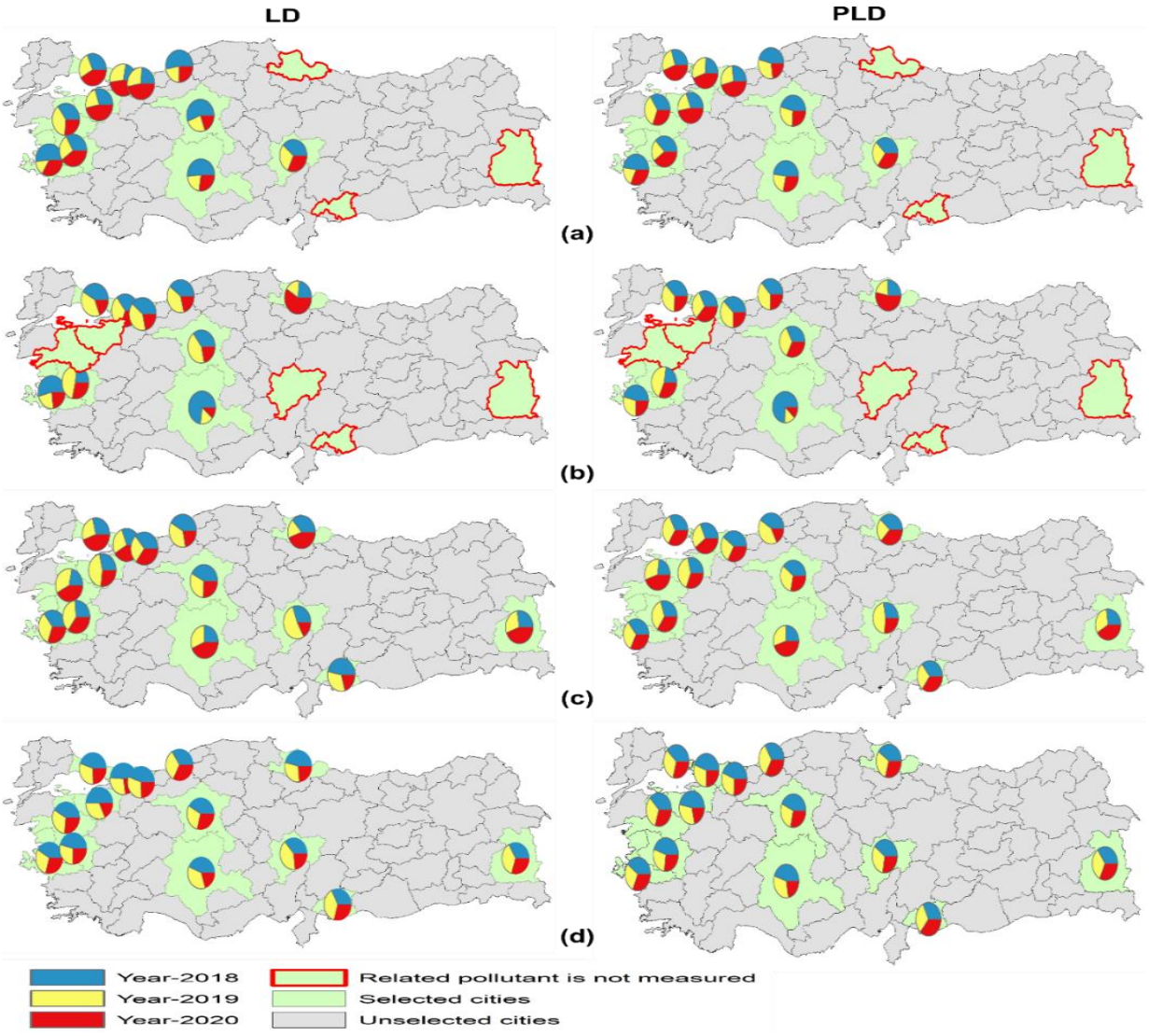

Figure 2: Air quality data in selected 14-city of Turkey in LD vs. that in PLD, according to years (a: CO, b: NO_x, c: SO_2, d: PM_{10})

Table 1: Some descriptive statistics for air pollutants in LD according to years

		PM_{10} (µg/m³)			SO_2 (µg/m³)			NO_x (µg/m³)			CO. (µg/m³)		
Province		2018	2019	2020	2018	2019	2020	2018	2019	2020	2018	2019	2020
Ankara	X̄±SE	61.6±0.8	43.2±0.9	42.8±1.5	7.0±0.1	5.2±0.2	4.3±0.1	51.1±0.7	62.3±2.0	31.4±1.2	1213.3±26.0	533.3±13.3	420.8±12.8
	M	57.7a	39.8b	30.3c	7a	3.8b	4b	48a	49.6a	21.6b	1259.2a	456.7b	335.4c
Balıkesir	X̄±SE	45.6±0.6	34.2±0.5	29.1±0.7	5.4±0.2	8.9±0.3	10.5±0.7				859.6±16.1	942.3±19.4	648±14.1
	M	43.5a	32.9b	25.2c	3.4a	7.3b	8.4c				762.6a	821b	596.3c
Bursa	X̄±SE	88.9±1.5	56.8±1.0	32.0±0.8	5.7±0.2	8.9±0.3	5.4±0.1				1162.0±20.0	902.1±20.5	1812.9±22.4
	M	82.3a	53.9b	25.7c	4a	7.1b	5c				1063.3a	831.9b	1706.9c
Gaziantep	X̄±SE	31.1±0.8	36.4±1.8	28.2±1.0	6.6±0.1	4.6±0.0	2.9±0.1						
	M	26.2a	31.1b	23c	6.4a	4.6b	3c						
İstanbul	X̄±SE	52.5±1.1	35.8±0.5	28.7±0.6	4.5±0.1	4.1±0.1	6.9±0.1	138.2±5.4	128.4±3.4	62.7±2.1	543.8±9.0	455.7±5.0	717.3±9.0
	M	42.4a	33.4b	25.4c	3.3a	3.5a	58b	95.4a	113.1b	49c	466.5a	421.8b	677.7c
İzmir	X̄±SE	42.1±0.6	29.9±0.7	29.9±0.9	9.6±0.1	9.2±0.2	8.3±0.0	35.8±1.0	15.0±0.3	15.3±0.3	558.4±5.2	157.9±3.7	363.8±3.2
	M	39.6a	25.4b	21.9c	8.6a	8.4a	8.2b	29.5a	12.2b	14.6c	562.5a	141.5b	345.7c
Kayseri	X̄±SE	46.0±1.0	51.1±1.4	29.5±1.0	4.1±0.1	7.2±0.2	2.3±0.2				517.3±12.0	400.7±11.4	427.3±12.8
	M	41.3a	44.1a	20.8b	3.6a	6.1b	1.5c				474.2a	327.9b	379.2b
Kocaeli	X̄±SE	61.1±1.2	35.1±0.5	28.2±0.6	8.3±0.3	7.5±0.2	11.2±0.5	54.5±1.7	52.0±1.2	46.8±1.2	608.6±13.5	822.9±14.2	1315.8±18.7
	M	54.8a	34.8b	24.0c	5.5a	5.5a	7.1b	43.2a	46.1a	37.1b	523.1a	766.1b	1206.2c
Konya	X̄±SE	47.6±0.9	39.4±1.0	21.8±0.8	6.4±0.2	7.8±0.1	11.0±0.3	179.7±15.1	38.9±1.0	27.6±0.9	830.0±14.8	344.4±9.4	441.7±15.9
	M	41.7a	33.5b	15.2c	4.3a	7.2b	9.6c	20.6a	31.4b	22.5a	778a	274.1b	324.7c
Manisa	X̄±SE	85.0±1.0	52.9±0.8	46.9±1.1	22.7±1.1	32.7±1.3	30.1±1.7	24.9±1.2	52.4±1.5	31.3±1.0	1143.0±31.0	904.6±18.5	1372.3±85.6
	M	80.3a	49.6b	38.7c	13a	20.6b	20.9b	23.9a	42.7b	26.9a	1034.8a	881.9b	1004.0a
Sakarya	X̄±SE	58.9±0.9	40.6±0.8	32.4±0.9	6.7±0.3	5.2±0.2	6.5±0.1	53.5±1.3	53.5±1.2	29.6±0.8	776.7±14.5	939.6±18.7	1531.1±25.0
	M	53.1a	37.7b	25.0c	4.5a	3.8b	5.9c	45a	47.0a	23.2b	702.2a	834.5b	1324.3c
Samsun	X̄±SE	55.1±0.8	36.2±0.6	28.1±0.7	11.2±0.2	5.8±0.2	13.6±0.2	55.7±1.3	41.8±1.2	139.9±6.4			
	M	50.9a	33.9b	24.5c	10.3a	5b	12.6c	50a	35.6b	138.6c			
Van	X̄±SE	27.9±0.8	31.1±0.9	24.9±0.8	6.1±0.3	6.2±0.1	9.8±0.1						
	M	23a	25.4a	19.2b	4.6a	5.3b	9.3c						
Zonguldak	X̄±SE	43.2±0.7	41.5±0.8	41.1±1.0	12.1±0.5	10.4±0.5	6.3±0.2	26.6±0.8	26.2±0.7	14.2±0.2	1380.6±9.4	577.4±16.0	660.4±8.0
	M	40.4a	38.5b	33c	9a	6.8b	5.5c	22.9a	23.3a	12.7b	1396.6a	436.3b	621.8c
Average	X̄±SE	53.3±0.3	40.3±0.3	31.8±0.3	8.3±0.1	8.8±0.1	8.8±0.1	73.8±2.0	52.0±0.7	36.3±0.6	870.9±6.4	627.7±5.6	813.5±8.6
	M	47.9a	36.3b	25.3c	6.3a	5.9a	7.3b	41.9a	38.0b	23.5c	753.7a	536.4b	614.1c

X̄: Mean, SE: Standard error of mean, M: Median
** Lowercase letters attaching to values show significant (p<0.001) differences in years according to Kruskal Wallis, followed by Dunns Bonferroni test.*

Table 2: Some descriptive statistics for air pollutants in PLD according to years

		PM_{10} (µg/m³)			SO_2 (µg/m³)			NO_x (µg/m³)			CO. (µg/m³)		
Province		2018	2019	2020	2018	2019	2020	2018	2019	2020	2018	2019	2020
Ankara	X̄±SE	68,6±0,5	45,2±0,5	45,0±0,5	6,1±0,1	5,1±0,1	4,4±0,0	52,3±0,5	56,6±0,7	52,0±0,5	969,1±12,8	590,6±8,5	549,4±8,1
	M	57,1a	34,9b	34,1b	4,3a	3,4b	3,9c	42,8a	35,9b	36,3a	840,5a	428,8b	401,1c
Balıkesir	X̄±SE	42,9±0,3	37,1±0,2	34,1±0,3	6,5±0,1	9,1±0,2	12,7±0,4				942,9±11,5	958,4±11,3	852,8±10,3
	M	37,5a	32,2b	28,3c	3,6a	4,9b	7,2c				788,6a	819,9a	750,9b
Bursa	X̄±SE	85,5±0,7	57,7±0,4	39,0±0,3	6,2±0,1	8,7±0,1	6,6±0,1				1278,9±14,3	913,6±12,7	1943,5±12,7
	M	74,1a	50,1b	33c	3a	5,3b	4,9c				1114,9a	801,1b	1823,6c
Gaziantep	X̄±SE	35,1±0,4	34,4±0,5	39,4±0,4	5,5±0,1	4,5±0,0	5,4±0,1						
	M	28,6a	29,8a	33,9b	5,5a	4,3b	3,9b						
İstanbul	X̄±SE	48,7±0,2	41,1±0,1	37,2±3,3	4,3±0,0	4,5±0,0	4,5±0,0	122,6±2,7	121,6±2,1	84,3±1,4	558,4±2,4	495,0±2,0	831,2±4,9
	M	36,6a	33,6b	25,9c	2,8a	3b	3b	85,8a	102,8b	64,2c	467,8a	425,6b	724,8c
İzmir	X̄±SE	41,5±0,3	29,7±0,2	32,5±0,2	9,9±0,1	8,9±0,0	8,9±0,0	27,8±0,4	17,4±0,3	15,2±0,2	559,5±3,4	234,5±3,2	372,2±2,0
	M	33,7a	25b	25,6c	8,8a	7,9b	7,9b	19,9a	10,4b	10,6c	529a	196,6b	360,5c
Kayseri	X̄±SE	53,8±0,5	43,8±0,4	37,3±0,4	4,5±0,1	7,4±0,1	4,3±0,2				580,7±8,2	418,2±6,9	540,1±8,7
	M	44,1a	37,1b	30,1c	4a	6b	2,3c				496,5a	341,5b	437,9c
Kocaeli	X̄±SE	56,3±0,3	38,5±0,2	31,2±0,2	8,4±0,1	7,6±0,1	10,5±0,2	50,5±0,4	47,8±0,4	56,9±0,6	662,4±7,9	864,1±7,9	1231,9±10,7
	M	45a	32,8b	25,7c	4,8a	4,1b	4,9c	29,3a	29,6b	26,1b	542,5a	794,7b	1262,5c
Konya	X̄±SE	46,8±0,4	33,8±0,3	23,2±1,1	7,0±0,1	8,1±0,1	12,3±0,2	234,7±9,1	43,1±0,5	37,7±0,4	825,8±7,7	408,4±5,0	492,9±8,4
	M	36,4a	26,9b	12c	4,4a	6,8b	7,1c	28,2a	33b	28,94c	718,4a	298,7b	323,9c
Manisa	X̄±SE	87,8±0,8	55,2±0,4	53,0±0,5	34,2±0,9	40,9±0,9	39,4±1,0	25,7±0,7	51,5±0,7	36,1±0,4	1223,5±13,6	736,2±10,2	1313,2±28,6
	M	79,5a	50,7b	47,6c	13,1a	21b	18,1c	23,7a	44,2b	32,5c	1132.0a	719,9b	1097c
Sakarya	X̄±SE	63,4±0,7	43,1±0,3	37,1±0,3	8,2±0,2	5,6±0,1	6,7±0,1	51,4±0,6	50,7±0,5	33,9±0,4	906,2±13,9	906,2±13,9	1546,1±11,9
	M	52,1a	38,6b	31,7c	4,1a	3,5b	6,5c	39,9a	39a	27,2b	743,5a	743,5a	1406,1b
Samsun	X̄±SE	53,6±0,4	39,7±0,3	39,2±0,3	12,1±0,1	7,7±0,1	11,7±0,1	55,4±0,8	44,4±0,5	112,9±2,5			
	M	46,8a	36,4b	34,1c	8,8a	5,2b	9,8c	38,7a	31,7b	34,6a			
Van	X̄±SE	30,8±0,9	29,2±0,6	28,2±0,6	9,3±0,3	10,9±0,3	14,1±0,2						
	M	25,5a	20,9b	20b	5,2a	7,1b	10,7c						
Zonguldak	X̄±SE	46,9±0,4	47,0±0,4	45,9±0,4	14,3±0,2	14,6±0,3	6,2±0,1	27,1±0,4	27,7±0,4	18,4±0,2	1236,6±6,0	843,6±7,8	607,0±4,2
	M	38.3	38.2	37.6	7,5a	7b	4,3c	14,5a	14,2a	11,2b	1206,6a	580,1b	499,4c
Average	X̄±SE	52,7±0,1	40,6±0,1	37,0±1,1	8,2±0,0	7,9±0,0	8,0±0,0	58,8±0,6	46,8±0,2	45,6±0,3	766,4±2,3	582,2±1,9	776,0±2,8
	M	41,3a	33,5b	28,3c	4,5a	4,7b	4,9c	31,2a	30,7b	24,5c	618,6a	451,9b	584,1c

X̄: Mean, SE: Standard error of mean, M: Median
** Lowercase letters attaching to values show significant ($p<0.001$) differences in years according to Kruskal Wallis, followed by Dunns Bonferroni test.*

While the Bursa, Bursa, and Manisa provinces had the highest PM_{10} levels in 2018, 2019, and 2020, respectively (Figure 2d), Van had the lowest PM_{10} level in all years for LD. Manisa and Van had the highest and lowest PM_{10} levels for the PLD period.

According to the Kruskal Wallis test followed by the Dunn's Bonferroni test, PM_{10} during both LD and PLD periods statistically varied among years ($p<0.001$). PM_{10} in 2020 for LD and PLD was statistically lower than in 2019 and 2020 (Table 1, Table 2). The reductions in PM_{10} level were 40.3% and 21.1% for LD and 29.8% and 8.9% for PLD, respectively, compared to 2018 and 2019 (Figure 3b). The PM_{10} levels in 2020 were statistically lower than those in previous years in almost all provinces. The reductions in concentrations of PM_{10} may be attributed to decreasing transportation, industry, and commercial activities as part of COVID-19 measures. Xu et al. (2020) reported that human activity is the primary contributor to PM_{10} emissions. Biomass combustion and traffic, among anthropogenic factors, have increased the PM_{10} level by 39% and 12-70%, respectively (World Health Organization, 2020a; Sicard et al., 2020). Our results (21.1-40.3% in LD and 8.9-29.8 in PLD) are consistent with the findings of researchers in Turkey (Alemdar et al., 2021; Celik & Gul 2022; Dursun et al., 2022; Efe, 2022; Orak & Ozdemir, 2021; Ozbay & Koc, 2022, Sari & Esen 2022). They found PM_{10} concentrations during COVID-19 1.2-67.0% lower than the previous year and attributed the reductions in PM_{10} to traffic, household heating, and fossil fuel combustion restrictions. Some other researchers over the world (Arora et al., 2020; Jain & Sharma, 2020; Kanniah et al., 2020; Kumari & Toshniwal, 2020; Mahato et al., 2020; Otmani et al., 2020) also found drastic reductions in PM_{10} levels due to LD or PLD implemented during the COVID-19 period. For example, Otmani et al. (2020) correlated a 75% reduction in PM_{10} with restricting road traffic, industrial exhaust emissions, and construction works due to COVID-19. Unlike the majority, despite the curfew, Shakoor et al. (2020) and Nadzir et al. (2020) found increased PM10 during COVID-19.

The average SO_2 concentrations during the LD period for selected cities were 8.3±0.1, 8.8±0.1, and 8.8±0.1 µg/m3 in 2018, 2019, and 2020, respectively. The SO_2 concentrations for the PLD period were 8.2±0.0, 7.9±0.0, and 8.0±0.0 µg/m3. The Zonguldak, Manisa, and Manisa provinces had the highest SO_2 levels, and Van, Istanbul, and Kayseri had the lowest in 2018, 2019, and 2020, respectively, during LD. For the PLD period, Zonguldak, Zonguldak, and Van had the highest, and Istanbul, Istanbul, and Kayseri had the lowest SO_2 levels in 2018, 2019, and 2020, respectively (Figure 2c). The change in the average SO_2 level during LD and PLD was statistically significant but slight. The determined SO_2 changes were 0.0% to 5.7% during LD and -2.4% to 1.2% during PLD (Figure 3d, Table 1, Table 2). Although the average shift during LD and PLD was slight, considering the individual provinces, the differences between the LD period and previous years increased. SO_2 levels during LD and PLD statistically increased 4.7-134.5% in Balikesir, Istanbul, Kocaeli, Konya, Manisa, Samsun, and Van compared to the previous two years. However, 3% to 57.5% reductions in SO_2 were determined in the remaining provinces. Celik and Gul (2022) also found similar findings, such as reductions in half of the stations and increases in the remaining attributable to household heating.

Many researchers (Arora et al., 2020; Kumari & Toshniwal, 2020; Bao & Zhang, 2020; Chen et al., 2020; Collivignarelli et al., 2020; Ghosh & Ghosh 2020; He et al., 2020) worldwide have reported SO_2 reductions of up to 29% due to LD and PLD measures during the COVID-19 period. Average decreases in SO_2 in studies implemented in Turkey (Alemdar et al., 2021; Celik & Gul 2022; Orak & Ozdemir, 2021; Sari & Esen 2022) ranged from 16.6% to 59.0%. Power plants, heating systems, industrial processes, fossil fuel combustion, and sulfur-containing ore smelting have contributed 70% to 90% of SO_2 emissions (Xu et al., 2020; Collivignarelli et al., 2020). Some provinces' unexpected increase in SO_2 emissions during LD and PLD may correlate with fossil fuel combustion in residential areas and emissions from fertilized agricultural areas, animal husbandry operations, and continued industrial activity. Meteorological parameters such as decreasing relative humidity and low temperature reinforced the influence of these factors on SO_2 emissions. Relative humidity (Figure 4d) and temperature (Figure 4c) during LD and PLD were significantly ($p < 0.001$) lower than in the previous years (Table 3, Table 4). The decreasing effect of increasing relative humidity and temperature on SO_2 may be attributed to the cleansing effect of water vapor and reduced use of fuels, especially coal, on warmer days (Holzworth, 1974). Similar results were also found by Chen et al. (2020), who attributed the increases in SO_2 to biomass burning.

The average NO_x concentrations during the LD period for selected cities were 73.8±2.0, 52.0±0.7, and 36.3±0.6 µg/m3 for 2018, 2019, and 2020, respectively. NO_x concentrations for the PLD period were 58.8±0.6, 46.8±0.2, and 45.6±0.3 µg/m3. Konya, Istanbul, and Istanbul had the highest, and Manisa, Izmir, and Izmir had the lowest NO_x levels in 2018, 2019, and 2020, respectively, during both LD and PLD (Figure 2b, Table 1, Table 2).

The average NO_x levels during LD and PLD were significantly ($p<0.001$) lower than those in 2018 and 2019. The reductions in NO_x were between 30.2% and 50.8% during LD and 2.6% and 22.4% during PLD (Figure 3c). Significant declines were observed in all selected provinces except Kocaeli, Samsun, and Manisa. While the reductions may be primarily attributed to restrictions in human activities such as transportation and industrial manufacturing due to COVID-19, the increase may be related to not shutting down industries such as natural gas plants and power conversion plants. The increases in the three provinces can also be associated with the increasing effect of decreasing relative humidity (Figure 4d, Table 3, Table 4). Other researchers (Arafat et al., 2020; Sicard et al., 2020; Kumari & Toshniwal, 2020; Collivignarelli et al., 2020; Adams, 2020; Krecl et al., 2020; Pei et al., 2020; Alemdar et al., 2021; Celik & Gul, 2022) also found reductions ranging between 30% and 77.3%. They related the decrease in NO_x to the combustion of fossil fuels in vehicles, industries, and households. Sicard et al. (2020), for example, reported a decline of 49% in NO_x in EU cities, which was attributed to transportation (47%) and combustion.

Han and Naeher (2006) and World Health Organization, (2020a) reported that up to 71.5% of atmospheric NO_x emissions came from traffic. In support of this, it was stated that the traffic in Ankara was reduced by 82% and in Istanbul by 80.5% during the pandemic (Sahraei et al., 2021).

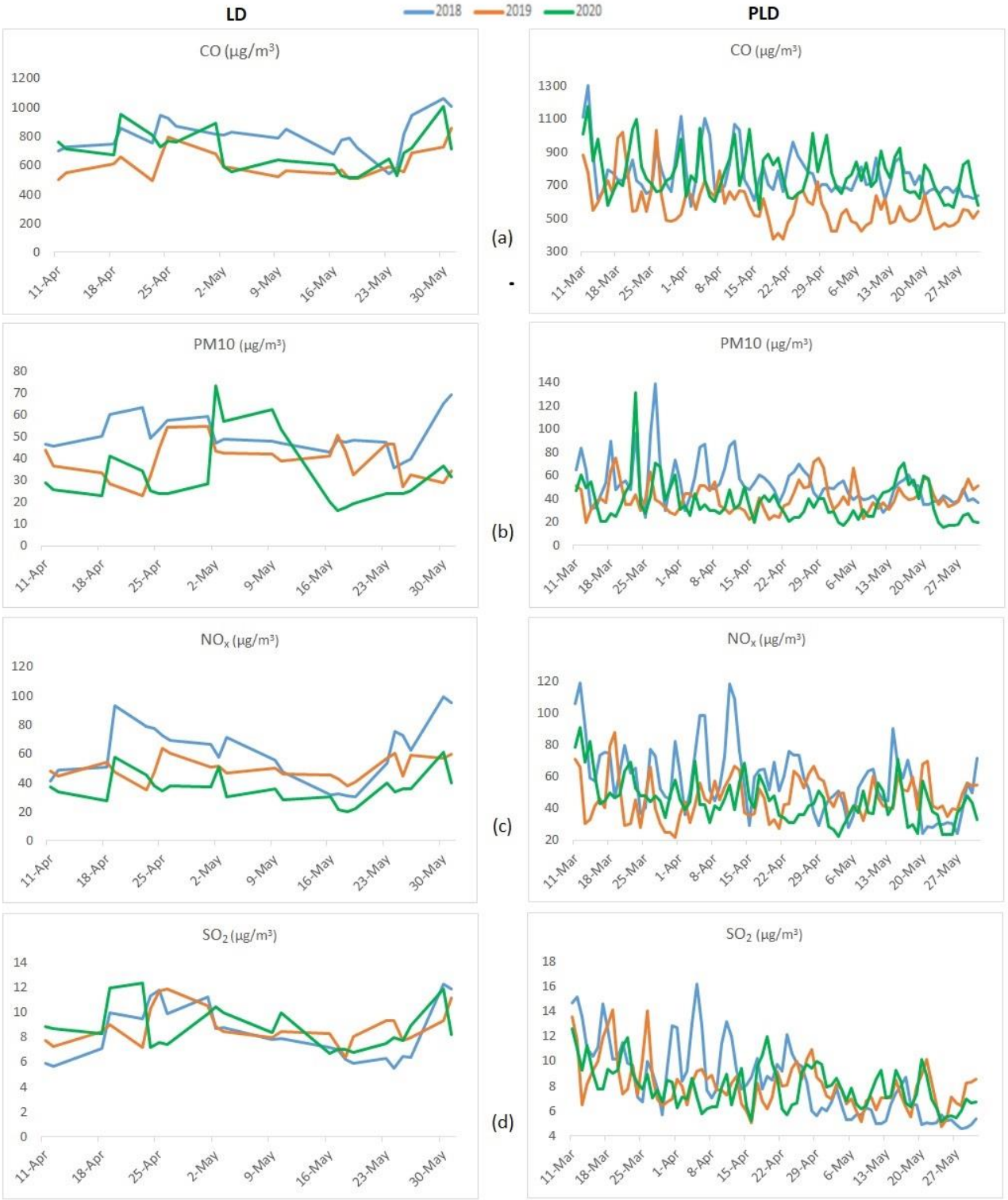

Figure 3: Air pollutants in LD vs. those in PLD according to years (a: CO., b: PM_{10}, c: NO_x, d: SO_2)

Table 3: Some meteorological data regarding selected cities in LD according to years

	Prec (mm)			RH (%)			Press (Kpa)			Temp (°C)			WS (m/s)		
Provinces	2018	2019	2020	2018	2019	2020	2018	2019	2020	2018	2019	2020	2018	2019	2020
Ankara	1.6a	1.3a	0.8a	57.5ab	61.6a	51.8b	89.6a	89.6a	89.7a	23.4a	19.9a	20.1a	1.5a	1.9b	1.9b
Balikesir	0.5a	1.4a	0.8a	63.4a	68.5a	57.1b	97.1a	97.2a	97.3a	25.6a	21.8b	23.1ab	2.0a	2.0a	2.2a
Bursa	1.0a	2a	0.8a	67.2a	68.6a	60.3b	95.1a	95.2a	95.3a	23.4a	20.0b	20.2b	1.4a	1.6a	1.6a
Gaziantep	1.1ab	0.2a	1.7b	52.7a	61.4b	61.5b	92.0a	92.1a	91.9a	25.7a	23.2a	22.2a	1.7a	1.8ab	2.2b
Istanbul	1.0a	1.7a	0.8a	80.9a	78.0a	72.5b	100.9a	100.9a	101.1a	19.9a	17.9ab	17.4b	2.4a	2.8a	2.8a
Izmir	0.3a	0.1a	0.5a	58.3a	67.3b	53.6a	99.0a	99.2a	99.2a	27.6a	23.1b	25.7ab	1.9a	2.2a	2.3a
Kayseri	1.2a	1.2a	1.1a	55.7a	57.8a	56.0a	86.6a	86.6a	86.6a	22.1a	19.5ab	17.9b	1.6a	2.0ab	2.3b
Kocaeli	1.3a	1.9a	0.7a	71.7a	71.8a	65.4b	98.1a	98.2a	98.3a	23.7a	20.4b	20.1b	1.4a	1.6a	1.6a
Konya	1.0a	0.8a	1.2a	54.0a	59.4a	56.3a	88.5a	88.5a	88.5a	23.6a	20.7ab	19.1b	1.4a	2.0b	2.2b
Manisa	0.2a	0.3a	0.6a	58.4a	68.2b	53.0a	98.6a	98.8a	98.8a	27.4a	22.7b	25.5ab	2.1a	2.1a	2.4a
Sakarya	1.4a	2.1a	0.6a	70.4ab	71.6a	64.4b	96.9a	97.0a	97.1a	23.7a	20.2b	19.9b	1.2a	1.3a	1.3a
Samsun	0.9a	1.4a	0.7a	71.4a	72.4a	66.7b	96.5a	96.6a	96.7a	21.6a	19.0ab	17.5b	1.4a	1.7ab	1.9b
Van	1.5a	1.1a	2.9a	59.4a	63.4a	66.4a	78.4a	78.3ab	78.1b	15.0a	13.4a	13.5a	1.9a	2.3ab	2.6b
Zonguldak	1.1ab	0.5a	3.5b	72.5ab	67.4a	74.4b	96.3a	96.5a	96.4a	21.3a	17.5b	18.1b	1.0a	1.1a	1.2a
Average	1.0a	1.2a	1.2a	63.8a	67b	61.4c	93.8a	93.9a	93.9a	23.1a	20.0b	20.0b	1.6a	1.9b	2.0c

Prec: Precipitation, RH: Relative humidity, Press: Air Pressure, Temp: Temperature, WS: Wind speed
Lowercase letters attaching to values show significant ($p<0.001$) differences in years according to one-way ANOVA followed by the Tukey test.

Table 4: Some meteorological data regarding selected cities in PLD according to years

	Prec (mm)			RH (%)			Press (Kpa)			Temp (°C)			WS (m/s)		
Provinces	2018	2019	2020	2018	2019	2020	2018	2019	2020	2018	2019	2020	2018	2019	2020
Ankara	1.8a	1.2a	1.2a	60.6a	62.7a	60.5a	89.5a	89.5a	89.6a	20.0a	17.2b	17.2b	1.9a	2.1a	2.2b
Balikesir	1.3a	1.5a	1.5a	68.5ab	70.8a	65.4b	97.1a	97.2ab	97.3b	21.8a	18.8b	19.2b	2.5a	2.6a	2.8a
Bursa	1.7a	1.4a	1.6a	69.5a	70.1a	68.6a	95.0a	95.2ab	95.2b	20.0a	17.6b	16.8b	1.6a	1.8ab	1.9b
Gaziantep	1.4a	2.4a	2.1a	59.3a	70.1b	66.8b	91.9a	92.0a	91.9a	22.4a	18.9b	19.7b	1.9a	2.0ab	2.2b
Istanbul	1.7a	1.4a	1.8a	81.7a	77.8b	75.9b	101.0a	101.0ab	101.1b	16.7a	15.5ab	14.7b	3.0a	3.2a	3.9b
Izmir	0.7a	1.5a	1.4a	65.6a	70.7b	63.4a	99.0a	99.1b	99.1b	23.8a	20.4b	21.8b	2.4a	2.6a	2.6a
Kayseri	1.4a	1.1a	1.7a	57.6a	62.2b	62.6b	86.5a	86.5a	86.5a	19.1a	16.2b	15.8b	2.2a	2.3a	2.3a
Kocaeli	2.0a	1.6a	1.8a	73.1a	72.8a	71.9a	98.0a	98.2ab	98.3b	20.4a	18.1b	17.0b	1.7a	1.8a	2.1b
Konya	1.0a	1.1a	1.4a	57.4a	64.9b	64.3b	88.4a	88.4a	88.4a	20.5a	17.1b	16.8b	2.0a	2.2a	2.3a
Manisa	0.8a	1.4a	1.4a	65.5a	70.9b	62.1a	98.6a	98.7b	98.7b	23.6a	20.0b	21.6b	2.5a	2.7a	2.8a
Sakarya	2.1a	1.7a	1.9a	71.4a	72.3a	71.4a	96.8a	97.0ab	97.1b	20.5a	18.0b	16.9b	1.4a	1.5a	1.7b
Samsun	1.2a	1.7a	1.1a	72.2a	73.9a	73.1a	96.5a	96.6ab	96.7b	18.8a	16.1b	15.4b	1.8a	2.1ab	2.2b
Van	1.7a	2.5a	2.6a	61.4a	71.1b	68.4b	78.2a	78.1a	78.1a	12.7a	9.2b	10.9b	2.3a	2.2a	2.3a
Zonguldak	1.9a	1.8a	2.0a	72.8a	73.9a	73.7a	96.3a	96.5b	96.4ab	18.3a	15.0b	16.0b	1.2a	1.5b	1.3a
Average	1.5a	1.6a	1.7a	66.9a	70.3b	67.7a	93.8a	93.9a	93.9a	19.9a	17.0b	17.1b	2.0a	2.2b	2.3c

Prec: Precipitation, RH: Relative humidity, Press: Air Pressure, Temp: Temperature, WS: Wind speed
Lowercase letters attaching to values show significant ($p<0.001$) differences in years according to one-way ANOVA followed by the Tukey test.

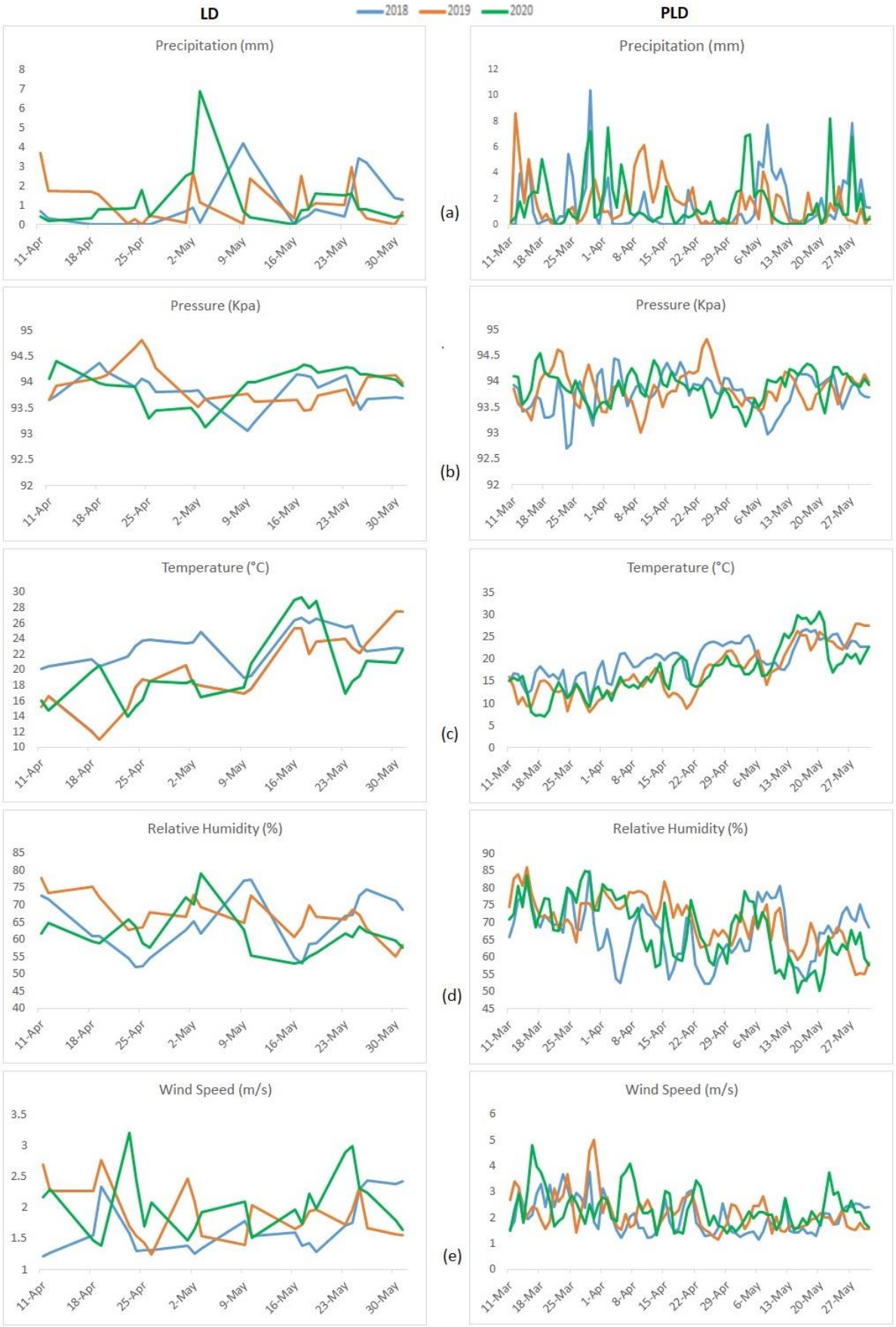

Figure 4: Meteorological data in LD vs. that in PLD according to years (a: Precipitation, b: Pressure, c: Temperature, d: Relative humidity, e: Wind speed)

The average CO concentrations during the LD period for the selected cities were 870.9±6.4, 627.7±5.6, and 813.5±8.6 µg/m3 for 2018, 2019, and 2020, respectively. The CO concentrations for the PLD period were 766.4±2.3, 582.2±1.9, and 776.0±2.8 µg/m3. Zonguldak, Ankara, and Balikesir had the highest, and Kayseri, Izmir, and Izmir had the lowest values of CO in 2018, 2019, and 2020, respectively, during LD (Figure 2a, Table 1). Bursa, Balikesir, and Bursa had the highest, and Istanbul, Konya, and Izmir had the lowest CO values in 2018, 2019, and 2020, respectively (Figure 2a, Table 2).

The average CO levels during LD and PLD were significantly ($p<0.001$) higher than those in 2018 and 2019. The changes in CO during LD and PLD were between -6.6% and 1.3% and between 29.6% and 33.3%, compared to 2018 and 2019 (Figure 3a). Considering the provinces individually, CO emissions during LD and PLD significantly increased compared to 2018 and 2019. A large part of the unexpected CO increase during LD and PLD can be attributed to heating systems in residential areas and a small part due to not shutting down industries such as natural gas plants and power conversion plants. Unlike our findings, CO level declines in LD and PLD periods due to restrictions have been found by other researchers (Kanniah et al., 2020; Mahato et al., 2020; Chen et al., 2020; Collivignarelli et al., 2020; Connerton et al., 2020; Dantas et al., 2020; Kerimray et al., 2020).

4. Conclusion

In this study, we determined the effects of LD and PLD implemented by the Turkish government during the COVID-19 pandemic on air quality in fourteen selected cities in Turkey. Our findings indicate that human mobility-related activities, like traffic and coal combustion, significantly reduced PM_{10} and NO_x levels during LD and PLD. On the other hand, we determined partially decreasing trends in CO and SO_2 because of not shutting down industries such as oil refineries, natural gas plants, power conversion plants, and power plants in some provinces and household coal combustion. The meteorological variables in the curfew period were also examined, but no significant changes were determined except slightly increased wind speed in a few provinces. However, as expected, the reduction rates in air pollutants during LD were higher than during PLD because of the denser restrictions in human activities. Reductions in air pollutant emissions observed during LD and PLD demonstrate the close relationship between human activities and air pollutants emitted into the atmosphere from transportation and industries.

Decreasing air pollution during COVID-19 is vital for preventing air pollutant deaths during LD periods. The results of this study suggest that using public transportation instead of private vehicles and using natural gas or other cleaner energy systems instead of coal can significantly improve air quality. In extreme cases of air pollution characterized by elevated PM_{10} and NO_x levels, a temporary lockdown or partial lockdown could be implemented.

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