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IMPACTS OF COVID-19 PANDEMIC ON TROPOSPHERIC NO_2 OVER TURKEY

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Abstract

The COVID-19 pandemic has strongly affected the tropospheric NO_2 levels due to imposed restrictions on anthropogenic activities. Utilizing space-based estimations of tropospheric NO_2, here we examine the relationship of tropospheric NO_2 to COVID-19 over Turkey. We have used 2015 - 2019 OMI tropospheric NO_2 data as a baseline period and have compared it with 2020. We have found a notable decrease in NO_2 in Turkey in April, May, and December while the most significant difference can be observed in the most populated and industrialized cities. The tropospheric NO_2 levels returned to nearly a regular pattern in the months that the curfew was partially lifted. We also have used Google Mobility data to explicate the relationship between mobility and the change in NO_2 levels for selected cities. Our research corroborates the effects of decreased anthropogenic activity on tropospheric NO_2 levels worldwide during the COVID-19 pandemic. However, the distinctive curfew procedures of Turkey revealed a discrete pattern on NO_2 levels.

Keywords: NO_2, COVID-19, OMI, DOMINO data, Turkey.

Öz

COVID-19 pandemisi, antropojenik faaliyetlere getirilen kısıtlamalar nedeniyle troposferik NO_2 seviyelerini önemli ölçüde etkilemiştir. Bu çalışma, NO_2'in COVID-19 ile olan ilişkisinin uydular aracılığıyla belirlenmesini Türkiye üzerinde incelemektedir. 2015 – 2019 yılları arasındaki OMI troposferik NO_2 verileri baz alınarak 2020 yılı verileri ile karşılaştırılmıştır. Türkiye genelinde Nisan, Mayıs ve Aralık aylarında kayda değer bir düşüş saptanmış, en fazla fark ise yüksek nüfuslu ve sanayileşmiş şehirlerde gözlemlenmiştir. Troposferik NO_2 seviyeleri, sokağa çıkma yasağının kısmen kaldırıldığı aylarda neredeyse normale dönmüştür. Diğer bir yandan, bu çalışmada seçilmiş bazı şehirlerde nüfus hareketliliği ile NO_2 seviyelerindeki değişim arasındaki ilişkiyi açıklamak için Google Mobility verilerini kullanılmıştır. Çalışmanın sonuçları dünya çapında azalan antropojenik aktivitenin troposferik NO_2 seviyeleri üzerindeki etkileri ile uyum göstermektedir. Ancak, Türkiye'nin kendine özgü sokağa çıkma yasağı prosedürleri, NO_2 seviyelerinde ayrı bir örüntü ortaya çıkarmıştır.

Anahtar Kelimeler: NO_2, COVID-19, OMI, DOMINO data, Türkiye

1. INTRODUCTION

Stemming from the Coronaviridae family of viruses, coronavirus disease 2019 (COVID-19) was firstly reported in December 2019 by World Health Organization (WHO). The first cases occurred in Wuhan, a city in the central Hubei Province of China. The first case in Turkey was recorded on 11 March 2020 while the first death due to COVID-19 happened four days later, on March 15. All schools in the country were closed the next day, and a total curfew was announced on March 21. Rather than a total lockdown, Turkey kept the young and the elderly to stay at home and asked nearly everyone else to continue working (The Economist, 2020). Starting from April 10, 31 biggest cities were applied a curfew on weekends and holidays. Cafés, restaurants, and parks reopened on June 1st with enhanced hygiene measures, use of masks and social distancing however, children and people over 65 were not allowed to go outdoors for more than

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a few hours a week. Turkey remained "open" during 2020 summer mostly because of economic reasons and tourism industry expectations. Since August 2020, rotational, flexible, and remote work in public institutions and organizations was allowed. On November 20th, the government stated that the schools would be closed to the end of the fall semester and a curfew has been applied except 10.00-20.00 on weekends, and restaurants would only provide takeaway service, shopping malls and markets would be closed at 20.00. This situation continued until May 2021, with many exceptions and changes.

It is well-known that the effects of COVID-19 on the world economy have been adverse regarding the abrupt decrease in economic activities because of transportation and movement restrictions of the pandemic. Since human activity is one of the major sources releasing the pollutants to the atmosphere, curfew situations, or limited social life is expected to decrease their concentrations. As a result, significant changes in air quality and pollutant levels have been recorded in countries such as Spain (Tobas et al., 2020), Iraq (Hashim et al., 2021), India (Gautam, 2020), Brazil (Nakada and Urban, 2020), China (Sharma et al., 2020) as well as Turkey (Topuz ve Karabulut, 2021).

Among these pollutants, NO_X is produced from the reaction of nitrogen and oxygen gases in the atmosphere at high temperatures such as fossil fuel combustion, burning biomass, and lightning strikes. The main source of NO_X is from anthropogenic emissions and is rapidly transformed into NO_2 by reaction with ozone (Castellanos and Boersma, 2012). NO_2 may also be harmful to human health, specifically by causing respiratory ailments such as lung diseases, coughing, common cold, influenza, pneumonia, asthma, and many other cardiac problems (US EPA, 2016). Regarding its short atmospheric lifetime (approximately a few hours), the concentrations are highly variable in time and space (Crippa et al., 2018). NO_2 is frequently used to quantify the degree of fossil fuel use, which is connected to economic activity (Luo et al., 2022).

Although the atmospheric NO_2 is traditionally measured with ground stations, they measure its concentration near the ground and suffer from temporal and spatial coverage. On the other hand, remotely sensed data provide a wider view of atmospheric NO_2 acquiring the total tropospheric column over an area. The first satellite measurements of tropospheric NO_2 were from the Global Ozone Monitoring Experiment (GOME) on European Remote-Sensing Satellite-2 (ERS-2) in 1995. Its successors, SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) that launched in 2002, Ozone Monitoring Instrument (OMI) onboard the Aura satellite in 2004 and more recently, TROPOspheric Monitoring Instrument (TROPOMI) onboard the Copernicus Sentinel-5 Precursor (Sentinel-5P) satellite launched in 2017 enabled understanding of tropospheric NO_2 with enhanced spatial and temporal resolution. Among these, OMI has spatial resolution of approximately 13 km by 24 km for nadir pixels, increasing in size to 24 x 135 km for the largest view angles and providing the tropospheric NO_2 data daily since late 2004.

Owing to a 16-year archive of data, most of the studies on tropospheric NO_2 with OMI have focused on the trends in time. For instance, Zhang et al. (2017) studied the spatial and temporal evaluation of the long-term trend of OMI retrieved NO_2 over China and found an increasing pattern between 2005 and 2011. Another study has found a 6% decrease in NO_2 level using OMI data over China after 2011 (Irie et al., 2016). The rapid decrease in 2011 on a local or larger spatial scale is attributed to a nationwide action such as the widespread use of denitrification units. Unlike developing areas, most of the developed cities of Europe experience decreasing trend of 2–5% per year for NO_2 levels due to the implementation of effective strategies to reduce emissions (Paraschiv et al., 2017). Sometimes the change in the tropospheric NO_2 can be instantaneous. For example, Lelieveld et al. (2015) found that NO_2 levels shifted in 2010, just after the economic crises and armed conflicts in the Middle East. Similarly, the findings of Yavaşlı (2020) imply an abrupt increase in the Syrian border cities of Turkey in 2011, after the revolt in Syria. This situation has been referred to as the changes in population concentration due to political circumstances. These examples have shown that NO_2 levels in the troposphere can be affected by economic, industrial, and other human-controlled activities. The lockdowns or curfews due to COVID-19 pandemic have had a worldwide impact on industrial activities, traffic and, the levels of atmospheric pollutants such as NO_2.

Tropospheric NO_2 level change due to COVID-19 lockdown quickly became a new topic of recent research studies. Prakash et al. (2021) have analyzed the lockdown effect for Indian megacities. A decrease in the concentration of air pollutants, specifically NO_2 and SO_2, has been observed during the lockdown period in India, measured by Sentinel-5P from 2019 and 2020. Correspondingly, Represa et al. (2021) used satellite-based measurements of NO_2 of Sentinel-5P in Buenos Aires (Argentina), and their results showed a significant reduction of NO_2 for the monthly mean in the metropolitan area at lockdown. However, after the strict lockdown, concentration values increased steadily. Naveed-ul-Zafar (2021) has selected 15 regions that emerged as hotspots in Europe to assess the Sentinel-5P Tropospheric NO_2 column to investigate if NO_2 levels have changed from 2019 to 2020 due to the lockdown. The results indicate that NO_2 concentration decreased due to lockdowns for all regions. The abrupt decrease of tropospheric NO_2 has been reported in various other countries such as Spain (Tobías et al., 2020; Baldasano, 2020), China (Liu et al., 2020), Greece (Koukouli et al., 2020), Iraq (Hashim et al., 2021), India (Biswal et al., 2020) as well as Turkey (Kaplan and Avdan, 2020). Almost all these studies use the 2019 NO_2 levels to compare with 2020.

Considering its idiosyncratic curfew procedures, the impacts on the tropospheric NO_2 over Turkey need to be examined in detail. Therefore, we have aimed to assess the impacts of COVID-19 conditions on the NO_2 levels throughout 2020. Because of the variation of tropospheric NO_2 levels from year to year, we have used the 2015-2019 averages of OMI as a base period and made a comparison of monthly average 2020 NO_2 levels. We have also analyzed selected cities to evaluate the change in detail.

2. STUDY AREA

Turkey, lying at the crossroads of the Balkans, Caucasus, Middle East, and the eastern Mediterranean, is situated in a geographical location where climatic conditions are quite temperate. However, the diverse nature of the landscape and the existence of the mountains that run parallel to the coasts result in significant differences in climatic conditions. The coastal areas experience milder climates, whereas the inland Anatolian plateau has extremes of hot summers and cold winters with limited rainfall. Turkey is a country with many urban centers, such as Istanbul with a population of 15 million, Ankara, the capital with 5 million and Izmir with 4 million inhabitants. Approximately 75% of Turkey's population lives in urban areas. With an estimated nominal gross domestic product of $764 billion ($9126 per capita), Turkey is the world's 19th largest economy (The World Bank, 2021).

3. MATERIALS AND METHODS

The DOMINO v2.0 dataset of the European Space Agency (ESA) Tropospheric Emission Monitoring Internet Service (TEMIS; www.temis.nl) is a set of OMI NO_2 data based on improved level-1b radiances. The NO_2 retrieval algorithm of the DOMINO dataset consist of three stages: using Differential Optical Absorption Spectroscopy (DOAS) to obtain NO_2 slant columns from the OMI reflectance spectra, separating the stratospheric and tropospheric contribution to the slant column and converting the tropospheric slant column to a vertical column with the tropospheric air mass factor (AMF) (Boersma et al., 2011). We obtained the monthly average dataset from TEMIS, converted 10^{13} molecules/cm^2 to 10^{15} molecules/cm^2 and filtered it with 30% cloud radiance fraction.

Although the NO_2 emission sources have not changed in one year, the effects of meteorological parameters on tropospheric NO_2 levels should not be discarded. Therefore, each month's 2015-2019 five-year average values have been calculated as a “base period” to ensure that the change in NO_2 levels is not dependent on diversified meteorological conditions. We have created difference maps using base period and 2020 monthly average data. We used difference maps to examine the change in administrative levels. Top 6 cities with the highest population are selected for this purpose. These cities, Istanbul, Ankara, Izmir, Bursa, Adana, and Antalya, constitute approximately 40% of the country’s population. To understand the change, we have calculated the mean values of the pixels in administrative boundaries in the base period and 2020 data for each city.

We also have analyzed daily sub-region Google Mobility data to investigate the causal relationship between mobility and change in NO_2 levels. This is accomplished by averaging the daily Google Mobility trend values for each month. These values represent the difference between people regarding their visits to retail & recreation, grocery & pharmacy, parks, transit stations, workplaces, and residential places (Yilmazkuday, 2020). The data demonstrates how visitation to (or time spent in) classified areas change over time in relation to pre-pandemic baseline days defined by Google.

4. RESULTS AND DISCUSSION

Fig. 1 represents the change in tropospheric NO_2 levels over Turkey before and during COVID-19. Since Turkey's restrictions did not start until April, no serious change has been observed in March. On the other hand, there has been a significant decrease in NO_2 levels in April, particularly in densely populated and industrialized cities. The decrease can be observed in May and June to a lesser extent. The highest difference in NO_2 levels before and after the pandemic can be observed in April and May. After abrogating the intercity travel prohibitions in summer of 2020, NO_2 levels mainly remained unchanged in July and

August, with a slight increase in September. In November 2020, it was observed that the NO_2 levels are higher in many cities of Turkey, more particularly on the southern coast. The NO_2 levels decreased drastically in December after the announcement of new restrictions and curfews. The idiosyncratic curfew processes of Turkey have made the tropospheric NO_2 levels much lower than the base period in April, May, June, and December 2020, while levels remain roughly the same in July, August, September, October, and November with ease of COVID-19 restrictions.

The NO_2 levels are lower compared to 2015 – 2019 average at all selected 6 cities in March – June (Fig. 2). The negative change observed in March 2020 is 50%, 42% and 24% for Istanbul, Ankara, and Izmir, respectively. May 2020 NO_2 levels are also lower than the 2015-2019 base period for the selected cities. The highest negative change observed in June appears to happen in Antalya, the touristic heart of Turkey, with -45%. After the ease of restrictions, in July and August, the difference between before and after pandemic NO_2 levels decreased; nevertheless, the negative difference still exists. The only considerable difference in September 2020 is observed in Istanbul. The NO_2 levels have increased by nearly $1*10^{15}$ molecules/cm (32%) in Istanbul and surrounding cities in October, decreasing in Ankara. Adana and Antalya had higher NO_2 levels in November 2020 compared with the 2015-2019 base period. The decrease in April and May 2020 for the NO_2 levels can be observed in December 2020 for all selected cities except Izmir.

The monthly averages of Google Mobility of selected six cities show that all mobility categories except grocery & pharmacy, transit stations and residential are lower than the base period in the whole 10-month period (Fig. 3). The decrease is notable, especially in April, May, June, November, and December. The residential areas are higher by 30% in these cities for April and May 2020. This is consistent with other studies that analyze Google and Apple mobility data (Nouvellet et al., 2021; Chan et al., 2020). Considering the possible primary source of anthropogenic NO_2 as the transportation, heating, and industrial production of humans, it can be said that the considerable decrease in mobility in all categories is the possible reason for the decrease in NO_2 production in April, May, and December 2020.

The result of this study is consistent with various studies around the world. For instance, Bauwens et al. (2020) stated that the average NO_2 column decrease across all Chinese cities is 40% lower than in the same period last year, and it may be as high as a factor of two in severely affected areas like Wuhan and Jinan. Sudden reduction in socio-economic activities in Europe has also resulted in a drop in NO_2 levels. After the first week of lockdown, deficient NO_2 concentrations were found everywhere in Italy, reducing to 21% compared to the same week of 2019 (Hoang et al., 2021). With an estimated 20 percent reduction, this reduction in NO_2 levels exceeded the combined effect of emission restrictions and the economic slump in Europe from 2004 to 2010 (Castellanos and Boersma, 2012). NO_2 concentrations in the Northeastern United States also decreased by 30% during the lockdown, according to NASA satellite data based on the AURA satellite (NASA, 2021). Similarly, Bauwens et al. (2020) used TROPOMI to evaluate the NO_2 concentration reduction in some northeastern parts of the US, and they realized that the noticeable decline of NO_2 emissions was 28% for New York and 24% for Philadelphia. Koukouli et al. (2021) investigated the sudden change in NO_2 emissions over Greece and some western parts of Turkey. Their results show that the NO_2 hotspot near Istanbul remains pronounced in March 2020, while most of the smaller urban emission locations in Greece are absent due to Turkey's late lockdown policy. Another study on other air quality parameters such as PM_{10} and SO_2 shows a decrease in lockdown months and a significant increase after the lockdowns over Turkey (Orak and Ozdemir, 2021).

5. CONCLUSIONS

During the COVID-19 pandemic, human activity dropped dramatically, leading in large decreases in pollution levels in the atmosphere. In this study, remote sensing techniques were used to analyze tropospheric NO_2 concentrations over Turkey during COVID-19 pandemic. For that purpose, OMI tropospheric NO_2 observations were examined to understand the possible negative effect on NO_2 levels. Even though, most of the countries have enforced a total lockdown, Turkey have chosen to use idiosyncratic curfew rules. Beginning on March 21, the Turkish government imposed significant mobility restrictions, and several economic sectors were temporarily shut down before a total lockdown began on April 10. Rather than imposing a comprehensive state of emergency, Turkey advised the young and old to remain at home and asked practically everyone else to continue working. On weekends and holidays, curfews were imposed in 31 major cities. Our hypothesis was that the curfews have impacted the pollutant levels as well as NO_2 over Turkey.

According to our findings, The COVID-19 mitigation lockdown and reopening procedures impacted the tropospheric NO_2 levels in Turkey. NO_2 levels drastically decreased in the spring of 2020, then began to rise again in the summer, and another decrease was detected in winter. In general, the curfew policy lowered NO_2 levels in Turkey; however, after the curfew was lifted or "normalized" NO_2 levels returned to a regular pattern compared to the 2015-2019 period. NO_2 levels fell over Turkey's most populous and industrialized cities during the curfews. However, smaller cities have not been affected regarding NO_2 levels.

The Google mobility data were used to understand the possible reasons of the decrease in NO_2 levels since it has been broadly known that NO_2 is mostly caused by anthropogenic activities. According to the Google mobility data, fewer mobility has been observed in April, May, June, November, and December 2020 when tropospheric NO_2 levels are also lower than the 2015-2019 base period in selected cities. In these cities, during the months of April and May 2020, there is a 30% increase in household mobility. According to the other studies as well as ours, the main reason for rise in NO_2 levels in troposphere is human activities. This also proves that if the NO_2 producing activities such as fossil fuel combusting could be controlled, the air quality levels might easily be nominal at short notice. This beneficial effect on the environment may be only temporary, but authorities should take notice of ways to reduce pollution on a long-term basis utilizing the experience gained during the lockdown or curfew times. The findings of the current study may contribute in the development of better air pollution management measures, as well as enhanced air quality modeling and forecasting for the benefit of human health and the environment.

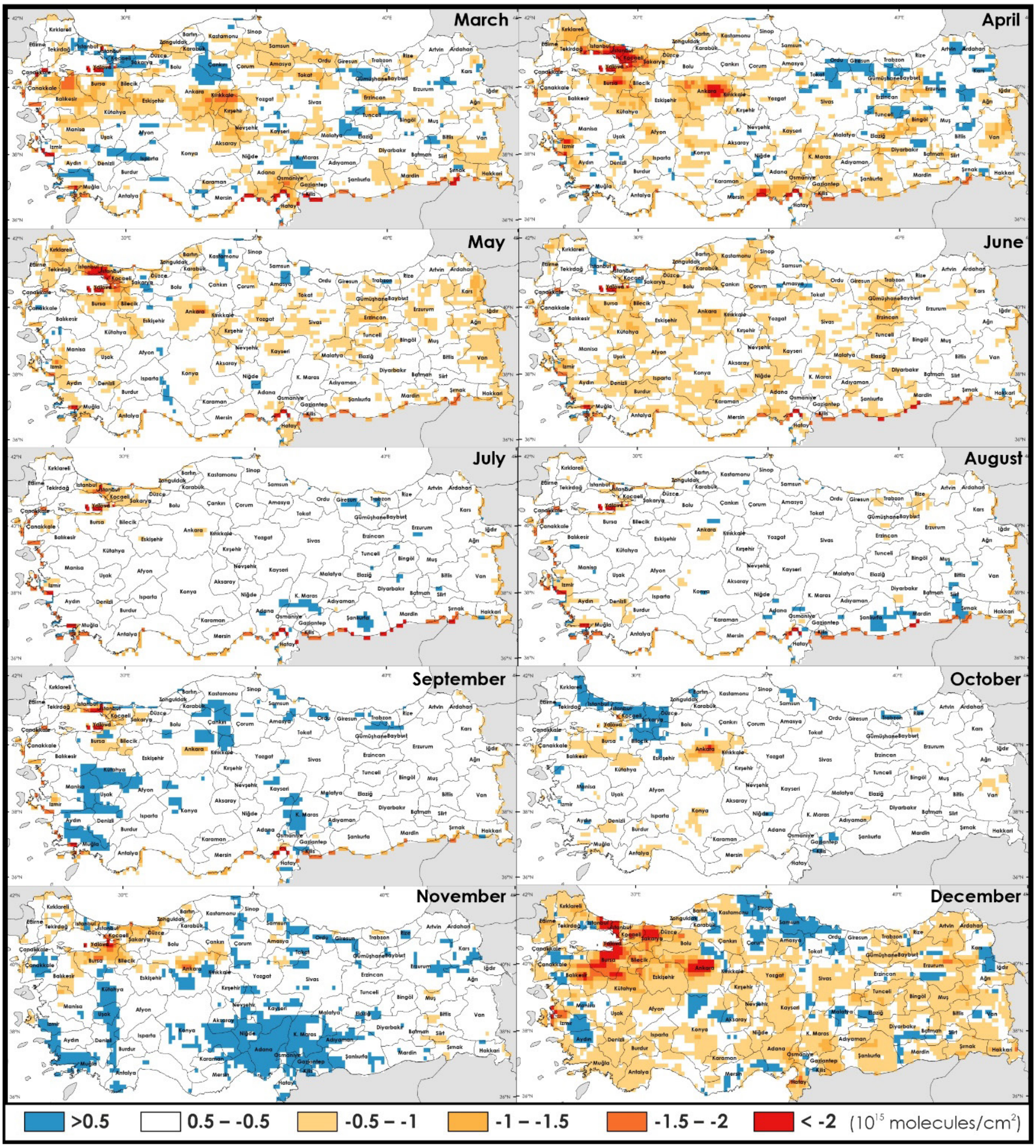

Figure 1- The change in tropospheric NO_2 levels over Turkey before and during COVID-19.

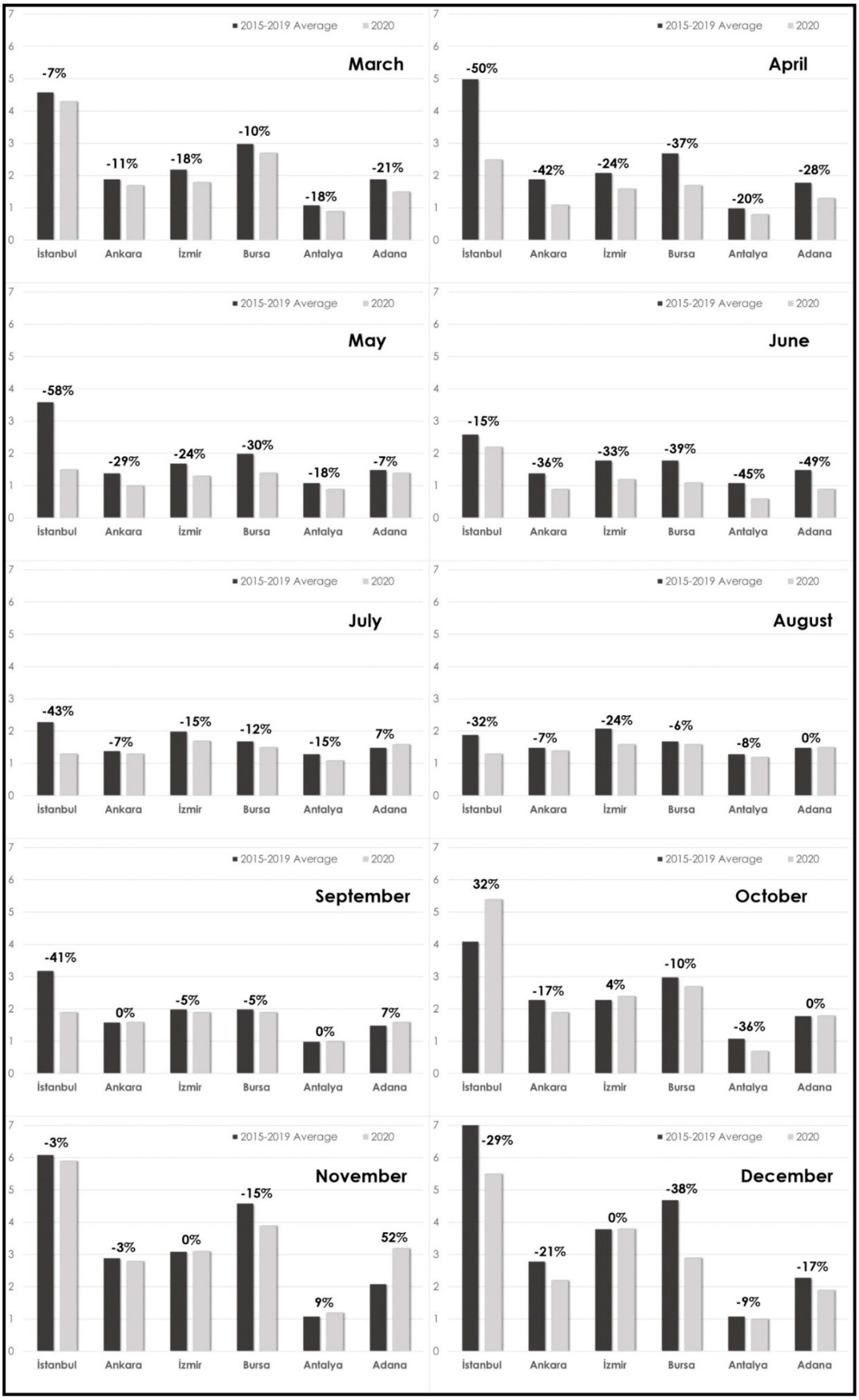

Figure 2- The average tropospheric NO_2 levels at selected cities before and during COVID-19 (vertical units represent 10^{15} molecules/cm^2).

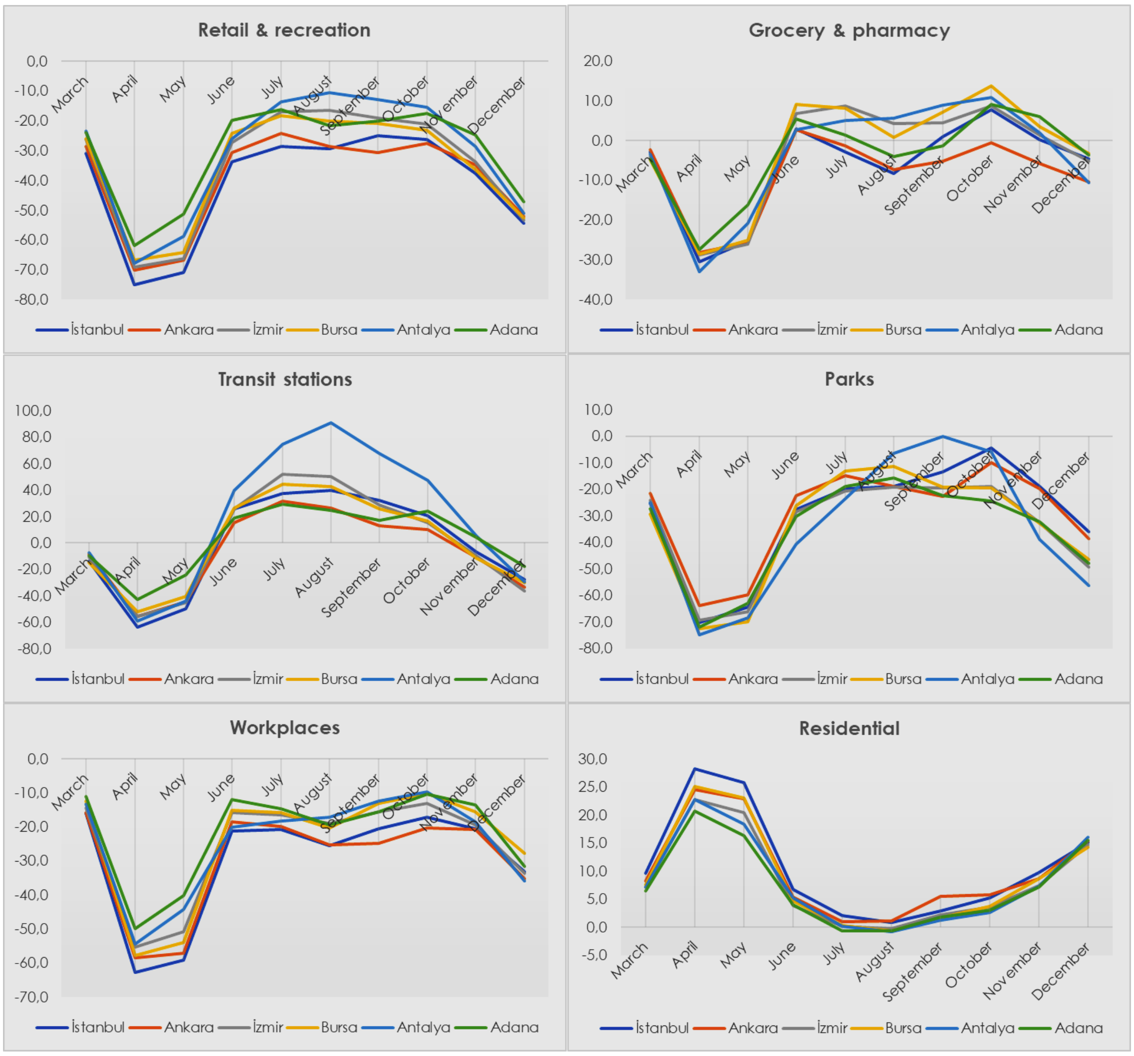

Figure 3- The Google Mobility averages of selected cities (vertical units represent percentage of change).

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Metodoloji/*Methodology*	D. D. Yavaşlı
Veri toplama-oluşturma-iyileştirme/*Data Curation*	D. D. Yavaşlı
Analiz/*Analysis and interpretation of data*	D. D. Yavaşlı,- M. K. Ölgen
Görselleştirme/ *Visualization*	D. D. Yavaşlı
Yazı taslağı/*Writing - Original Draft*	D. D. Yavaşlı
Yazma - İnceleme ve Düzenleme/*Writing - Review & Editing*	M. K. Ölgen
Proje yönetimi/*Project administration*	M. K. Ölgen

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