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Air Pollution/Quality Trends in the Pandemic of the 21st Century: Approaches in Türkiye

21. Yüzyıl Küresel Salgınında Hava Kirliliği/Kalitesi Trendleri: Türkiye'deki Yaklaşımlar

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ABSTRACT

COVID-19 was declared a pandemic by the World Health Organization (WHO) in 2020. The pandemic of the 21st century has attracted attention as an important issue, and studies have been carried out in many areas in terms of the related issue. One of these areas is air pollution/quality, which received wide coverage in the media and where positive developments became visible with restrictions. In studies conducted on a national basis regarding COVID-19 pandemic and air pollution/quality, it has been determined that the selected cities have at least one specific feature. These features include population density, excess industrial activities, excess vehicle or transportation network connections, mining activities, and energy recovery. As a result of the study, a decrease was observed in outdoor air pollution emissions, especially during the restrictions, and it was determined that there were improvements in terms of general air quality in Türkiye. While there have been previous studies on the interaction between pandemics and air pollution, this study distinguishes itself by providing a comprehensive and detailed analysis within the context of Türkiye. Unlike earlier works, this research evaluates Türkiye in a broader framework, offering a holistic perspective on the topic. It not only summarizes and interprets findings but also provides actionable recommendations for future pandemic periods and sustainable urban development. This study highlights the situation before and during the COVID-19 pandemic in terms of air pollution, sheds light on future scenarios, and offers policymakers and decision-makers practical proposals applicable to regions worldwide. In the event of future pandemics or efforts to promote healthy and sustainable living, the insights and assessments presented in this study can serve as a valuable reference. Furthermore, it provides actionable strategies for reducing urban air pollution, making it relevant for different countries and cities globally.

Keywords: Air Pollution, Air Quality, COVID-19, Lockdown, Pandemic, Türkiye

Öz

COVID-19, Dünya Sağlık Örgütü (WHO) tarafından 2020 yılında pandemi olarak ilan edilmiştir. 21. yüzyılın bu pandemisi, önemli bir mesele olarak dikkat çekmiş ve bu konuda birçok alanda çalışmalar yürütülmüştür. Bu alanlardan biri de hava kirliliği/kalitesi olup, medyada geniş yer bulmuş ve kısıtlamalarla birlikte olumlu gelişmeler gözlemlenmiştir. COVID-19 pandemisi ve hava kirliliği/kalitesi üzerine ulusal bazda yapılan çalışmalarda, seçilen şehirlerin en az bir spesifik özelliğe sahip olduğu belirlenmiştir. Bu özellikler arasında nüfus yoğunluğu, aşırı sanayi faaliyetleri, yoğun araç veya ulaşım ağı bağlantıları, madencilik faaliyetleri ve enerji geri kazanımı yer almaktadır. Çalışmanın sonucunda, özellikle kısıtlamalar sırasında dış hava kirliliği emisyonlarında bir azalma gözlemlenmiş ve Türkiye'de genel hava kalitesinde iyileşmeler olduğu tespit edilmiştir. Pandemiler ve hava kirliliği arasındaki etkileşim üzerine daha önce yapılan çalışmalar bulunmakla birlikte, bu çalışma kendini Türkiye bağlamında kapsamlı ve detaylı bir analiz sunmasıyla öne çıkarmaktadır. Önceki çalışmalardan farklı olarak, bu araştırma Türkiye'yi daha geniş bir çerçevede değerlendirerek konuya bütüncül bir perspektif sunmaktadır. Bulguları özetlemek ve

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yorumlamanın yanı sıra gelecekteki pandemi dönemleri ve sürdürülebilir kentsel gelişim için uygulanabilir öneriler de sunmaktadır. Bu çalışma; COVID-19 pandemisi öncesi ve sırasındaki durumu hava kirliliği açısından vurgulamakta, gelecekteki senaryolara ışık tutmakta ve politika yapıcılar ile karar vericilere dünya genelindeki bölgelere uygulanabilecek pratik öneriler sunmaktadır. Gelecekteki pandemiler veya sağlıklı ve sürdürülebilir yaşamı teşvik etme çabaları söz konusu olduğunda, bu çalışmada sunulan içgörüler ve değerlendirmeler değerli bir referans olarak kullanılabilir. Çalışma, kentsel hava kirliliğini azaltmaya yönelik uygulanabilir stratejiler sunarak, dünya genelindeki farklı ülkeler ve şehirler için de geçerlilik taşımaktadır.

Anahtar Kelimeler: COVID-19, Hava Kalitesi, Hava Kirliliği, Kısıtlama, Pandemi, Türkiye

INTRODUCTION

Coronavirus, or as the World Health Organization (WHO) termed it, COVID-19, is a pandemic that continues to affect the world through various variants (WHO, 2020). This 21st-century pandemic, which rapidly spread across the globe, first emerged in Türkiye on March 11, 2020 (T.R. Ministry of Health, 2022). As the pandemic progressed, various restrictions began to be implemented in April 2020, based on recommendations from policymakers and the scientific committee. The initial restrictions, introduced between April 10 and 12, 2020, were first applied in 30 metropolitan cities and Zonguldak (T.R. Ministry of Interior, 2020). The first full lockdown was implemented from May 22 to 26, 2020. In terms of restrictions, the period between March and June 2020 stands out as the most significant. As of May 31, 2022, the total number of cases in Türkiye reached 15,060,609, with 99,081 deaths (T.R. Ministry of Health, 2022). While metropolitan cities are notable for their high incidence and death rates, the elevated number of deaths in Zonguldak, where mining activities are intensive, is particularly striking (Ulutaş et al., 2022). Since COVID-19 is an upper respiratory tract disease that can be transmitted through the air, its relationship with air pollution and air quality has become an important area of research (Faruk et al., 2022). The impact of restrictions during the COVID-19 period on air pollutant parameters has garnered as much attention as the airborne transmission of the virus (Perrone et al., 2022). Discussions have centered on potential improvements in air quality, with many scientists conducting studies to explain these visible changes using scientific methods (Adams, 2020; Jain and Sharma, 2020; Mahato et al., 2020; Briz-Redón et al., 2021; Ghahremanloo et al., 2021; Ju et al., 2021). Additionally, numerous studies have demonstrated that COVID-19 measures reduced air pollution emissions (Copat et al., 2020; Menut et al., 2020; Borhani et al., 2021; Gouda et al., 2021; He et al., 2021; Hu et al., 2021; Islam et al., 2021; Rathore et al., 2021; Rodríguez-Sánchez et al., 2022; Saha et al., 2022). The findings of the study align with the United Nations (UN) Sustainable Development Goals (SDGs), particularly Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action). Rita et al. (2021) reported that WHO data from various regions, assessed between April and August 2020, revealed global renewable energy potential by examining emissions during the COVID-19 lockdown. The study emphasized that investing in renewable energy sources to meet the energy needs of various countries could help maintain the clean and green environment achieved during the COVID-19 period, even after the pandemic. It was found that the curfews imposed during COVID-19 had a positive environmental impact by reducing CO and other pollutant emissions to levels below those seen before the pandemic (Tunç and Toros, 2020; Aydın and Yetişkul, 2021; Efe, 2021). The application of biofuels for energy recovery was highlighted as a significant outcome, as it significantly reduced emissions, similar to the effects observed during the COVID-19 lockdown. The notable results of the COVID-19 quarantine in relation to the UN's SDGs are among the primary objectives of the study.

Outdoor air pollutant parameters, including particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), and ozone (O_3), are measured by the air quality monitoring stations of the Ministry of Environment, Urbanization, and Climate Change in Türkiye. These stations conduct traffic, industrial, or urban measurements, and the parameters measured vary depending on the location. Some stations measure six air pollutant parameters ($PM_{2.5}$, PM_{10}, NO_x, SO_2, CO, and O_3), while others measure only two parameters (PM_{10} and SO_2). Air pollution and air quality status are assessed using the Air Quality Index (AQI). Data from the National Air Quality Monitoring Network have

been widely used in Turkish studies (Tunç and Toros, 2020; Aydın and Yetişkul, 2021; Çelik and Arıcı, 2021; Çelik and Gül, 2021; Gören et al., 2021; Orak and Özdemir, 2021; Özbay and Koç, 2021; Ö.F. Tekin, 2021; Toksoy and Atalay, 2021; Topuz and Karabulut, 2021). The distribution of these studies across Türkiye is illustrated in Figure 1. The cities most frequently studied, along with the number of studies conducted in each, are as follows: Istanbul (6), Ankara (3), Izmir (2), Izmit (2), Mersin (2), Trabzon (2), and Zonguldak (2). Additionally, there is one nationwide study (Orak and Özdemir, 2021) and two studies covering specific regions of the country (Dursun et al., 2021; Ulutaş et al., 2023).

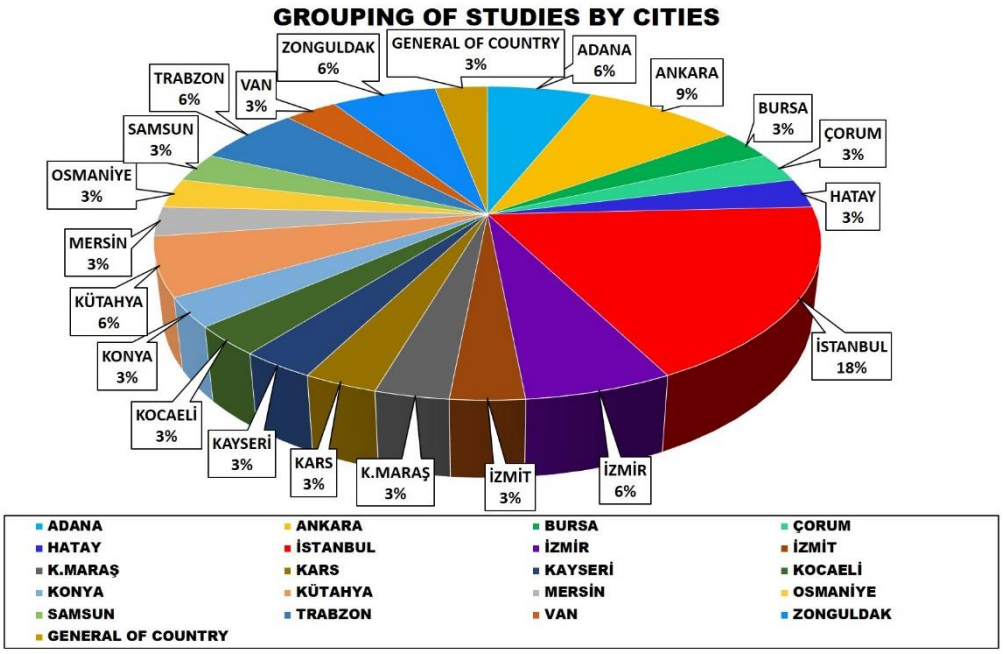

Figure 1. Grouping of Studies by Cities of Türkiye

This study, which includes the summary, interpretation, and future recommendations of research examining the interaction between the recent pandemic and air pollution/quality in Türkiye, evaluates Türkiye within a general framework in the literature and can serve as a guide for future pandemic periods. Nationwide and city-based studies aim to analyze the air pollution situation during and after the COVID-19 restrictions and to interpret the positive and negative effects of the pandemic in terms of air pollution and air quality. The relationship between air pollution and restrictions during the pandemic period has been discussed throughout the study. While the study does not address the relationship between meteorological factors and air quality, it is acknowledged that meteorological factors can influence air quality. However, this study does not include information about the transmission of COVID-19 via air pollutants or their residence time. Therefore, no conclusions are drawn regarding the relationship between meteorological factors and air pollutants. The study focuses on the upward and downward trends in air pollutant emissions during the COVID-19 pandemic restrictions and evaluates the corresponding changes in air quality within this framework.

1. Literature Review on the Recent Pandemic and Air Pollution/Quality

In this manuscript, studies on the relationship between the pandemic of the 21st century (COVID-19) and air pollution/quality in Türkiye and its cities are reviewed. Türkiye's geological location and

different climatic features have been determined as important criteria in terms of the COVID-19 pandemic, air pollution, and evaluation of air quality. Türkiye's role as an intercontinental link and being an important location for transportation is a crucial opportunity to observe the impact of traffic and transportation emissions. Studies have been examined and summarized in line with various parameters such as traffic and transportation emissions; fossil fuel consumption for energy recovery, heating, and production-oriented process outputs in anthropogenic activities due to overpopulation.

Gören et al. (2021) emphasized the variability of pollutant concentrations. In their study, it was stated that there was no significant change in PM concentrations; a decreasing trend was observed in terms of NO_x, and the measurement stations followed half-and-half different trends in respect of SO_2. Orak and Özdemir (2021) examined the averages of PM_{10} and SO_2 between 2015 and 2019 and comparatively revealed the changing trends that occurred with the impact of the pandemic in 2020. It is underlined that changing trends are mixed, as in the study of Gören et al. (2021), and that there are decreasing and increasing trends in the cities. In the study, it was observed that there were generally decreasing trends. Tunç and Toros (2020) compared the 2018 and 2019 concentrations for 2020 for the same periods in their study. They stated that the COVID-19 restrictions in Adana did not lead to an important change in average concentration values, but decreases in concentrations were observed. They offered several reasons for the reduction in concentrations. One of the concrete reasons for this is climate. However, Orak and Özdemir (2021), in their study, found a 1% increase in SO_2 concentration. It is thought that Orak and Özdemir (2021) also included data from 2015, 2016, and 2017 in their studies and that it was due to the lack of attention to vehicle fuel prices, restrictions, or precautions at that time. Another study supporting the work of Orak and Özdemir (2021) belongs to Ö.F. Tekin (2021). Ö.F. Tekin's study aimed to compare the change in air pollutants in Van during the COVID-19 pandemic to the previous year. The PM_{10} and SO_2 concentrations obtained from the National Air Quality Monitoring Network website constitute the data set for study. The mean PM_{10} measurement values before (40.89±19.6 µg/m^3) and after (41.3±20.4 µg/m^3) COVID-19. The mean SO_2 measurement values before and after COVID-19 were determined as 17.8±18.5 and 23.5±21 µg/m^3, respectively. When evaluated pollutant concentrations, it was stated that there was no difference in PM_{10} values in terms of yearly averages, at the same time SO_2 values increased compared to the previous year. According to Ö.F. Tekin's results, in the studies of Orak and Özdemir, no change was found in PM_{10} concentrations in Van. They also observed a 29% increase in SO_2 concentration. Another study showing a decrease in concentrations belongs to Aydın and Yetişkul (2021). In this study, PM_{10} emissions were compared between January 1 and July 31 from 2015 to 2020. Researchers who wanted to examine the effect of restrictions on PM_{10} concentration tried to obtain a significant difference by applying statistical methods (Sample t-test, Friedman test, and Wilcoxon test). As a result of the study, it was emphasized that the restrictions caused a decreasing trend in PM_{10} concentrations and the importance of the effect of daily lifestyle on air quality was stated.

Azgın et al. (2021) discussed the effects of COVID-19 restrictions on air quality in Kayseri. Data on PM_{10} and SO_2 concentrations, natural gas consumption data, average air temperature, and vehicle traffic for 2020 and the last 5 years for the 56 days (11 March-5 May) were compiled and their effects on climate change were analyzed. As a result of the examination, they stated that PM_{10} and SO_2 concentrations decreased by 40% and 34%, respectively, in the city center in 2020 compared to 2019, while these values decreased by 9% and 30%, respectively, for the Organized Industrial Zone (OIZ) region compared to 2019. Orak and Özdemir (2021) found that PM_{10} and SO_2 concentration changes in Kayseri were 76% and 46%, respectively. The 56-day study reveals the effectiveness of the COVID-19 lockdown in the overall framework. Other cities that benefit most from COVID-19 restrictions are Istanbul, where the population is the largest; Izmit, which is famous for its industry; and Zonguldak, the main centre of mining activities in Türkiye. In the study carried out by Özbay and Koç (2021), the situation of Izmit, one of Türkiye's most industrial cities, in terms of air pollutant emissions during the COVID-19

pandemic period was discussed. Emission trends in urban, rural, and industrial areas were examined in the study, which was prepared using data from 4 air pollution measurement stations between March and June 2020. It was revealed that downward trends of 32.95%, 58.26%, 17.11%, and 47.87% were observed for PM_{10} and NO_x emissions in urban and industrialized regions, respectively. In addition, it was emphasized that there is a strong correlation between NO_x and SO_2. The most striking point in the study was that a decrease of 50.07% in NO_x values was recorded in the industrialized region. Observing a decrease in pollutant concentrations in Izmit is important for the design, plan, and implementation of future air pollution prevention solutions. This is also true for Zonguldak, another city that stands out in terms of air pollution. Çelik and Arıcı (2021) used machine learning to predict air quality, emphasizing the study's similarities and interactions between air pollution and COVID-19. In their study based on Zonguldak, researchers drew attention to the high concentrations of air pollutant emissions by referring to the energy, mining, and transportation sectors in the city. As a result of the study, it was stated that the best values were obtained with the decision tree algorithm. The impact of the COVID-19 outbreak and lockdowns on air quality in Istanbul was observed and discussed by Çelik and Gül (2021). PM_{10}, SO_2, CO, NO_2, NO, NO_x, and O_3 concentrations were evaluated at 19 air pollution measurement stations. It was stated that there were improvements in air quality during the pandemic period, and a considerable decrease was observed, especially in PM_{10}, NO_2, NO, and NO_x concentrations. On the other hand, it was emphasized that SO_2 and CO concentrations for different air pollution measurement stations followed variable trends. According to Toksoy and Atalay (2021), the transportation sector is the second largest source of greenhouse gas emissions in Istanbul, and the preference for diesel-engined vehicles is one of the primary causes of rising pollution. The data from March, April, May, and June 2019-2020 were used. According to reports, the traffic index has the strongest relationship with the air quality indicators CO, NO, and NO_x, while the relationship with $PM_{2.5}$ is weakest. In April and May of the previous year, traffic index values fell by 46-63% compared to air quality indicators. The study revealed a decreasing trend of 26-27%, 24-28%, 22%, 58-59%, 33-35%, and 47% for AQI, $PM_{2.5}$, PM_{10}, NO, NO_2, and NO_x, respectively. Ghasempour et al. (2021) investigated the effects of the COVID-19 pandemic on air pollution. Parameter-based changes during the first-wave quarantine period were assessed. These researchers investigated the spatio-temporal density of TROPOMI-based NO_2, and SO_2 products from January 2019 to September 2020 over Türkiye using Google Earth Engine (GEE). As a result of the study, it was determined that the NO_2 concentration decreased significantly during the first wave quarantine period of the COVID-19 pandemic. The researchers emphasized that transportation and industrial activities play a key role in reducing the NO_2 level. In addition, it was stated that agricultural and touristic activities cause NO_2 levels to rise in the post-quarantine summer period. Another similar study in terms of method, data set, and results belongs to Matci et al. (2022). In this study, the relationship between air and temperature in various land cover classes in Türkiye was investigated. In the study, MODIS and Sentinel-5P TROPOMI remote sensing data from Türkiye between the years 2019 and 2021 were used. Researchers processed and analyzed the dataset on Google Earth Engine (GEE). The interesting part of the study is that a significant decrease in NO_2 was observed, especially in urban areas, during the period coinciding with the COVID-19 restrictions in terms of time. Researchers emphasized the effectiveness of the restrictions and stated that the restrictions taken could be used in long-term strategies to reduce global air pollution.

Different from other studies, two studies stand out due to the location of the study. In the study prepared by Topuz and Karabulut (2021), which deals with the Eastern Mediterranean cities, and in the study on the city of Samsun by Efe (2021), the effects of the restrictions taken within the scope of COVID-19 on air quality were examined. It has been stated that the results were analyzed by obtaining daily measurement data from a total of 9 measurement stations in Adana, Mersin, Hatay, Kahramanmaraş, and Osmaniye from the website of the National Air Quality Monitoring Network of the Ministry of Environment and Urbanization between January 1, 2019, and June 1, 2020. As a result

of the study, it was stated that almost all stations showed a significant decrease in all measured pollutant values, especially PM_{10} and SO_2, mainly in the March-June period of 2020 compared to the same period of the previous year (March-June 2019) (Topuz and Karabulut, 2021). In the study conducted by Efe (2021), it was stated that the change in CO, NO_x, NO_2, and PM_{10} concentrations for Samsun, the largest city in the Black Sea Region, during these measures and different measures compared to the pre-quarantine period. In the restriction period, the average CO, NO_x, and NO_2 concentrations decreased compared to the pre-restriction period, while the PM_{10} concentration increased by 3%. There is a weak positive correlation between the decrease in mobility and NO_2 concentrations. Another study by Efe (2022) compared the trends in PM_{10}, $PM_{2.5}$, and NO_2 concentrations for cities in Türkiye's Marmara Region before the COVID-19 quarantine and during the same period in different years. In the study, it was stated that daily average PM_{10}, $PM_{2.5}$, and NO_2 concentrations obtained from 11 stations, and it was stated that some increase trends were observed for the PM_{10} parameter, while the average $PM_{2.5}$ and NO_2 concentrations decreased at all stations. In the concluding comments, it was emphasized that there was a significant relationship between the decrease in mobility in big cities and NO_2 concentrations.

Although emission increase trends are observed in some cities and/or urban regions, the positive effect of restrictions on air pollution and air quality has been proven by scientific data in general. The increasing trend in emissions is thought to be caused by natural sources such as desert dust transport and the relaxation of restrictions. By examining the time periods and data in the studies, it has been determined that the shift system and full closure restrictions in industrial establishments are the two most important practices in reducing pollutant concentrations in Türkiye. Restrictions on 29 April-17 May 2020, 22-26 May 2020, and 14-28 April 2021 applied in 81 cities draw attention as periods in which concentration values show a serious downward trend.

In studies conducted within the scope of the link between COVID-19 and air pollution; it is stated that air pollution is effective on the contact rate, transmission route, infected period and long-term exposure to high PM concentration causes high blood pressure (Fidan and Akdur, 2022). In another study, it is stated that around 2020, when the COVID-19 period is experienced, the frequency of acute effects of pollutants on heart and lung diseases increases and is directly effective in the formation of diseases (Bostan and Olcay, 2022). Undoubtedly, the most important findings for the COVID-19 virus targeting the upper respiratory tract are upper respiratory tract diseases, the number of cases and deaths. In a study conducted in this context, it was determined that general and personal measures taken during the COVID-19 pandemic period led to a decrease in hospital admissions of chronic obstructive pulmonary disease (COPD) and asthma patients (Koyuncu et al., 2023). In this context, considering the studies carried out, it is of great importance to reduce air pollution that causes various acute and chronic problems, especially upper respiratory diseases and related deaths.

Summarizing information from the studies on the pandemic of the 21st century (COVID-19) and air pollution/quality relationship in Türkiye is given in Table 1. Although pandemics occurring around the world have primarily negative effects on living a healthy life, they also create a positive trend, especially in terms of affecting anthropogenic activities and frequency. Since pandemics usually caused by upper respiratory tract infections (e.g., Spanish flu, coronavirus) are contagious, they restrict social life and ensure social distances. These pandemics, which have continued from the past to the present and caused the deaths of millions of living things in certain periods, are likely to affect the world in the future. This study has been carried out to indicate restrictions that can be placed on air pollution; to shed light on efforts to prevent and reduce air pollution in a similar pandemic; and to be an informative guide. Research shows that restrictions implemented during the COVID-19 pandemic period were successful in preventing air pollution. During this period, it is estimated that grouping the provincial pollutant sources and determining the effects of restrictions on these groups will play an active role in

establishing a more effective air pollution control mechanism. Table 1, which includes location-based pollutant sources and parameters, will guide policymakers to take effective measures on air pollution in the event of a pandemic such as COVID-19.

Table 1. Location-Based Studies and Summary Information

City of Türkiye	Duration of the Study	Air Quality Parameters (AQPs)	Source of AQPs	Reference
Adana	January 1–June 30, 2020 (compared with 2018 and 2019)	PM_{10}, O_3, NO_2 and SO_2	Cement, Food and beverage, Energy, Paper and pulp Industries	Tunç and Toros (2020)
	January 1, 2019–June 1, 2020	PM_{10}, SO_2, CO, NO, NO_2, NO_x, and O_3 (especially PM_{10} and SO_2)		Topuz and Karabulut (2021)
Ankara	March 1, 2019–April 21, 2020	PM_{10}, $PM_{2.5}$, SO_2, CO, NO, NO_2, NO_x, and O_3	Military and Metal Industries, Quarries	Gören et al. (2021)
	January 2020 until the end of May 2020	AQI	Traffic and Transportation	Sahraei et al. (2021)
	January 2018–June 2020	PM_{10}, $PM_{2.5}$, SO_2, CO, NO_2, and O_3	Domestic heating, Transportation	Dündar et al. (2020)
Bursa	March 1, 2019–April 21, 2020	PM_{10}, $PM_{2.5}$, SO_2, CO, NO, NO_2, NO_x, and O_3	Automotive, Cement, Furniture, Food, and Textile Industries	Gören et al. (2021)
Çorum	March 1, 2019–April 21, 2020	PM_{10}, SO_2, CO, NO, NO_2, NO_x, and O_3 (especially PM_{10} and SO_2)	Construction and Food Industries	Gören et al. (2021)
Hatay	January 1, 2019–June 1, 2020	PM_{10}, SO_2, CO, NO, NO_2, NO_x, and O_3 (especially PM_{10} and SO_2)	Food Industry and Transportation	Topuz and Karabulut (2021)
City of Türkiye	**Duration of the Study**	**AQPs**	**Source of AQPs**	**Reference**
İstanbul	March– April– May– June 2019-2020	PM_{10}, $PM_{2.5}$, SO_2, CO, NO, NO_2, NO_x, and O_3	Aviation, Cement, Metal, Textile Industries, Tourism, and Transportation	Toksoy and Atalay (2021)
	March 1, 2019–May 22, 2020	PM_{10}, $PM_{2.5}$, SO_2, CO, NO, NO_2, NO_x, and O_3		Çelik and Gül (2021)
	March 1, 2019–April 21, 2020	PM_{10}, $PM_{2.5}$, SO_2, CO, NO, NO_2, NO_x, and O_3		Gören et al. (2021)
	2016–2020	PM_{10}, NO_2, and NO_x	Industry, Traffic and Transportation	Aykaç et al. (2021)
	January 1–June 30, 2020 (compared with 2018– 2019)	NO_2, and O_3	Domestic heating, Traffic and Transportation	Bacak et al. (2020)
	January 2020 until the end of May 2020	AQI	Traffic and Transportation	Sahraei et al. (2021)
İzmir	January 1–July 31, 2020 (compared with 2015– 2019)	PM_{10}	Aviation, Cement, Petrochemical, Food, Metal Industries, Transportation and Tourism	Aydın and Yetişkul (2020)
	March 1, 2019–April 21, 2020	PM_{10}, $PM_{2.5}$, SO_2, CO, NO, NO_2, NO_x, and O_3		Gören et al. (2021)

City of Türkiye	Duration of the Study	AQPs	Source of AQPs	Reference
İzmit	March–June 2020	PM_{10}, SO_2, CO, NO, NO_2, NO_X, and O_3	Traffic and Transportation	Özbay and Koç (2021)
Kahramanmaraş	January 1, 2019–June 1, 2020	PM_{10}, SO_2, CO, NO, NO_2, NO_X, and O_3 (especially PM_{10} and SO_2)	Cement, Domestic heating, Energy, Quarries	Topuz and Karabulut (2021)
Kars	March 1, 2019–April 21, 2020	PM_{10}, $PM_{2.5}$, SO_2, CO, NO, NO_2, NO_X, and O_3	Domestic heating, Food and Wood Industries	Gören et al. (2021)
Kayseri	March 11–May 5, 2020 (compared with 2019)	PM_{10} and SO_2	Cement, Food, Mining Industries and Transportation	Azgın et al. (2021)
Kocaeli	March 1, 2019–April 21, 2020	PM_{10}, $PM_{2.5}$, SO_2, CO, NO, NO_2, NO_X, and O_3	Aviation, Automotive, Cement, Pulp and paper, Iron and steel, Petrochemical, Energy, and Transportation	Gören et al. (2021)

City of Türkiye	Duration of the Study	AQPs	Source of AQPs	Reference
Konya	March 1, 2019–April 21, 2020	PM_{10}, $PM_{2.5}$, SO_2, CO, NO, NO_2, NO_X, and O_3	Automotive, Food and beverage, Energy, Machinery, Tourism, Plastic	Gören et al. (2021)
Kütahya	March 1, 2019–April 21, 2020	PM_{10}, $PM_{2.5}$, SO_2, CO, NO, NO_2, NO_X, and O_3	Ceramic	Gören et al. (2021)
	March 11–May 25 2019 and 2020	PM_{10}, $PM_{2.5}$, SO_2	Industry, Traffic and Transportation	Yılmaz (2021)
Mersin	January 1, 2019–June 1, 2020	PM_{10}, SO_2, CO, NO, NO_2, NO_X, and O_3 (especially PM_{10} and SO_2)	Aviation, Food and beverage, Tourism, Transportation	Topuz and Karabulut (2021)
Osmaniye	January 1, 2019–June 1, 2020	PM_{10}, SO_2, CO, NO, NO_2, NO_X, and O_3 (especially PM_{10} and SO_2)	Metal and Textile Industries	Topuz and Karabulut (2021)
Samsun	January 1–June 1, 2020	PM_{10}, CO, NO_x, and NO_2	Cement, Energy, and Wood Industries	Efe (2020)

City of Türkiye	Duration of the Study	AQPs	Source of AQPs	Reference
Trabzon	March 1, 2019–April 21, 2020	PM_{10}, $PM_{2.5}$, SO_2, CO, NO, NO_2, NO_x, and O_3	Cement, Food, and Metal Industries	Gören et al. (2021)
	January 1–June 30, 2020	PM_{10}, $PM_{2.5}$, SO_2, CO, NO_2, and O_3	Industry, Traffic and Transportation	Kara et al. (2020)
Van	March 1, 2019– February 28, 2021	PM_{10} and SO_2	Domestic heating, Traffic and transportation, Quarries	Tekin (2021)
Zonguldak	January 1, 2019–December 31, 2020	PM_{10}, SO_2, CO, NO_2 and O_3	Cement, Mining, Traffic and transportation, Quarries	Çelik and Arıcı (2021)
	March 1, 2019–April 21, 2020	PM_{10}, $PM_{2.5}$, SO_2, CO, NO, NO_2, NO_x, and O_3		Gören et al. (2021)
Türkiye (General of Country)	2015–2020	PM_{10} and SO_2		Orak and Özdemir (2021)

2. Results and Discussion

Considering many Turkish and worldwide studies, it has been observed that there are changes in human habits with the COVID-19 pandemic and the environment responds positively to this lifestyle. Thanks to air pollution and positive changes in air quality, people realized that they were living in air conditions that were touted as polluted in the pre-pandemic period. As in many studies based on different countries and cities, the restrictions put in place during the pandemic were effective in reducing air pollution. In two studies focusing on Kayseri, one of the prominent cities in the studies, it was found that PM_{10} and SO_2 concentrations decreased significantly (Azgın et al. 2021 by 40% and 34%, respectively, and Orak and Özdemir 2021 by 76% and 46%). Similar findings have been found in studies conducted in major metropolitan cities. A study conducted in Naples, Rome, Bologna, Florence and Monza, Italy, on 4 major pollutants reported that restrictions caused a significant downward trend in all of them, with a 7% decrease in PM_{10} and an 11% decrease in O_3 (Aragão et al., 2024). During the 2020 COVID-19 lockdown in India, NO_2 concentrations decreased by 20% in Mumbai, 18% in Delhi, 14% in Kolkata, 12% in Chennai and 15% in Hyderabad (Mathew et al., 2024). While Zonguldak and Istanbul, where air pollution is intense, are frequently included in the studies, improvements in air quality and reductions in pollutant emissions with the effect of restrictions have been demonstrated by various studies (Çelik and Arıcı, 2021; Gören et al., 2021; Ulutaş et al., 2022).

Several studies, particularly on SO_2 and NO_x, have found that in locations or cities where traffic-related pollution is reduced by restrictions but the concentration levels remain constant, the relevant levels are already low or are influenced by other factors (Azgın et al., 2021; Dursun et al., 2021; Orak and Özdemir, 2021). Various studies have indicated that the most significant and favorable concentration changes have occurred in cities with large populations, such as Istanbul, Izmir, and Ankara. Decreasing trends in pollutant levels have been observed in other metropolitan cities across Türkiye, although periodic increases have been noted in some cities during certain periods. It is well-established that

population size and meteorological parameters are directly related to air pollution (Dursun et al., 2021). In this context, it can be argued that the results of restrictions—such as reduced mobility due to population changes, decreased vehicle use, and lower energy demand in industry—have a positive effect on reducing air pollution. However, these effects are less evident in cities with smaller populations and limited industrial activity.

At this point, it is necessary to consider the living conditions and activities of the relevant provinces. For example, in Zonguldak, mining activities are prevalent, and various air pollutants, especially particulate matter, are released into the atmosphere as a result of these activities. Additionally, some cities (e.g., Kütahya) experience high levels of traffic-related air pollution as they serve as transit routes (Ö.F. Tekin, 2021). For this reason, changes in concentrations due to fossil fuel consumption from vehicles and heating—which are the main sources of pollution in smaller provinces—are less pronounced compared to metropolitan areas (with the exception of Kütahya).

During the COVID-19 period in Türkiye, geographical features played a crucial role in influencing pollution levels. Coastal cities like Izmit, with their natural ventilation, experienced greater reductions in pollutants when industrial activities were curtailed. Inland cities like Ankara, while benefiting from reduced traffic emissions, faced challenges in pollutant dispersion due to their geographical setting. Meanwhile, industrial coastal cities like Zonguldak—a major mining hub—saw limited improvements in air quality because exempted industries continued to operate, highlighting the role of industrial exemptions in shaping air quality outcomes. These variations underscore the complex interplay between geographical features, industrial activity, and pollution dynamics during the lockdown period.

Studies have shown that the relationship between the COVID-19 pandemic and air pollution is based on anthropogenic activities in general; traffic emissions; the use of fossil fuels for heating, and industrial combustion processes are the main sources of pollutants. This situation has also been demonstrated by studies conducted in different geographies. Especially from the COVID-19 restrictions, the effects of the shift system and full closure have an important impact in the reduction of air pollution. With the threat of global warming and climate change, improving air quality during pandemic restrictions could be an important starting point/milestone. It is possible to look to the future with hope by fulfilling the requirements of the Paris Climate Agreement ((i) Long-term temperature target, (ii) climate neutrality, (iii) adaptation, (iv) financial, technological, and capacity building support, (v) climate change education, training, and public awareness) and the environmentally sustainable green policies to be followed. In particular, the operation of mechanisms such as the EU Emissions Trading System and the continuation of increasing international cooperation will play an important role in reducing the negative effects of phenomena such as global climate change. For various countries, the use or transition to renewable energy will help sustain the clean and green environment created by the COVID-19 lockdown. Similar to the COVID-19 lockdown, the use of renewable resources to generate energy and power was found to significantly reduce emissions of greenhouse gases (like CO_2), and other pollutants into the atmosphere. Policymakers and non-governmental organizations should accelerate the transition to renewable energy, limit fossil fuel consumption, and integrate smart systems into existing systems not only to comply with the European Union (EU)'s Green Deal commitments and the UN's SDGs but also to reduce air pollution. In addition, energy strategies should be reviewed in developing countries, and increased use of renewable resources should be encouraged. For a sustainable environment, it is necessary to implement the mechanisms to reduce pollution together, and each person should do their part to ensure a livable environment. This study, which can serve as a guide in the literature, focuses on Türkiye and its 81 cities, selected due to the country's intercontinental location, large surface area, and diverse geographical and meteorological conditions.

Environment and urban planning action plans are being developed for cities in Türkiye. Plans generally cover a 5-year process. It is considered appropriate to actively implement the proposed restrictions in the plan -such as using quality fuel, performing periodic chimney maintenance on time, and avoiding the use of recyclable waste (e.g., waste oil, paper, or wood) as fuel- classify them according to their level of impact, and enforce strict supervision to ensure their effective implementation. Subsequently, sanctions for deterrence should be increased and environmental sensitivity must be emphasized. Especially in terms of energy recovery, the privileges granted to thermal power plants should be reviewed. It should be mandatory to eliminate the deficiencies in the power plant chimneys and to establish the necessary infrastructure in all industrial institutions and organizations. Additional solutions should be produced by developing projects with university-industry cooperation. Incentives and support for such projects should be increased. People should be informed with supporting materials (short films, posters, brochures, and social media) to create preliminary awareness about the environment, especially air pollution. Various interactive applications should be developed and organizations suitable for all age levels should be established.

While there have been previous studies on the interaction between pandemics and air pollution, this study distinguishes itself by providing a comprehensive and detailed analysis within the context of Türkiye. Unlike earlier works, this research evaluates Türkiye in a broader framework, offering a holistic perspective on the topic. It not only summarizes and interprets findings but also provides actionable recommendations for future pandemic periods and sustainable urban development. This study highlights the situation before and during the COVID-19 pandemic in terms of air pollution, sheds light on future scenarios, and offers policymakers and decision-makers practical proposals applicable to regions worldwide. In the event of future pandemics or efforts to promote healthy and sustainable living, the insights and assessments presented in this study can serve as a valuable reference. Furthermore, it provides actionable strategies for reducing urban air pollution, making it relevant for different countries and cities globally.

CONCLUSION AND FUTURE RECOMMENDATIONS

Based on the studies about the pandemic of the 21st century (COVID-19) and air pollution in the literature, various comments and future suggestions are given under sub-headings.

Emission Trends

The cities most frequently evaluated in studies from Türkiye are Ankara and Istanbul. Population density, socio-economic development level, the number of industrial activities, and geographic locations stand out as important parameters (Ulutaş et al., 2021). It has been determined that most of the studies focused on one of the 30 metropolitan cities and Zonguldak, which were most frequently subjected to restrictions during the COVID-19 period. The decrease in mobility in cities and, consequently, in vehicle emissions led to a significant reduction in PM_{10} and SO_2 levels. However, the continuation of agricultural activities with special permission did not cause any significant change in NO_x levels. On the other hand, the increase in fossil fuel consumption for domestic heating resulted in a rise in CO emissions.

Environmental and Public Health

Various studies have shown that reductions in air, water, and soil pollution occurred in many parts of the world (e.g., Beijing, Istanbul, Delhi, Venice) during the COVID-19 pandemic period. The decrease in mobility and anthropogenic activities, combined with COVID-19 restrictions, allowed nature to repair itself—effectively reshaping environmental health. The revival of the wetland ecosystem in Venice's

canals, the visibility of Uludağ in Bursa from Istanbul's sky, and the increased visibility in Beijing demonstrate that the primary cause of pollution is human-induced (Braga et al., 2020; Zhang et al., 2023). In light of this, it should be a priority for countries to fulfill their commitments to protect environmental health and to impose joint sanctions on activities that adversely affect environmental health in the international arena. Public health must also be addressed in the context of environmental health. Although air pollution does not cause direct and sudden deaths, it remains a significant public health issue. Zonguldak and Kahramanmaraş, in particular, serve as examples for Türkiye.

In Zonguldak, insufficient precautions in mining activities, and in Kahramanmaraş, inadequate measures in energy recovery activities, result in harmful emissions being released into the air. The emission limit values set by the WHO are exceeded almost year-round. Specifically, the annual average PM_{10} levels in these regions exceed the WHO limit of 15 µg/m³ (WHO, 2021; Topuz and Karabulut, 2021). This situation, which poses a severe risk to public health, contributes to various upper respiratory tract diseases (primarily COPD, lung cancer, and oxidative stress) and leads to numerous deaths in the region (Değer, 2022). To safeguard public health, it is essential to strengthen emission reduction measures in industrial activities, raise public awareness about these issues, and increase the frequency of inspections by competent authorities.

Another issue that needs to be addressed and considered in terms of public health is the economic challenges created by the pandemic. As the pandemic's impact intensified, the quarantine measures implemented negatively affected many sectors (Bozkurt, 2020). During this period, layoffs and insufficient or delayed wage payments caused significant financial difficulties for employees (A. Tekin, 2021). This led to stress-related illnesses and malnutrition. The resulting negative effects on the immune system made people more susceptible to illness and increased health expenditures (Kaner Tohtak and Çalık, 2020). The high number of deaths and cases, particularly in areas with intense air pollution, also caused widespread unease among the population. Istanbul, Ankara, Izmir, Zonguldak, and Kahramanmaraş were among the top five cities with the highest COVID-19 cases in Türkiye for an extended period. The common characteristics of these cities include high industrial activity, strategic importance in terms of transportation, and air pollution levels exceeding limit values (Orak and Özdemir, 2021).

Reducing air pollution is a critical step in mitigating the impact of zoonotic diseases like COVID-19 that can spread through the air. It is also essential for ensuring that more effective measures are taken during similar pandemics that may occur in the future, as well as for protecting and improving both environmental and public health.

Emission Sources

Studies have shown that the relationship between the COVID-19 pandemic and air pollution is primarily linked to anthropogenic activities, including traffic emissions, the use of fossil fuels for heating, and industrial combustion processes, which are the main sources of pollutants. The implementation of shift systems, particularly in industrial institutions and organizations, is identified as a key factor contributing to the decreasing trend in emission values. However, the consumption of fossil fuels for heating, especially in low-income areas, has diminished the overall impact of emission reductions. This phenomenon has also been demonstrated by studies conducted in various geographic regions.

Global Warming and Climate Change

With the threat of global warming and climate change, the improvement in air quality observed during pandemic restrictions could serve as an important starting point or milestone. By fulfilling the requirements of the Paris Climate Agreement and adopting environmentally sustainable green

policies, it is possible to look to the future with hope. For various countries, the use of or transition to renewable energy will help maintain the clean and green environment achieved during the COVID-19 lockdown. Similar to the effects seen during the lockdown, the use of renewable resources for energy generation has been found to significantly reduce emissions of greenhouse gases and other pollutants into the atmosphere.

Compliance with National and International Targets

Policymakers and non-governmental organizations should accelerate the transition to renewable energy, limit fossil fuel consumption, and integrate smart systems into existing infrastructures—not only to comply with the European Union (EU)'s Green Deal commitments and the UN's Sustainable Development Goals (SDGs) but also to reduce air pollution. Additionally, energy strategies should be reviewed in developing countries, and the increased use of renewable resources should be encouraged. For a sustainable environment, it is essential to implement pollution-reduction mechanisms collectively, and every individual must contribute to ensuring a livable future. This study focuses on Türkiye and its cities due to the country's intercontinental location, vast surface area, and diverse geographical and meteorological conditions. Environmental and urban planning action plans are being developed for cities across Türkiye, generally covering a five-year period. It is crucial to actively enforce the restrictions outlined in these plans, classify them based on their impact levels, and conduct strict supervision to ensure their effective implementation. Furthermore, deterrent sanctions should be strengthened, and environmental awareness should be emphasized.

In terms of energy recovery, the privileges granted to thermal power plants should be reassessed. It must be mandatory to address deficiencies in power plant chimneys and establish the necessary infrastructure in all industrial institutions and organizations. The following key points are highlighted in this context: (i) Existing regulations should be fully and effectively implemented. (ii) The flexibility mechanism is currently being misapplied and should be revised. (iii) Integrated environmental inspections should be increased to ensure compliance. (iv) Sustainable improvements should be made in industries with high pollution loads (e.g., cement, iron-steel, and paper) through process and pollution profile assessments, supported by mechanisms such as incentives, financial support, and technical assistance.

These measures aim to address potential gaps in the regulatory framework and promote sustainable industrial practices. While this study does not explicitly cite specific articles from the Regulation on the Control of Industrial Air Pollution, the proposed recommendations offer a practical pathway for strengthening enforcement and achieving environmental targets.

Increasing the Effectiveness of Science in the Field

Considering the COVID-19 measures, practices should be developed to reduce air pollution. Real-life applications should be transitioned to simulation or model environments, and projections should be created alongside R&D projects. Studies on nuclear energy and its waste management should be conducted to enhance reliability and reduce fossil fuel consumption. With the increasing adoption of digital twin applications, production-based emissions may decrease. Projections generated through simulation and modeling studies can serve as a guide for policymakers and decision-makers. From an academic perspective, additional solutions should be developed through university-industry collaboration. Incentives and support for such projects should be increased.

Awareness Activities about Air Pollution

People should be informed through supporting materials such as short films, posters, brochures, and social media to create preliminary awareness about the environment, particularly air pollution. Games

have become an important educational resource in today's world. In joint projects with game developers, simple yet effective elements—such as environmental awareness—should be emphasized. Social environmental awareness should be increased through various activities and expanded to all segments of society. To ensure lasting impact, messages should engage both visual and auditory senses through exhibitions, musical performances, and theater plays. Joint meetings and awareness days should be organized in collaboration with various institutions to highlight the importance of air quality and its consequences, delivering a clear message to society about the seriousness of the issue.

Sustainability

Sustainable development has slowed due to the pandemic, disrupting compliance with international commitments such as the Paris Climate Agreement and the EU Green Deal. As a result, millions of people suffer premature deaths each year due to inadequate implementation of necessary precautions against environmental pollution. To reduce air pollutant emissions, improve air quality, and mitigate the effects of global warming and climate change, sustainable systems and mechanisms must be established and effectively implemented. Since air is a vital resource essential for all living beings, sustainability is crucial for enhancing or maintaining air quality. Immediate and collaborative action is required to ensure sustainable air quality for the future. This study, based on Türkiye's approaches to air pollution, air quality, and the COVID-19 pandemic, provides future recommendations and serves as a model for cities in other countries worldwide.

Compliance with Ethical Standard

Conflict of Interest: *The author(s) declare that they do not have a conflict of interest with themselves and/or other third parties and institutions, or if so, how this conflict of interest arose and will be resolved, and author contribution declaration forms are added to the article process files with wet signatures.*

Ethics Committee Permission: *Ethics committee authorisation is not required for this study. The wet signed consent form is attached to the article process file.*

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EXTENDED SUMMARY

Research Problem:

The study aims to provide both an informative and awareness-raising contribution to the literature by summarising and interpreting the studies evaluating air pollution and air quality in Türkiye, which are discussed worldwide due to the 21st century (COVID-19) pandemic and which are described as positive or negative based on anthropogenic activities, and by making future suggestions.

Research Questions:

Do COVID-19 pandemic restrictions have an overall positive or negative impact on air pollution/quality? How can the achievements obtained in the studies be interpreted from an environmental point of view and what kinds of a paths should be followed for the future?

Literature Review:

The aim of the literature review is to reveal the air pollution/quality orientated situation in the 21st century (COVID-19) pandemic in Türkiye and to provide a basis for the interpretations and future recommendations, which are the original part of this publication.

Methodology:

Researchers examined relevant publications from or about Türkiye in the light of various keywords (COVID-19, pandemic, air pollution, etc.) through ScienceDirect and Google Scholar databases. They shared air pollution and air quality-focused interpretations and future suggestions based on their obtained data.

Results and Conclusions:

Researchers have determined that most of the studies were evaluated in one of the 30 metropolitan cities and Zonguldak that were most frequently exposed to restrictions during the the 21st century (COVID-19) period. While relevant studies found that the decrease in mobility in cities and the resulting decrease in vehicle emissions led to serious decreases in PM_{10} and SO_2 parameters and that there was generally no significant change in terms of NO_x released into the atmosphere due to agricultural activities, they found that quarantine decisions generally caused positive results. It has been determined that the effects of the shift system and full closure, especially with the restrictions of the COVID-19 pandemic, have a significant impact on reducing air pollution. In the studies examined (World and Türkiye). At the same time, it was emphasized that there were decreases in environmental pollution especially in many parts of the world (Beijing, Istanbul, Delhi, Venice, etc.) during the COVID-19 pandemic period, the idea that the decrease in mobility and anthropogenic activities was the biggest factor came to the fore. Based on the literature they have examined, the authors define it as a priority for countries to fulfill their commitments to protect environmental health and impose joint international sanctions on activities that will negatively affect environmental health. Accordingly, it is emphasized that public health should be addressed as much as environmental health - especially in scientific outputs. Although air pollution does not cause direct and sudden deaths, it is claimed by the authors that it is an important public health problem and that it is not a coincidence that the cities of Istanbul, Ankara, Izmir, Zonguldak, and Kahramanmaraş have been among the top 5 cities in COVID-19 cases for a long time in Türkiye. The common points of these cities are that their industrial activities are high, they are in an important location in terms of transportation, and they are above the limit values in terms of air pollution. On the other hand, the authors expressed their opinions and future suggestions on popular topics such as climate change, sustainability, and environmental awareness, and they wanted the publication to be both informative and awareness-raising.