Trends of CO and NO₂ Pollutants Change in Iran during Covid-19 Pandemic using Time-Series Sentinel-5 Images in Google Earth Engine

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Abstract

The end of the Persian year (March 2020) coincided with its global pandemic, which led to quarantine and lockdown in Iran. Many studies have shown that with the spread of this disease and the decline of industrial activities, environmental pollutants were drastically reduced. Among these pollutants, Nitrogen Dioxide (NO₂) and Carbon Monoxide (CO) are widely caused by anthropogenic and industrial activities. In this study, the changes of these pollutants in Iran and its four metropolises (i.e., Tehran, Mashhad, Isfahan, and Tabriz) in three time periods from March 11 to April 8 of 2019, 2020, and 2021 were investigated. To this end, time-series of the Sentinel-5P TROPOMI and in-situ data within the Google Earth Engine (GEE) cloud-based platform were employed. It was observed that the results obtained from the satellite data were in agreement with the in-situ data (average correlation coefficient =0.7). Moreover, the concentration of NO₂ and CO pollutants in 2020 was 5% lower than in 2019, indicating the observance of quarantine rules as well as people's initial fear of the Coronavirus. Contrarily, these pollutants in 2021 were higher than those in 2020 by 5%, which could be due to high vehicle traffic and the lack of serious policy by the government to ban urban and interurban traffic. Furthermore, the increase of these pollutants in 2021 was followed by an increase in the deaths caused by Covid-19 and triggering the fourth peak in the Covid-19 cases, signifying a link between exposure to air pollution and Covid-19 mortality in Iran.

Highlights

- COVID-19 lockdown improved the air quality by the reduction in NO₂ and CO concentration.
- The time-series analysis of NO₂ and CO pollutants derived from Sentinel-5P using Google Earth Engine (GEE) during three periods (Nowruz 2019, 2020 and 2021).
- NO₂ and CO concentrations were reduced by 5 % in 2020 compared with 2019, due to COVID lockdown and public fear.
- NO₂ and CO concentrations in 2021 were higher than 2019 by 5 %, due to the lack of serious policy by the government to ban urban and interurban traffic.

1. Introduction

Corona! Corona! And Corona! A menacing word has been repeated and heard more than any other word since its outbreak in Wuhan, China, in late 2019. The Covid-19 pandemic has changed human activities on Earth, including social distancing, telecommuting, online shopping, and closure of public places, such as markets, parks, schools, businesses (Berman & Ebisu, 2020; Gautam, 2020). The direct association of Covid-19 with several factors, such as air pollution, the body immune system, and environmental impacts, is an example of current knowledge from the study of Covid-19 (Contini & Costabile, 2020).

The first cases of the infection with Coronavirus in Iran were reported on February 19, 2020 (Razavi-Termeh et al., 2021). Outbreaks emerged in Asia, Europe, and other countries, and by the end of March 2020, Covid-19 turned into a global pandemic (Muhammad et al., 2020). As quarantine and lockdown started in many countries, a substantial decline in air pollution was reported due to the closure of factories and businesses, halting industrial sectors, and reducing transportation and traffic. These consequently resulted in a

considerable drop in oil and fuel usage (Berman & Ebisu, 2020; Muhammad et al., 2020). On the other hand, Covid-19 mainly affects the human respiratory system causing lethal lung injury and death. Studies conducted on Covid-19 (Allu et al., 2021; Berman & Ebisu, 2020; Burnett et al., 2018; Faustini et al., 2014; He et al., 2020; Muhammad et al., 2020; Ryan et al., 2020) showed that exposure to air pollution could cause severe cardiovascular and respiratory problems. Therefore, there should be a potential relation between air quality and Covid-19 (Conticini et al., 2020; Ryan et al., 2020; Travaglio et al., 2021; Zhang et al., 2021; Zhu et al., 2020).

The lockdown was imposed in Iran from March 21 to April 21 in 2020 (Broomandi et al., 2020; Ravindran et al., 2021). During this period, the country witnessed a massive decline in transportation, industrial, and business activities. The traffic was reduced by 73%, which resulted in a 50% reduction in gas consumption in Tehran, the capital city of Iran (Rad et al., 2020). Other industrial metropolises in Iran were faced with Covid-19 restrictions, resulting in lower pollutants and cleaner air.

Extensive studies have been conducted worldwide to analyze the impact of Coronavirus spread on air pollution. For example, the effects of pollutants change due to decline in anthropogenic activities as a result of Covid-19 have been investigated in U.S. (Berman & Ebisu, 2020; Naeger & Murphy, 2020; Wu et al., 2020), England (Travaglio et al., 2021; Wyche et al., 2021), Italy (Fattorini & Regoli, 2020; Filippini et al., 2021), Spain (Briz-Redón et al., 2021; Cárcel-Carrasco et al., 2021; Querol et al., 2021; Tobías et al., 2020), India (Allu et al., 2021; Karuppasamy et al., 2020; Naqvi et al., 2021; Shehzad et al., 2020; Vadrevu et al., 2020), South Korea (Ju et al., 2021), China (Chen et al., 2020; Fan et al., 2020; Zhang et al., 2021; Zhu et al., 2020), Netherlands (Cole et al., 2020), Canada (Adams, 2020), South Africa (Ryan et al., 2020), France (Magazzino et al., 2020), Brazil (Debone et al., 2020; Nakada & Urban, 2020), Asia (Ghahremanloo et al., 2021; Gupta et al., 2021), Europe (Ogen, 2020; Skirienė & Stasiškienė, 2021), and worldwide (Albayati et al., 2021; Gautam, 2020; Muhammad et al., 2020; Pozzer et al., 2020; Singh et al., 2021; Zambrano-Monserrate et al., 2020). A few studies have also assessed the impact of the Covid-19 pandemic on air pollution in Iran. For example, Kaviani Rad et al. (Rad et al., 2020) studied air pollutants in the first and second waves of the disease in Tehran over 40 days from March 1 to April 9, 2020. Their results showed that the amount of Carbon Monoxide (CO), Nitrogen Dioxide (NO₂), PM₁₀, and PM_{2.5} pollutants decreased, and SO₂ and O₃ pollutants increased from March 1 to April 9, 2020, compared to the same period in 2019 (Rad et al., 2020). In another study, Broomandi et al. (Broomandi et al., 2020) identified environmental pollutants (e.g., O₃, NO₂, SO₂, CO PM₁₀, and PM_{2.5}) using data from 12 ground stations from March 21 to April 21 in 2019 and 2020. The results showed that, except for O₃ and PM_{2.5}, the average concentrations of pollutants were decreased. Similarly, Borhani et al. (Borhani et al., 2021) investigated atmospheric pollutants, including O₃, NO₂, SO₂, CO PM₁₀, and PM_{2.5}, using 21 stations in three time periods (February 23, 2020, to March 15, 2020, March 18, 2020, to April 3, 2020, and April 5, 2020, to April 17, 2020) for Tehran during the pandemic.

Although a few studies have been conducted in Iran to investigate the effects of Covid-19 spread on air pollution, to the best of our knowledge, they mainly focused on the capital of Iran (i.e., Tehran) using only ground station data, which are not available in most cities of Iran. Therefore, in this study, the temporal and spatial distributions of CO and NO₂ pollutants produced by vehicles and urban traffic were investigated using the Sentinel-5P, TROPospheric Monitoring Instrument (TROPOMI) data. The accuracy of the results obtained

from the TROPOMI sensor has been confirmed in several recent studies. For example, in a study in Helsinki, Finland (Ialongo et al., 2020), a correlation coefficient of 0.68 was obtained between the results of satellite-based TROPOMI NO₂ and ground observations. Correlation coefficients of 0.44 and 0.75 for Frankfurt and Barcelona were also obtained in another research (Vîrghileanu et al., 2020). This indicates that this sensor has a high potential for accurate estimation of air pollutants, especially large-scale NO₂ concentration. The analyses were conducted in Iran (mainly four cities of Tehran, Tabriz, Isfahan, and Mashhad) in three years of 2019 (a year before the outbreak), 2020 (start of the outbreak), and 2021 (a year after the outbreak).

The remainder of the paper is as follows. After the introduction, the methods and materials, study area, and methodology is discussed in part 2. Then, the output of the NO₂ and CO and results are presented. In the next part, the results are evaluated and compared with daily new deaths due to Covid-19. Finally, the paper is concluded in part 4.

2. Materials And Methods

Study area

The study area was Iran (within 25° 3' to 39° 47' latitudes and 44° 5' to 63° 18' longitudes), the second most populated country in the middle east area, with a population of more than 83 million (see Figure 1). Among its cities, Tehran, Mashhad, Isfahan, and Tabriz are the highest populated cities with 9, 3, 2, and 1.5 million people, respectively. A detailed investigation of the effect of the Covid-19 pandemic on the concentration of pollutants was mainly conducted over these metropolises.

Datasets

In this study, the open-access Sentinel-5P satellite data was used to monitor Iran's air pollutants during the Covid-19 pandemic. The European Space Agency (ESA) launched the Sentinel-5P satellite on October 13, 2017, following its program for daily environment monitor and analyzing air pollutants throughout the planet. One of the missions of Sentinel-5P is monitoring atmospheric gases, such as NO₂, CO, Sulfur Dioxide (SO₂), Ozone (O₃), Formaldehyde (CH₂O), Methane (CH₄), and Aerosol using the TROPOMI sensor (Loyola et al., 2018). NO₂ is emitted into the atmosphere as a result of anthropogenic activities (e.g., combustion of fossil fuels and biomass burning) and natural processes (e.g., microbiological processes in soil, firing, and lightning) (He et al., 2020; Ogen, 2020). CO is also a result of the incomplete combustion of carbon-containing fuels, such as oil and natural gas (Karimi et al., 2016; Moiseenko et al., 2016). Therefore, the NO₂ and CO products derived from Sentinel-5P data collected between March 11 – April 8 in 2019, 2020, and 2020 were used in this study (Table 1). This selected period starts a few days before the Iranian new-year's holidays (Nowruz) and ends several days after Nowruz, during which people do their new-years shopping, travel, and get together.

Table 1. The detail of the Sentinel-5P TROPOMI products used in this study

TROPOMI products	levels of processing	Unit	Spatial resolution	Source
nitrogendioxide_tropospheric_column_count	Level-2		0.01 arc degrees	Sentinel-5 variables https://developers.google.com/earth-engine/datasets/tags/tropomi
carbonmonoxide_total_column_count	Level-2		0.01 arc degrees	

Data Processing Methodology

In this study, all the processing and analyses were conducted in Google Earth Engine (GEE) (<https://earthengine.google.com/>) through the method illustrated in Figure 2. GEE was launched by Google in 2010 for cataloging and processing a wide variety of earth observation data in a cost- and time-efficient approach (Amani, Kakooei, et al., 2020; Gorelick et al., 2017; Kumar & Mutanga, 2018). This platform is precious when the objective is to process big open-access earth observation data over a large area and within a long time (Amani, Ghorbanian, et al., 2020; Hui et al., 2008).

According to Figure 2, the Sentinel-5P data were first converted from level 2 to level 3 through the *harpconvert* tool by *bin_spatial* operation (Gorelick et al., 2017). Then, after applying the spatial and temporal filters, NO₂ and CO products from the study area were generated. It's worth noting that the products were filtered to remove pixels with values less than 75% and 50% Quality Assurance (QA) for NO₂ and CO, respectively (Butz et al., 2012).

After processing the data, two types of outputs, including maps and statistical reports of the pollutants, were produced. In-situ data obtained from the ground-based air pollution stations were used to verify the produced results. In addition, the covid-19 mortality rate was investigated to assess the potential relationship between the death rate and air pollution.

3. Results And Discussion

In this section, the results of the experiments are presented in three subsections. First, the concentration of NO₂ and CO during the Corona pandemic were examined to investigate the impact of quarantine and traffic ban. In the second subsection, the values obtained in Tehran were compared with the corresponding values in 19 ground-based air monitoring stations to validate the remote sensing results. Finally, the relationship between NO₂ and CO pollutions and COVID-19-related deaths was investigated.

Spatiotemporal Distribution of the NO₂ and CO

The results of the spatiotemporal distribution of NO₂ and CO in Iran and, more specifically, over Tehran, Tabriz, Isfahan, and Mashhad, are demonstrated in Figures 3 and 4. Based on Figure 3, the NO₂ concentration in 2021 (the second year of the Covid-19 pandemic) was similar to those in 2019 (before the start of the pandemic) on some days (e.g., March 23 to 30). Its values were even higher in 2021 compared to 2020 on several days (e.g.,

April 4 to 8). This might be due to the fact that the necessary and practical measures of reducing traffic and shutting down businesses during the pandemic in 2021 were not effectively implemented. On the other hand, the NO_2 concentration throughout Iran in 2020 decreased by an average of 5% compared to 2019 and 2021. This result can be mainly due to the strict regulations and actions adopted by the government to reduce traffic between March 20 to 31, 2020 (coinciding with the Nowruz holidays) and the closure of many industrial and business sectors, as well as the high panic of people in the initial encounter with the Coronavirus.

The concentration of this pollutant in the four cities in these three periods was not the same. For example, the trend of NO_2 concentration in Tehran during the Nowruz holidays in 2019, 2020, and 2021 did not considerably change. However, after the Nowruz holidays (April 4-10), NO_2 concentration was significantly increased compared to the same period in 2019 and 2020. This can be due to the acceleration of businesses and the influx of many employees from other cities to Tehran. On the other hand, the trend of NO_2 concentration in the other three cities was different from Tehran. For instance, the average NO_2 concentrations in Tabriz, Isfahan, and Mashhad in 2020 were respectively decreased by 19%, 13%, and 17% compared to those in 2019. However, the concentration of this pollutant was increased in 2021 in all three cities. This might mainly be due to the increased gathering and parties in Nowruz, as well as the increase of travels to these cities during the 2021 Nowruz holidays. Moreover, the role of wrong policy-making of the government in the implementation of the inter-provincial traffic ban during Nowruz 2021 should not be ignored.

According to Figure 4, the concentrations of CO in 2019, 2020, and 2021 in Iran's northern and southern parts were more than in other regions. The results showed that the average concentration of this pollutant in the country in each of these three years was approximately 0.029 mol/m^2 . A nationwide analysis of the CO time series data showed that the level of this pollutant was significantly increased from March 23 to April 5 in 2021 compared to the same period in 2019 and 2020, ranging between 0.03 to 0.035 mol/m^2 . These results corresponded well with those of NO_2 and indicated the high traffic of vehicles and the traffic ban violation during the corona pandemic in the 2021 Nowruz holidays.

On a local scale, the concentration of the CO pollutant in the period of 2021 in the three cities of Tabriz, Isfahan, and Mashhad significantly increased compared to 2020 and 2019. This might be because these cities welcome many tourists every year during the Nowruz holidays due to their rich historical and leisure places. During Nowruz 2021, many people from Tehran and other cities traveled to these three cities because of the lack of a specific law on traffic ban, paving the way for the widespread outbreak of Covid-19 and the beginning of its fourth peak in Iran. The average CO concentration from March 10 to April 10, 2021, in Isfahan increased by approximately 7% compared to the same period in 2019 and 2020. Although the average concentration of CO in Tehran in 2021 increased by 8% compared to 2020, this amount did not significantly change compared to the same period in 2019. In general, the concentration of this pollutant in all four cities in 2020 significantly decreased compared to that in 2021 and 2019, confirming the observance of the traffic ban and quarantine during Nowruz 2020 by people. Furthermore, it showed improving the implementation of proper policies (telecommuting, prohibiting traffic, and locking down the parks, public, and leisure places) by the government in this period.

Sentinel-5P NO₂ vs. Ground-Based Measurements

As mentioned, NO₂ and CO are among the most critical pollutants emitted due to vehicle traffic and factory activity. The reported CO data from the selected ground stations had many gaps and, therefore, the *in-situ* measurements of NO₂ were only used in this study. In this regard, due to the high importance of Tehran as the capital of Iran and the existence of a large number of ground stations with appropriate distribution, the stations of this city were used as a basis for verification. For this purpose, NO₂ concentration from 19 ground stations in Tehran between March 11 and April 8 in 2019, 2020, and 2021 was acquired. Then, the correlation between these *in-situ* data and those obtained from the TROPOMI sensor was investigated, where the results are demonstrated in Figure 5. As shown in Figure 5, the lowest and highest correlation coefficients were 0.36 and 0.86, obtained at the S5 and S17 stations in 2019 and 2021, respectively. Moreover, the average correlation coefficients in most stations in Tehran were higher than 0.6, indicating the high potential of the TROPOMI sensor for NO₂ estimation.

Daily deaths of COVID-19 vs. NO₂ and CO distribution

An investigation of statistics published by the World Health Organization on the Covid-19 death rate in Iran indicates an increase in the number of deaths from March 11 to April 22, 2021, compared to the same period in 2020 (see Figure 6). The highest number of deaths per day in 2020 and 2021 were 158 and 453, respectively. Furthermore, the average number of deaths in 2020 and 2021 during this period reached 118 and 172 people per day, respectively. This represents a 1.45-fold increase in the number of deaths due to Covid-19 in Iran in 2021 compared to 2020. The results also showed an increase and decrease in post-holidays mortality in 2021 and 2020, respectively. The rate of increase in 2021 immediately started after the Nowruz holidays (i.e., on April 2) and continued in the following days. As discussed in the above subsections, the results of the time series of NO₂ and CO pollution also showed that the average air pollution in Iran in 2021 was higher than in 2020.

4. Conclusion

In this study, the effect of quarantine and traffic reduction on the concentration of CO and NO₂ pollutants during the Covid-19 pandemic in Iran was investigated. To this end, time-series data of Sentinel-5P/TROPOMI were analyzed in GEE. The results showed that the TROPOMI sensor with consistent data had acceptable accuracy in estimating NO₂ and CO pollutants for Iran. Analysis of the Sentinel-5P NO₂ and CO data during the Nowruz holidays in 2019, 2020, and 2021 showed that the amount of these pollutants in 2021 were 5% higher than that of 2020. This could be due to high vehicle traffic and the government's failure to consider serious policies and laws to ban urban and interurban traffic. On the contrary, the concentrations of NO₂ and CO pollutants during Nowruz 2020 were 5% lower than those of 2019. The reduction in the amount of these pollutants in 2020 compared to 2019 indicated the observance of quarantine rules, as well as people's initial fear of getting infected with the disease. Furthermore, the time-series analysis of NO₂ and CO pollutants during Nowruz 2020 and 2021, along with the daily deaths due to Covid-19, showed an increase in air pollutants, indicating higher urban and interurban traffic. Therefore, 2021 witnessed an increase in NO₂ and CO pollutants

compared to the same period in the last two years, which consequently caused the emergence of the fourth corona peak and an increase in mortality within this year.

Declarations

Author contribution: Siavash Shami: methodology, data curation, implementation. Babak Ranjgar: writing-original draft preparation, and conceptualization. Mahdi Khoshlahjeh Azar: draft visualization, investigation preparation. Armin Moghimi: supervision, validation, methodology and writing-reviewing. Samaneh Sabetghadam: validation, and writing-reviewing. Meisam Amani: conceptualization, writing-reviewing and editing. All authors approved the submitted version of the manuscript. All authors have contributed to the preparation of the manuscript, have read, and approved the submitted manuscript.

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Compliance with Ethical Standards

Ethics approval Not applicable.

Consent to participate Not applicable.

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Conflict of interest The authors declare that they have no conflict of interest.

Code Availability The Google earth engine code is available on request from the authors.

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Figures

Figure 1

The study area and the selected cities (Tehran, Mashhad, Isfahan, Tabriz) for assessing the effects of Covid-19 spread on air pollution.

Figure 2

The process of producing air pollutants maps in the GEE.

Figure 3

The Comparative representations of the 30-day (March 11 -April 8) average value of NO₂ (left column) over the entire country of Iran and (right column) its four metropolises (Tehran, Tabriz, Isfahan, and Mashhad) in (a) 2019, (b) 2020 and (c) 2021, as well as (d) the trend of NO₂ over Iran and the four metropolises.

Figure 4

the Comparative representations of the 30-day average CO over Iran (left column) and its four metropolises (Tehran, Tabriz, Isfahan, and Mashhad) (right column) during the period March 11 to April 8 (a) 2019, (b) 2020 and (c) 2021 as well as (d) the trend of CO over Iran and the four metropolises.

Figure 5

The location of the NO2 ground stations in Tehran and the correlation coefficients obtained by comparing their in-situ measurements with those of the Sentinel-5P.

Figure 6

The time-series of daily deaths of Covid-19 in Iran during March 11 to April 22 (World Health Organization Coronavirus Disease (COVID-2019) Situation Reports., 2021).