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CASE STUDY

Changes in NO2 and O3 levels due to the pandemic lockdown in the industrial cities of Tehran and Arak, Iran using Sentinel 5P images, Google Earth Engine (GEE) and statistical analysis

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Abstract
Air pollution has very damaging effects on human health. In recent years the Coronavirus disease (COVID-19) pandemic has created a worldwide economic disaster. Although the consequences of the COVID-19 lockdowns have had severe effects on economic and social conditions, these lockdowns also have also left beneficial effects on improving air quality and the environment. This research investigated the impact of the COVID-19 lockdown on NO2 and O3 pollutants changes in the industrial and polluted cities of Arak and Tehran in Iran. Based on this, the changes in NO2 and O3 levels during the 2020 lockdown and the same period in 2019 were investigated in these two cities. For this purpose, the Sentinel-5P data of these two pollutants were used during the lockdown period from November 19 to December 05, 2020, and at the same time before the pandemic from November 19 to December 05, 2019. For better results, the effect of climatic factors such as rain and wind in reducing pollution was removed. The obtained results indicate a decrease in NO2 and O3 levels by 3.5% and 6.8% respectively in Tehran and 20.97% and 5.67% in Arak during the lockdown of 2020 compared to the same time in 2019. This decrease can be caused by the reduction in transportation and socio-economic and industrial activities following the lockdown measures. This issue can be a solid point to take a step toward controlling and reducing pollution in non-epidemic conditions by implementing similar standards and policies in the future.

Keywords Google Earth Engine · NO2 · O3 · Pandemic lockdown · Sentinel · Statistic

Abbreviations

WHO	World Health Organization
O3	Ozone
NO2	Nitrogen dioxide
CO2	Carbon dioxide
SO2	Sulfur dioxide
CO	Carbon monoxide
PM	Particulate matter
PM2.5	Particulate matter 2.5 micrometers and smaller
PM10	Particulate matter 10 micrometers and smaller
NOx	Nitrogen oxides
SOGIS	State of the art online geographic information systems
VOCs	Volatile organic compounds
AOD	Aerosol optical depth
MCO	Movement control order
ICP-OES	Inductively Coupled Plasma Optical Emission Spectroscopy
GEE	Google Earth Engine
MODIS	Moderate Resolution Imaging Spectroradiometer
ESA	European Space Agency

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TROPOMI	TROPOspheric Monitoring Instrument
UV	Ultraviolet
SWIR	Shortwave Infrared

1 Introduction

Severe air pollution in big cities is one of the problems that the relevant authorities always have problems to control. Despite the economic problems that the COVID-19 pandemic has brought with it, in many cases it has improved the pollution situation in big cities. According to the reports of the World Health Organization (WHO), air pollution has very damaging effects on human health, such that 34% of deaths are caused by stroke, 36% by lung cancer, and 27% by heart disease (WHO, 2016). The major air pollutants encountered in our life are ozone (O3), nitrogen dioxide (NO2), carbon dioxide (CO2), sulfur dioxide (SO2), carbon monoxide (CO), and particulate matter (PM) (Chen et al., 2007). The main source of NO2 in the atmosphere is the combustion of fossil fuels such as gas, oil, and coal. NO2 is one of the most reactive pollutants and is mainly created from burning fossil fuels. Transportation is an important source of NO2 production (Muhammad et al., 2020). O3 is also a common oxidant gas in urban regions, exposure to which increases respiratory problems (Lee et al., 2021). The concentration of O3 on the earth's surface depends on the emission of gases such as nitrogen oxides (NOx), and volatile organic compounds (VOCs), atmospheric conditions, the occurrence of photochemical reactions, and therefore regional, local, and seasonal factors. In most regions, as NOx levels decrease, O3 also decreases; however, in some urban areas with high-NOx emissions, O3 may at first increase in response to decreasing NOx levels, but eventually decrease as the urban mass moves to rural areas (Dentener et al., 2020). These pollutions are also effective in socio-economic issues and the process of attracting tourists (Jamali et al., 2021; He et al., 2020). Investigating these issues and problems with state of the art online geographic information systems (SOGIS) has greatly increased the speed of problem solving. This is despite the fact that in the past these problems were analyzed and solved with slow and long steps with desktop software (Jamali and Abdolkhani 2009).

In February 2020, the first case of coronavirus was detected in the city of Qom, Iran. With the rapid increase in the prevalence of this disease, its spread became a national problem. The government decided to fight the epidemic by reducing transportation within and between cities, closing commercial centers, educational institutions such as universities and schools, holy places, etc. In Iran, the first lockdown for controlling this disease started from March 21 to April 21, 2020 (Broomandi et al., 2020).

COVID-19 has sparked a worldwide economic disaster unlike any seen in the past, with effects that will last for many years (Boccaletti et al., 2020). Although the consequences of the COVID-19 lockdowns have had severe effects on economic and social conditions, these lockdowns have also left beneficial effects on improving air quality and the environment (Hashim et al., 2021). Following this, remarkable improvement in air quality levels in some countries like Spain (Baldasano, 2020), Brazil (Siciliano et al., 2020), China (Sharma et al., 2020), India (Gautam, 2020), and cities such as Bangkok, Paris, and Tokyo have been observed (He et al., 2020).

Many studies have been done on the effects of the Coronavirus disease on changes in air pollution. Benchrif et al. (2021) examined air pollutants like NO2 and PM2.5 and Air Quality Index (AQI) during the COVID-19 lockdown in many cities of the world. The results showed that the NO2 level reduced by 3 to 58% across the cities, during the lockdown. However, NO2 levels increased in cities such as Abidjan by 1%, Conakry by 3%, and Chengdu by 10%. The NO2 concentration increased in the unlocking time in approximately all cities (Benchrif et al., 2021). Shami et al. (2022) investigated changes in pollutants such as NO2 and CO in four metropolises of Iran (Tehran, Mashhad, Isfahan, and Tabriz) in three periods from March 11 to April 8, 2019, 2020, and 2021. The results showed that the concentration of NO2 and CO in 2020 (the first year of the COVID-19 epidemic), was 5% less than in 2019, which indicates the observance of lockdown rules and also people's initial fear of Corona. But, these pollutants in 2021 (the second year of the COVID-19 epidemic) are more than the pollutants in 2020 due to high vehicular traffic and lack of serious policy (Shami et al., 2022). Even though Shami et al. (2022) had investigated the effect of COVID-19 on NO2 and CO pollutants in the four metropolises of Tehran, Isfahan, Tabriz, and Mashhad, but because the selected time frame was partly in winter and partly in early spring, the effect of climatic factors such as rainfall, wind and temperature inversion can have an effect on the concentration of pollutants, but they did not investigate the effect of atmospheric factors in their study. But in our research, the influence of climatic factors has been investigated. Tehrani et al. (2021), also at the beginning of the corona disease, they examined the average rainfall and several pollutions in the whole country of Iran for all provinces during one month (from 20 to 2020 to 19 April 2020) and reported the comparison and correlation between the disease and factors such as rain and wind in 22 provinces during one month. Their findings showed that precipitation, NO2 and SO2 have a high correlation with the number of cases of COVID-19.

Sathe et al. (2021) also examined air pollutants and meteorological parameters by surface and satellite information in India. Their study showed a significant reduction in surface data of NO2 46–61% and PM2.5 42–60% during the COVID-19 lockdown. These results were confirmed by the reduction in satellite information for aerosol optical depth (AOD) and tropospheric NO2, 3–56% and 25–50%, respectively over some cities. Also, other pollutants such as PM10 and O3 showed a substantial reduction of 24–62% and 22–56%, respectively whereas CO showed a moderate decrease of 16–46% (Sathe et al., 2021). Latif et al. (2021) studied concentrations of different air pollutants during movement control order (MCO) resulting from COVID-19 lockdown in the Klang Valley, located in Malaysia. The results showed that CO, NO2, PM2.5, and PM10 levels decreased during MCO compared to the same time in 2019 and 2018. Also, the largest decrease during MCO was related to NO2 concentration with a 55% and 72% decrease. On the other hand, O3 levels increased in several areas (Latif et al., 2021). Gautam and Kumar (2019) studied the state of air pollution, especially particulate matter 2.5 micrometers and smaller (PM2.5), in 21 Chinese cities. The results of spatial distribution reported that the cities of the east, north, and northeast China are highly polluted. The high percentage of pollution in China is caused by heavy traffic or the emission of vehicles and the burning of solid fuel that is used in most parts of China) Gautam and Kumar 2019 (. Masih et al. (2019) concentrations of submicron particulate matter (PM), and concentrations of related metals in urban and semi-urban areas of western part of India investigated using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). The results showed which sources of sub-micron particles associated with metals in outdoor air, greenhouse gases from industries, vehicle activities and dust from construction sites and indoor the house, there was more cooking, cleaning and other human activities (Masih et al., 2019).

In addition, a very high reduction in NO2 levels was observed following the COVID-19 lockdown in Wuhan, China (Sun and Wang, 2020; NASA, 2020; Doutille et al., 2020). In Almaty city of Kazakhstan, the COVID-19 lockdown caused the reduction of (35%) of NO2 (Kerimray et al., 2020). Also, in Rio de Janeiro, Brazil, compared to 2019 and before the coronavirus pandemic, a decrease in the levels of CO, NO2, and particulate matter 10 micrometers and smaller (PM10) has been observed (Dantas et al., 2020). So, the median values of CO lowered by 37.0–43.6% and NO2 by 24.1–32.9% compared to the last year. But, it resulted in an increase in O3. In São Paulo city, Brazilian, a significant reduction in NO2 (54.3%), CO (64.8%), and nitrogen oxide (NO) (77.3%) were observed during the lockdown. But, resulting vehicular traffic O3 increased by 30% (Nakada and Urban, 2020). In a study, Sharma et al. (2020) showed a reduction in NO2 (8%), CO (10%), PM2.5 (43%), and PM10 (31%) compared to 2019 in some cities; while, the O3 level increased by 17% (Sharma et al., 2020). Also, Mahato et al. (2020) showed that CO and NO2 concentrations decreased by 30% and 53%, respectively, during the COVID-19 lockdown in Delhi (Mahato et al., 2020).

In 44 cities in China, from 1st January to 21st 2020, reductions in NO2, PM10, PM2.5, SO2, and CO levels were observed by 24.67%, 13.66%, 5.93%, 6.76%, and 4.58%, respectively (Bao and Zhang, 2020). In a study, Bromandi et al. (2020) investigated the impact of the COVID-19 lockdown on changes in air quality in Iranian cities. Their results showed that concentrations of NO2 1–33%, CO 5–41%, PM10 1.4–30%, and SO2 5–28%, decreased. Conversely, PM2.5 and O3 increased by 2–50% and 0.5–103% (Broomandi et al., 2020). In India, Chakrabortty et al. (2021) selected weather indicators such as NO2, CO, SO2, Ammonia (NH3), O3, PM10, and PM2.5. They examined the association of these parameters with the COVID-19 pandemic. The results showed that in lockdown, the air quality has improved in India (Chakrabortty et al. 2021).

Satellite imaging plays a major role in monitoring air quality at different scales (Geddes et al., 2016; Lin et al., 2015; Ialongo et al., 2016). Remote sensing information for air quality monitoring is significant for health investigation (Putrenko and Pashynska 2017). Google Earth Engine (GEE) is a powerful platform capable of performing geographic analysis at large scales. it has computational capabilities for studying issues like natural disasters, climate monitoring, deforestation, food security, drought, water management, and environmental protection (Gorelick, 2017).

One of GEE's platforms is the Earth Engine (EE) Platform, which is a data visualization platform that allows users to access the massive datasets available in the EE Data Catalog. The data catalog contains millions of datasets, including a complete set of Landsat-4, -5, -7, and – 8, Moderate Resolution Imaging Spectroradiometer (MODIS), Sentinel-1, -2, -3, and – 5P, atmospheric, meteorological, and vector data. Workspace allows users to view, zoom and move quickly. In addition, it allows users to adjust visualization settings such as contrast, brightness, and transparency levels. Users can also add multiple layers to Workspace to better examine changes over time (Amani et al., 2020).

Iran's industrial cities such as Arak and Tehran are among the most polluted cities in the world, whose pollution control has always been one of the concerns of the relevant officials. But gaps seen in the background contain no research in these cities using modern methods remote sensing such as use of Sentinel 5P (Precursor) data and GEE platform and this aspect also is the importance and significance of the study. This way is a low-cost and fast method using GEE codes and new modern satellite images Sentinel 5P to compare both time and industrial cities that way is merit of the paper and it has added new issues to the current literature. The limitations of technique applied can be time access of the data and spatial resolution. In this investigation, filling these gaps was considered. This research was conducted with the objective of investigating the impact of the COVID-19 lockdown on the changes in air quality in Tehran and Arak cities using remote sensing and the GEE platform and statistical comparison that these integration is unique aspect and new knowledge is added by this study. The hypothesis was that there was a decrease in NO2 and O3 concentration during the lockdown period from November 19 to December 5, 2020, compared to the same time in 2019. The reason can be due to the reduction of transportation and economic activities during the lockdown period in these cities. If the assumption of reduction of pollution under lockdown conditions were proven, similar conditions can be implemented in the future, as a suitable solution to control pollution in these cities. Thus, similar polluted areas and these are type of this paper contribution to scientific decision-making.

2 Materials and methods

2.1 Study area

Our study focuses on Tehran and Arak as two metropolitans and industrial cities in Iran. Tehran city with a population of around 8.6 million is located in the northern part of Iran (Shahbazi et al., 2016, 2018), and the northeast of the Namak Lake basin (Fig. 1). During the day, the population of Tehran city reaches more than 12.5 million people as a result of commuting from nearby cities (Shahbazi et al., 2016; Alipourmohajer et al., 2019). This city is located at high altitudes and is surrounded by the Alborz Mountains, which causes pollutants to be trapped in these areas. Fast population growth, increase in fuel consumption, urbanization and industrial developments are barriers to clean air in Tehran city (Heger and Sarraf 2018). Same in other megacities, transportation plays a significant role in the air pollution of this city (Azarmi and Arhami 2017). Also, Arak is known as the industrial capital of Iran. It's geographic coordinates are 34°05′30″ N and 49°41′21″ E. The average annual rainfall of Arak is about 350 millimeters and the annual average temperature is 13.9 °C. Also, the relative humidity is 46% (Solgi 2015). Arak is about 288 km far from Tehran and is located in the central part of Iran (Fazelinia et al. 2013). This city faced drastic air pollution in recent years, due to different emission sources, such as the increased number of vehicles, population growth, and industrial activities (Solgi 2015 and Hosseini and Shahbazi, 2016).

2.2 Methods

The framework for studying pollutants changes result of the COVID-19 lockdown in Tehran and Arak cities is shown in Fig. 2. This flowchart shows the beginning of the research with three parts: location, time, and data. The location of two large industrial cities, one of which is also the capital, has been chosen. Times in two different years but similar months are used for comparison. Point data has been collected for statistical analysis. Pollution and climate data were included. Precipitation and wind can reduce the pollution that was considered. Statistical analysis and time series were used in the comparisons. The outputs of these modeling were charts and maps that were included in the results.

2.3 Satellite data

The Sentinel 5P satellite was launched into orbit by the European Space Agency (ESA) on October 13, 2017 (Veefkind, et al., 2012). TROPOspheric Monitoring Instrument (TROPOMI) is a multispectral imaging spectrometer carried on Sentinel 5. TROPOMI detects solar radiances. It has more spectral bands than its predecessors (Theys et al., 2019).

The instrument has a high spatial resolution that covers Ultraviolet (UV) to Shortwave Infrared (SWIR). Also, this tool allows the recovery of atmospheric components, namely SO2, Methane (CH4), NO2, CO, O3, Formaldehyde (CH2O), clouds, and aerosols (ESA 2020). Various data streams are used to observe aerosols and gases, such as the offline stream (OFFL), the near-real-time stream (NRTI), and the reprocessed stream (RPRO). NRTI data will be available after 3 h of data collection, while, OFF Land PRO data will be available a few days after collection.

In this research, NO2 and O3 pollutants were selected to investigate the air quality of Tehran and Arak cities during the COVID-19 lockdown and pre-lockdown periods. The TROPOMI NRTI stream of NO2 column datasets and OFFL stream of O3 were used for evaluating the deviation of air quality. The concentrations of these parameters have been compared before the pandemic, November 19 to December 05, 2019, and during the lockdown, November 19 to December 05, 2020. The data used was analyzed using the Earth Engine Code Editor.

To get the changes during the lockdown period, statistic parameters for 2 weeks during the lockdown (19 November – 05 December 2020) and at the same time in 2019, (19 November – 05 December 2019) as a control period, were calculated. The maximum, minimum, and average values have been used to check the changes in the concentration of pollutants in the studied period. Also, the relative difference of the average values in percentage has been used as

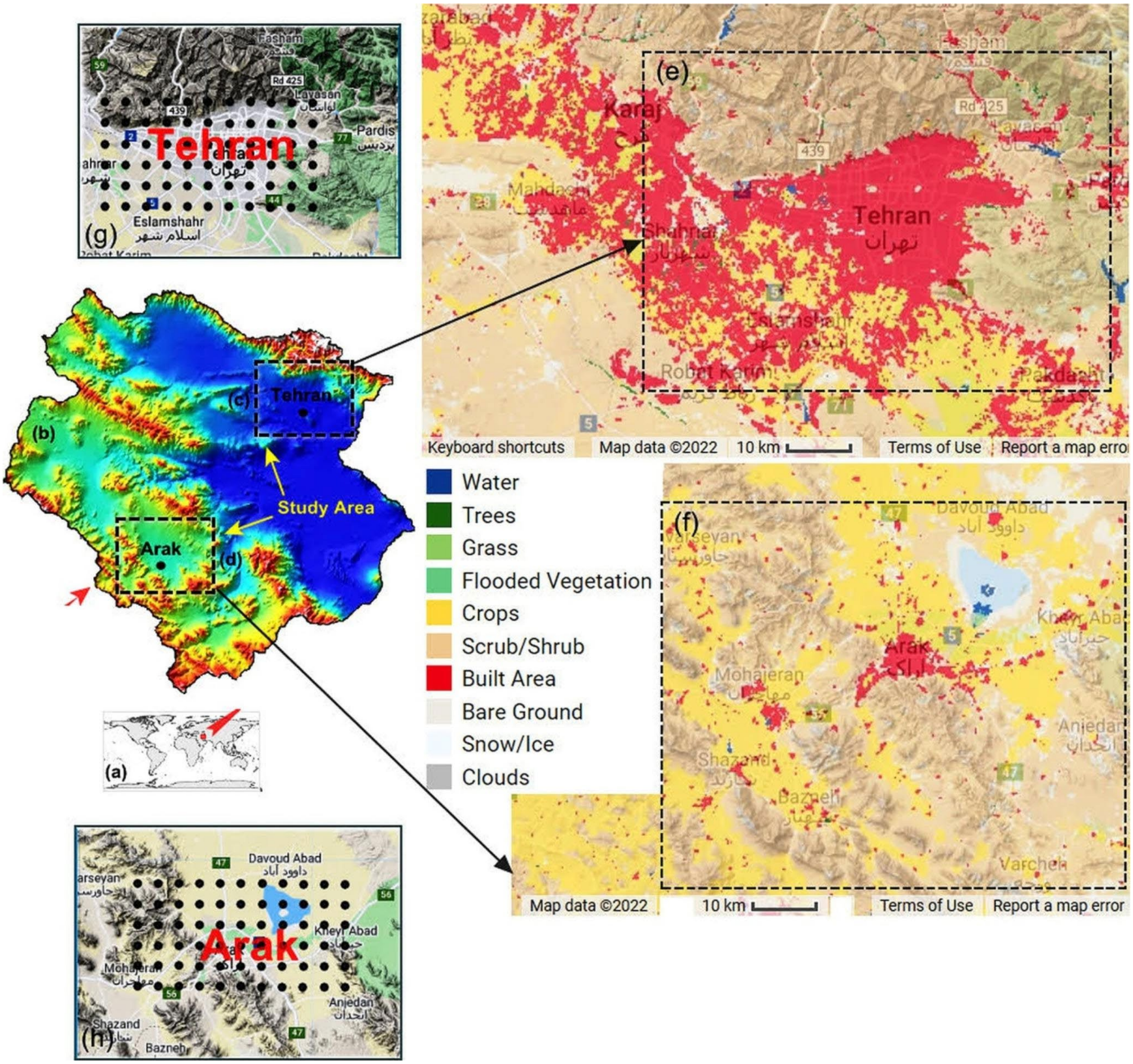

Fig. 1 The study area (**a**) The location of Namak Lake basin in the world (**b**) Namak Lake basin (**c**) The location of Tehran city in Namak Lake basin (**d**) The location of Arak city in Namak Lake basin (**e**) and (**f**) ESRI land use from Sentinel 2 in 25.06.2021Tehran and Arak respectively (**g**) and (**h**) sample points in two cities (GEE code: https://code.earthengine.google.com/9a2fe37d0dc4b321926f0ce30fb8abe4)

a representative of the concentration of pollutants. Wind and precipitation data were also analyzed to investigate the effect of weather parameters on pollutants.

Gains or losses in pollutants were assessed by normalizing the difference between the control period and the COVID-19 lockdown (Eq. 1). Positive values demonstrate a rise in the concentration of the pollutants while negative values show a decline in the pollutants.

$$LossorGain\,(\%) = \frac{Pollutantsp - Pollutantsc}{Pollutantsc} \times 100 \tag{1}$$

Pollutants $_p$ display the pollutants value during the lockdown and Pollutants $_c$ show pollutant's concentration during the normal or control period.

3 Results and discussion

In this section, the results obtained are presented in two sections. First, the concentration of NO2 and O3, and climatic factors such as the speed and direction of wind and precipitation during the COVID-19 epidemic in 2020 in the cities

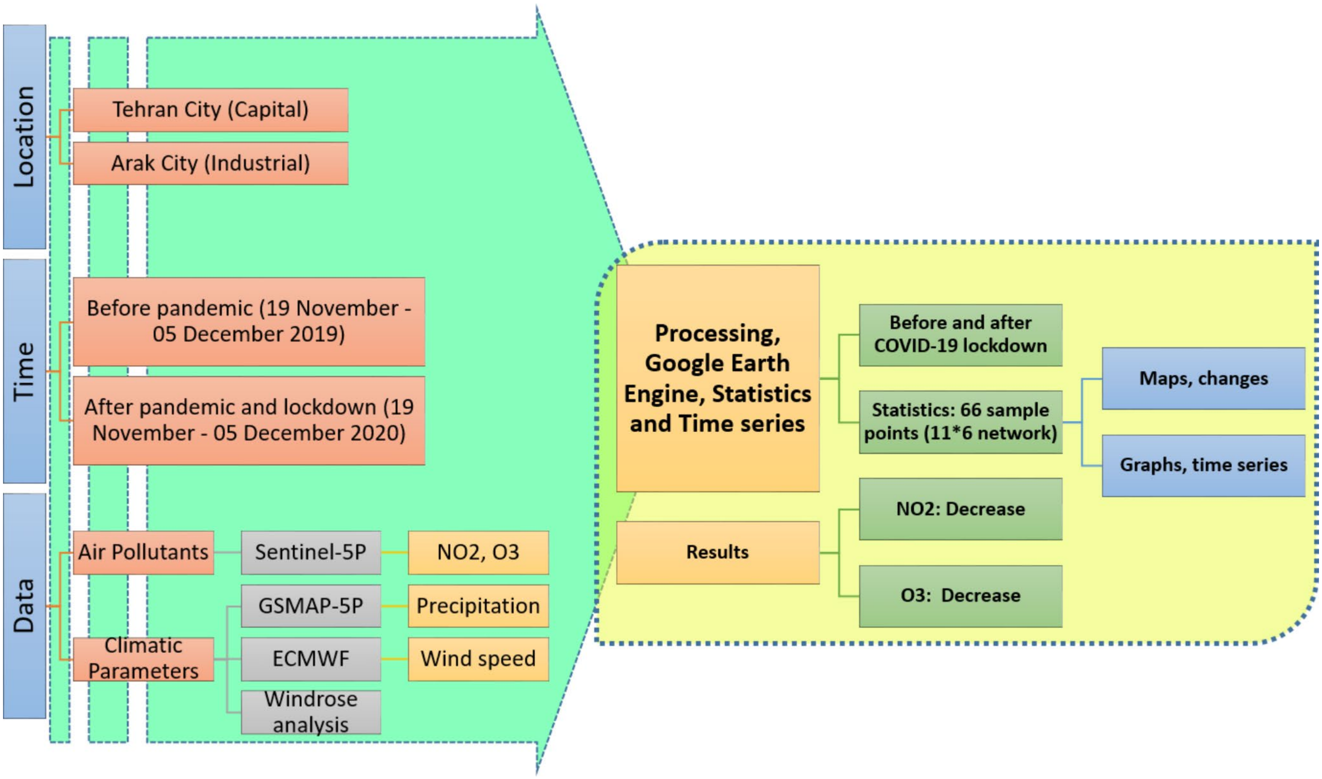

Fig. 2 The framework for analyzing pollutants changes in the study areas

of Arak and Tehran are investigated. Then these parameters were examined in 2019 and before the pandemic and the results obtained were compared with the pandemic period.

3.1 Evaluation of changes in pollutants and climatic parameters

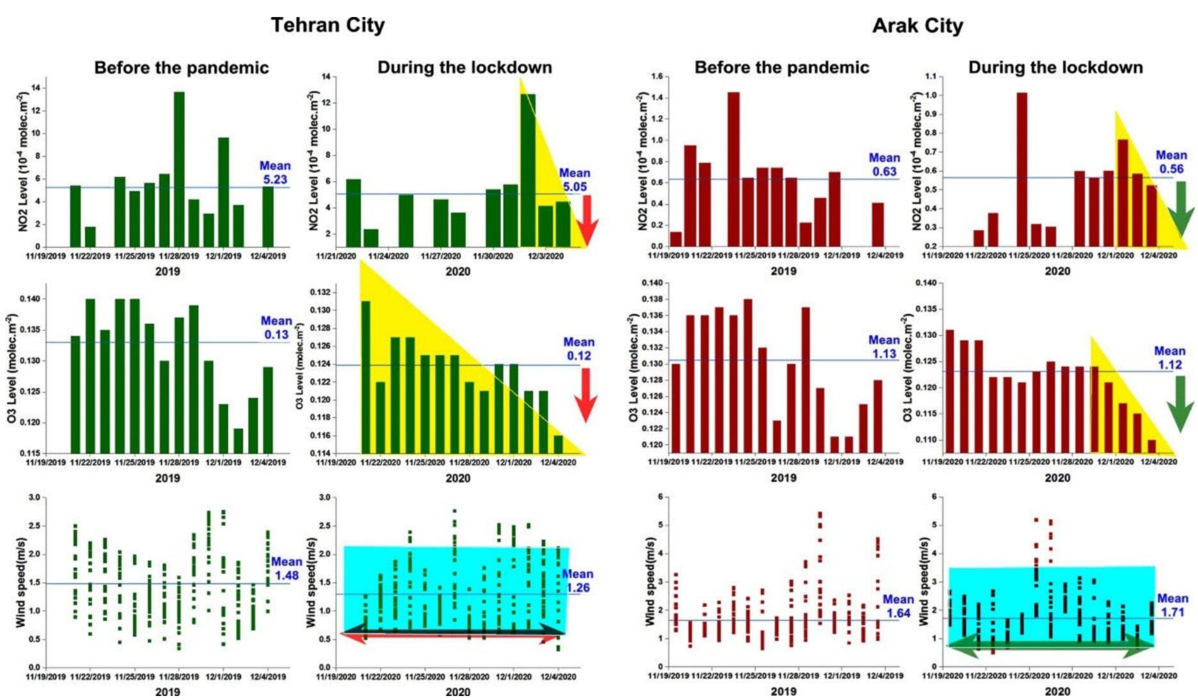

Fig. 3 NO2 level, O3 level, and wind speed charts of Tehran and Arak cities before the pandemic, November 19 to December 05, 2019, and during the lockdown, November 19 to December 05, 2020

Table 1 The changes in NO2, O3, precipitation, and wind speed before the pandemic, November 19 to December 05, 2019, and during the lockdown, November 19 to December 05, 2020, in Tehran and Arak cities

City	Parameters	Time	Max	Min	Average	Average change(%) from 2019 to 2020
Tehran	NO2(e-4 mol/m^2)	Before the pandemic, 2019	13.677	0.611	5.231	-3.5
		During the lockdown, 2020	12.672	2.347	5.048	
	O3(mol/m^2)	Before the pandemic, 2019	0.14	0.119	0.133	-6.8
		During the lockdown, 2020	0.131	0.116	0.124	
	Precipitation(mm/hr)	Before the pandemic, 2019	0.492	0.00	0.00	0.00
		During the lockdown, 2020	3.286	0.00	0.00	
	Wind speed(m/s)	Before the pandemic, 2019	2.749	0.338	1.48	-12.5
		During the lockdown, 2020	2.765	0.323	1.295	
Arak	NO2(e-4 mol/m^2)	Before the pandemic, 2019	1.451	0.312	0.71	-20.97
		During the lockdown, 2020	1.013	0.285	0.56	
	O3(mol/m^2)	Before the pandemic, 2019	0.138	0.121	0.130	-5.67
		During the lockdown, 2020	0.136	0.11	0.12	
	Precipitation(mm/hr)	Before the pandemic, 2019	0.903	0.00	0.01	0.00
		During the lockdown, 2020	6.606	0.00	0.10	
	Wind speed(m/s)	Before the pandemic, 2019	5.411	0.503	1.64	3.78
		During the lockdown, 2020	5.20	0.507	1.71	

The results of the study of parameters NO2, O3, precipitation, and wind speed of Tehran and Arak cities before the pandemic, November 19 to December 05, 2019, and during the lockdown, November 19 to December 05, 2020, are shown in Table 1.

3.1.1 NO2 level

NO2 concentration charts and maps of Tehran and Arak are shown in Figs. 3 and 4. The results showed that before the COVID-19 pandemic from November 19 to December 05, 2019, NO2 levels in maximum, minimum, and average in Tehran were 13.677e-4, 0.611e-4, and 5.231e-4 mol/m2, and in Arak were 1.451e-4, 0.312e-4, and 0.71e-4 mol/m2, respectively. Also, the maximum, minimum, and average NO2 values in Tehran during the lockdown from November 19 to December 05, 2020, were 12.672e-4, 2.347e-4, and 5.048e-4 mol/m2, and in Arak were 1.013e-4, 0.285e-4 and 0.56e-4 mol/m2, respectively. Therefore, the average NO2 concentration during the lockdown of 2020 in Tehran and Arak has decreased by approximately 3.5% and 20.97%, respectively compared to 2019. It may be due to the decrease in economic activities and urban traffic in this period compared to the previous year (Filonchyk et al., 2020). As can be seen in Fig. 4, the amount of pollution at the point of collision with the heights, which like a barrier prevented it from moving, in Tehran has reached its maximum value and has decreased in the surrounding area.

3.1.2 O_3 level

O3 concentration charts and maps of Tehran and Arak are shown in Figs. 3 and 4. Examination of charts of the pre-COVID-19 pandemic from November 19 to December 05, 2019, in Tehran showed that the O3 levels at maximum, minimum, and average were 0.14, 0.119, and 0.133 mol/m2, and in Arak were 0.138, 0.121, and, 0.130 mol/m2, respectively. Also, the maximum, minimum, and average values in lockdown 2020 in Tehran were 0.131, 0.116, and 0.124 mol/m2, and in Arak were 0.136, 0.11 and 0.12 mol/m2, respectively. These results show that the average concentration of O3 in Tehran and Arak cities during the lockdown has decreased by approximately 6.8% and 5.67%, respectively, compared to the same time in 2019.

3.1.3 Wind speed

In this study, wind speed charts and maps of Tehran and Arak cities were drawn in Figs. 3 and 4. The results show that the hourly wind speed in Tehran during the lockdown of 2020 compared to 2019 has decreased by 12.5% and in Arak has increased by 3.78%. It seems that the wind parameter, as a climatic parameter during the lockdown, did not have an effect on reducing NO2 and O3 pollution in the region.

As shown in Fig. 3, in Tehran and Arak cities, during the lockdown of 2020, the number of days with NO2 and O3 concentrations above their daily average, decreased compared to the same time in 2019, but wind speed has not changed much from before the pandemic.

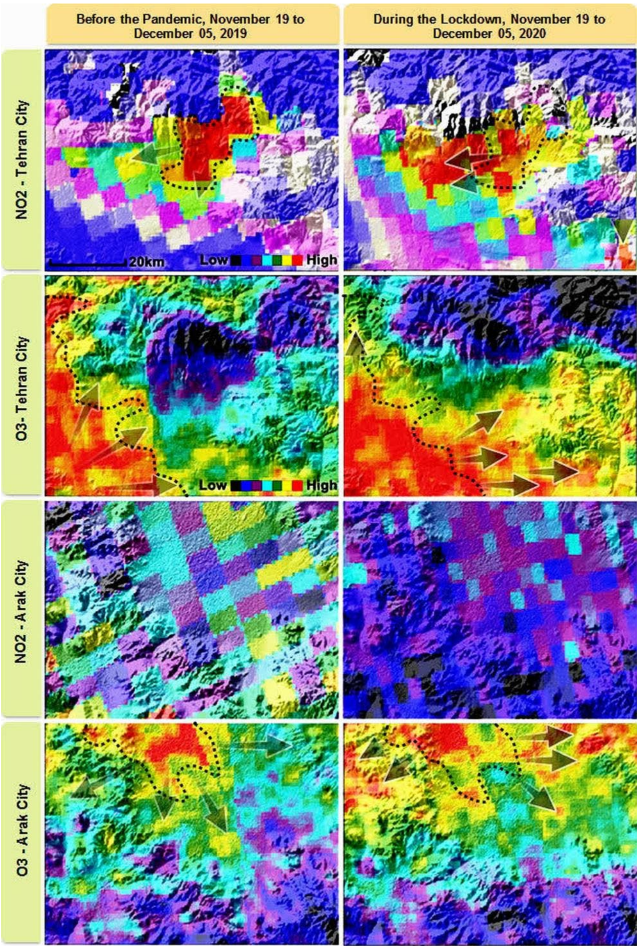

Fig. 4 Average TROPOMI NO2 tropospheric columns, O3 concentration, and wind speed in Tehran and Arak cities before the pandemic, November 19 to December 05, 2019, and during the lockdown, November 19 to December 05, 2020, Arrows show the pollution movement and changing of their distribution

3.1.4 Wind direction

The wind rose diagrams of Tehran and Arak are shown in Fig. 5. The results of studying the charts showed that the prevailing wind direction in Tehran is northwest and west, which causes the transfer of pollution to the southeast and east of Tehran. On the other hand, the existence of heights such as Bibi Shahrbanoo and Al-Qader heights in the southeast and the heights like Firoozeh Palace in the east of Tehran as a barrier has prevented pollution from leaving these areas. Therefore, the concentration of pollutants in these areas has reached its maximum and has turned it into an area with a high pollution density. Also, the prevailing wind direction in Arak is north and northeast, which causes the transfer of pollutants to the south and southwest of the region. On the other hand, the presence of heights in the southern and western regions has prevented the spread of pollutants outside the region and has caused their concentration in these parts.

3.1.5 Precipitation

The study of precipitation graphs showed that the average precipitation in the region during the lockdown in 2020 and at the same time in 2019 was inconsiderable, which indicates that the precipitation parameter does not affect reducing the concentration of NO2 and O3 pollutants in the lockdown compared to the same time in 2019.

3.2 Statistical studies

For statistical studies, a network containing 66 points with 5 km distance was randomly placed on Tehran and Arak cities (Fig. 1 g and h). Then the values of NO, O3, and wind speed for each point were determined during the COVID-19 lockdown in 2020, and at the same time in 2019.

Table 2; Fig. 6 show the correlation between NO2 and O3, and climate parameters (wind speed) in Tehran and Arak before and during the lockdown. As can be seen, there was no significant relationship between air pollutants and climate parameters during the study period. On the other hand, NO2 and O3 levels have decreased during the 2020 lockdown compared to 2019.

As can be seen in the results, in the metropolis of Tehran, the amount of NO2 has decreased sharply at the end of the lockdown. The amount of O3 has also shown this decreasing trend with a gentler slope during a longer period. It can be said that in Tehran, the activities during the lockdown, such as reducing car traffic, have been more effective in reducing the amount of NO2 than O3. A similar situation has occurred in Arak. Arak, which is a large and industrial city, is of course smaller than Tehran and has more limited industries. The decrease in pollution can also be seen there during the lockdown, but it is not as severe as in Tehran. Therefore, bigger and more polluted cities show a stronger and more appropriate and effective response in pollution reduction policies. In the maps, the spread of pollution seems to be spreading, while the amount and concentration of pollution has decreased, but it has shown some expansion in terms of location. It can be said that with the reduction of pollution, its movement towards the nearby places has increased, although there is no logical reason for that now. In wind roses, the prevailing wind of Tehran blows from the west, which causes pollution to move from west to east. Many factories and industries are located in the west of Tehran, and this causes pollution to be transferred to the city by the prevailing wind. In Arak, the prevailing wind blows from north and the northeast, and there was not much trend and movement of pollution during the lockdown. In this study, like similar studies such as (Benchrif et al., 2021; Sathe et al., 2021; Latif et al., 2021; Sun and Wang, 2020; NASA, 2020; Dutheil et al., 2020; Kerimray et al., 2020;

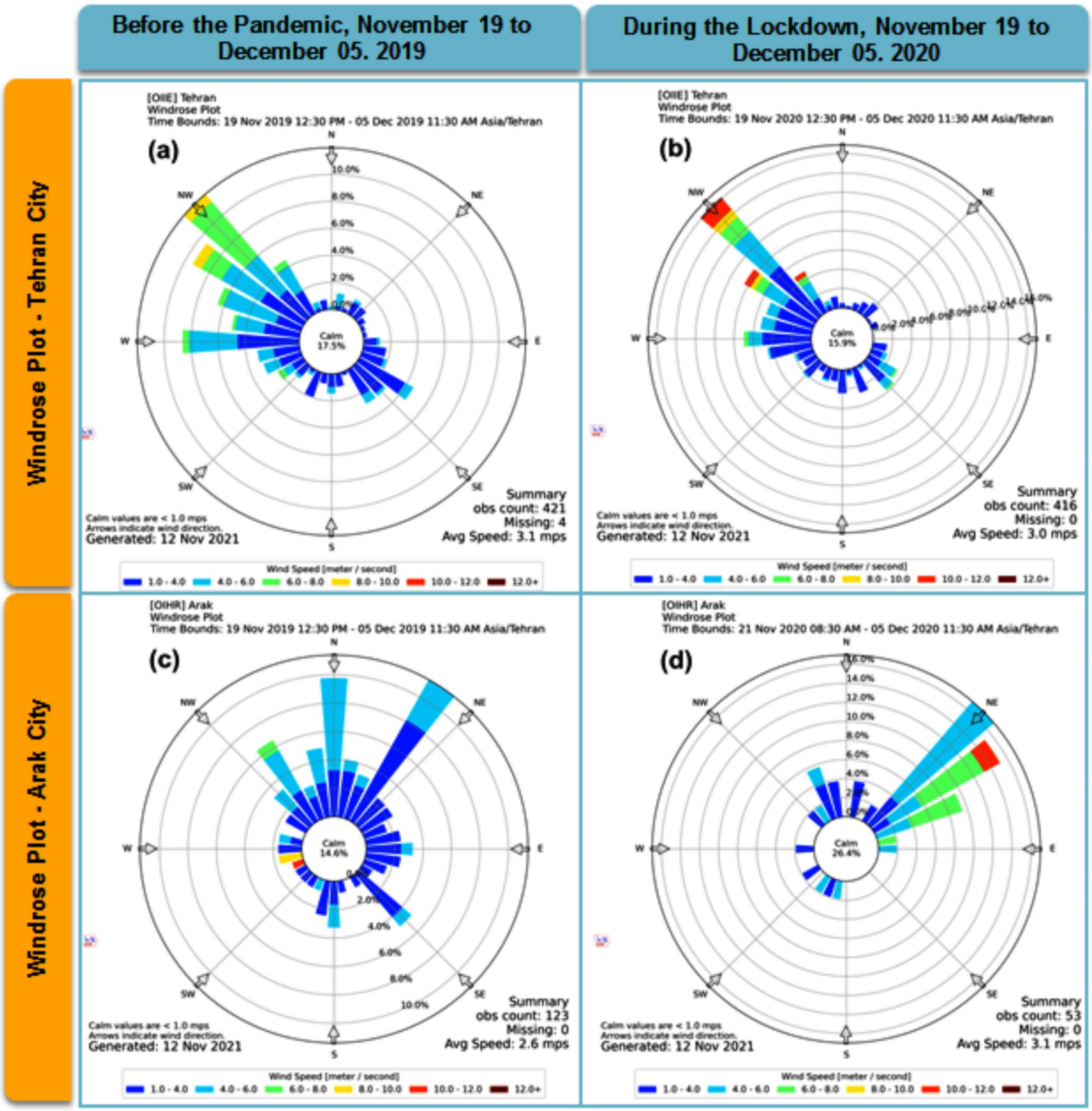

Fig. 5 The wind rose plots of (a) Tehran city before the pandemic, November 19 to December 05, 2019 (b) Tehran city during the lockdown, November 19 to December 05, 2020 (c) Arak city before the pandemic, November 19 to December 05, 2019 (d) Arak city during the lockdown, November 19 to December 05, 2020

Dantas et al., 2020; Nakada and Urban, 2020; Sharma et al., 2020; Mahato et al., 2020; and Broomandi et al., 2020), we have seen a decrease in NO2 concentration by 3.5% during 2 weeks of lockdown. Also, contrary to studies that showed an increase in O3 concentration, the O3 level has decreased during this period (e.g. Latif et al., 2021; Tobias et al., 2020; Sharma et al., 2020; Dantas et al., 2020; Nakada and Urban, 2020; Broomandi et al., 2020).

4 Conclusion

Research and development (R&D) is the generation of new knowledge in a research. In this research we undertake in order to develop new method and processes to improve those that already exist. In order to do this, some managers often take on risk thus, propagation is next our stages that should be focused. In this research, the hypothesis of

Table 2 Mann-Whitney U Test for NO_2, O_3, and wind speed in Tehran and Arak cities

city	Null Hypothesis	Test	Sig.
Tehran	The distribution of NO2 is the same across categories of Situation.	Independent-Samples Mann-Whitney U Test	0.000
	The distribution of O3 is the same across categories of Situation.		0.000
	The distribution of Wind speed is the same across categories of Situation.		0.124
Arak	The distribution of NO2 is the same across categories of Situation.	Independent-Samples Mann-Whitney U Test	0.000
	The distribution of O3 is the same across categories of Situation.		0.000
	The distribution of Wind speed is the same across categories of Situation.		0.111

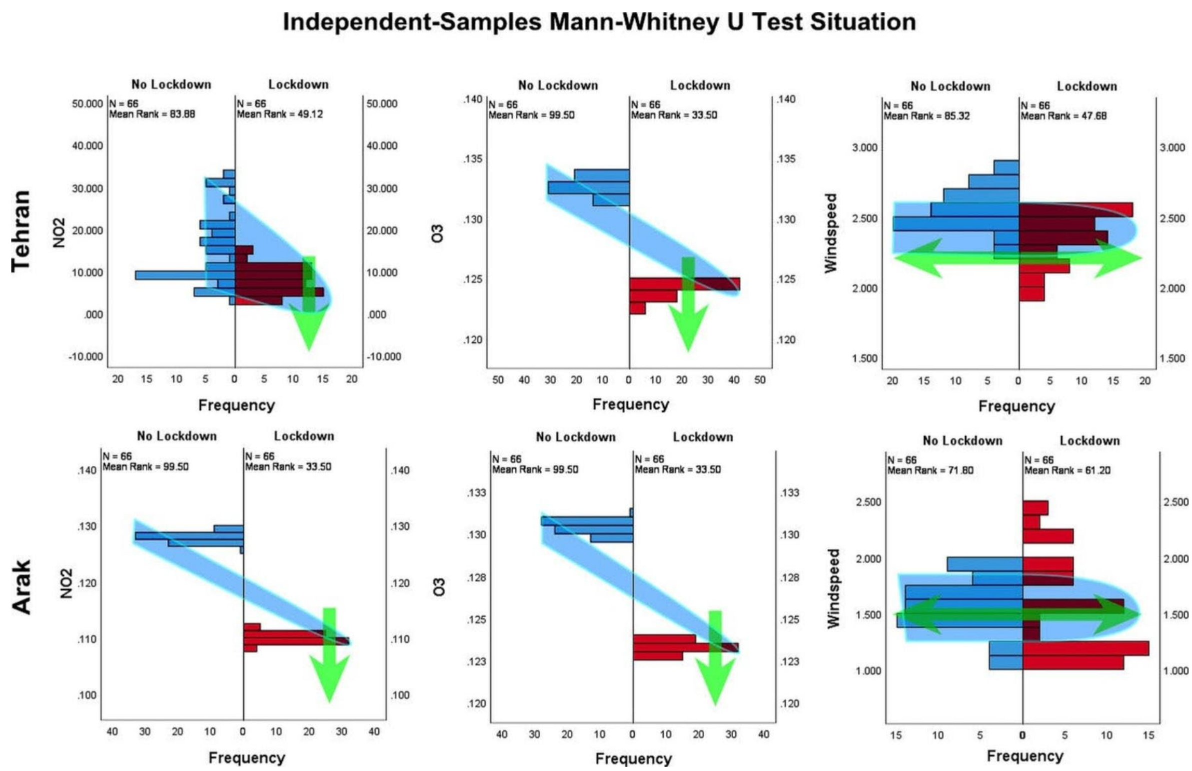

Fig. 6 The changes of NO2, O3, and wind speed in Tehran and Arak cities, before the pandemic, November 19 to December 05, 2019 (no lockdown) and, November 19 to December 05, 2020 (lockdown)

reducing tropospheric air pollution in urban areas as a result of measures such as transportation control and reducing economic activities following the implementation of the lockdown due to COVID-19 was investigated. Based on this, the changes in the level of NO2 and O3 pollutants in the two industrial and polluted cities of Tehran and Arak were evaluated by the data obtained from the Sentinel 5P satellite. Examining the pollutant maps and graphs showed that during the lockdown of 2020 compared to the same time in 2019, NO2 and O3 levels decreased by 3.5% and 6.8% respectively in Tehran city and by 20.97% and 5.67% in Arak city respectively. Also, the results of related statistical studies showed that during the 2020 lockdown, the number of days with NO2 and O3 concentrations higher than the daily average decreased compared to the same time in 2019. On the other hand, by studying the climatic parameters of wind and precipitation, it was found that these factors did not play a role in reducing these pollutants in the studied time period. Among the limitations of this study was the selection of specific times when climatic factors such as rain and wind did not increase and only the effect of lockdown was investigated. The increasing trend of pollution in big cities is one of the obstacles to sustainable development. By knowing this trend and effective factors, policies and decisions can be made in the direction of reducing pollution and sustainable development in megacities and industrial cities. The consequences and applications of this research are in the way of implementing suitable policies for the future in controlling and reducing urban pollution caused by urban and industrial activities in Iranian metropolises and similar regions. It is suggested that for further research, the changes and growth of megacities should be investigated with long-term data. Also, to further confirm the effects of the lockdown, more polluting factors in Iran and other countries should be investigated, compared and analyzed.

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Data Availability (Data are available when requested)

Code Availability (Land use land cover ESRI 2021, https://code.earthengine.google.com/9a2fe37d0dc4b321926f0ce30fb8abe4)

Declarations

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