ISEIS

Journal of Environmental Informatics 41(2) 130-140 (2023)

Journal of Environmental Informatics

www.iseis.org/jei

Spatiotemporal Variation of Nitrogen Dioxide and Nighttime Light Dataset of Iranian Metropolises in the COVID-19 Outbreak

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Received 25 July 2021; revised 23 October 2021; accepted 10 April 2022; published online 11 January 2023

ABSTRACT. COVID-19 lockdown has caused a reduction in traffic volume and industrial activities which are the main sources of air pollution in whole of the world. As tropospheric NO_2 pollutant and nighttime light (NTL) are the representative of human activities, this study focused to quantify the annual and monthly change of NO_2 concentration and NTL in 14 metropolises of Iran before, during and after the lockdown months such as March, April, October and November. TROPOMI images of Sentinel-5p were used for investigation of NO_2 column density in 2019, 2020 and 2021, and the variation of NTL was monitored by VIIRS images. The findings showed the majority of metropolises have an increase of NO_2 concentration in March and October and a decrease in April and November in 2020 but a significant increase in 2021. The similar pattern of NTL change as NO_2 was observed in the most metropolises. The correlation coefficient between NO_2 concentration and NTL was calculated from 0.66 to 0.75. So, in majority of metropolises, the reduction of NO_2 was observed with reduction of NTL. According to the results, reducing traffic volume as mobile source does not has an effective contribution in NO_2 emission in some metropolises of Iran which the stationary sources are dominant such as Isfahan. Tehran as the capital of Iran showed the highest annual mean NO_2 reduction in lockdown, this finding showed the important role of traffic volume on air quality of Tehran compared to industrial activities. The integrated application of TROPOMI and NTL data will help to better decision making for controlling and managing of air quality in country's urban area.

Keywords: air pollution, lockdown, Sentinel 5p, Suomi NPP, TROPOMI, VIIRS

1. Introduction

Following the outbreak of COVID-19 virus at the beginning of 2020, many people went to quarantine and human activities decreased dramatically throughout the world. In many countries, different types of restriction and lockdown were issued including prohibition of transportation and closure of cultural, educational, commercial, and industrial places. Not only human life was affected by the virus, but also it had a great impact on environment, e.g., the air quality has been improved in different parts of the world.

Satellite monitoring of air pollutants around the world has revealed a reduction in greenhouse and pollutant gases during quarantine (ESA, 2020). Among all air pollutants, nitrogen dioxide (NO_2) is proved to have a considerable reduction during COVID-19 lockdown in many researches. The main source of NO_2 is traffic pollution due to burning fossil fuels (He et al., 2020a, b) and majority of NOx emissions occur in populated regions which can affect lung function and raise the risk of respiratory illness (Panella et al., 2000). On the other hand, NO_x emissions are crucial in the troposphere since they play a major role in creating tropospheric ozone and acid rain (Richter, 2009).

Space-based monitoring of air quality has been started in 1995 by Global Ozone Monitoring Experiment (GOME) satellite data which revealed the information of NO_2, H_2O, BrO, SO_2, O_3, and HCHO in the tropospheric layer (Burrows et al., 1999; Orrell et al., 2001). Afterwards, numerous studies have been conducted by other instruments such as Global Ozone Monitoring Experiment 2 (GOME-2), Scanning Imaging Absorption spectrometer for Atmospheric CHartographY (SCIAMACHY), Ozone Monitoring Instrument (OMI) and TROPOspheric Monitoring Instrument (TROPOMI). TROPOMI is the Sentinel 5P sensor which was launched by the European Space Agency (ESA) and the Netherlands on October 13, 2017 and its mission has been monitoring air quality and climate change.

The National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) reported 30% reduction in NO_2 concentrations in March 2020 compared to March 2019 in most countries such as USA, China, Italy, Spain, and France due to the spread of COVID-19 (ESA, 2020; NASA, 2020). Sannigrahi et al. (2020) have studied air pollution during lockdown in 20 metropolises over the world by Sentinel 5p product in Google Earth Engine (GEE) environment. Paris have shown the largest decrease in NO_2 with 46%. Followed by Detroit (40%), Milan (37%), Turin (37%), Frankfurt (36%), Philadelphia (34%), London (34%), and Madrid (34%). At the same time, lower NO_2 reductions have been observed in Los Angeles (11%), Sao Paulo (17%), Antwerp (24%), Tehran (25%), and Rotterdam (27%) during quarantine. Liu et al. (2020) used OMI

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ISSN: 1726-2135 print/1684-8799 online
 doi:10.3808/jei.202300488

and TROPOMI data for study the sudden reduction in NO_2 of the China's because of the outbreak of COVID-19. Satellite data showed a decrease of 48 percent in tropospheric nitrogen dioxide from 20 days before the 2020 Lunar New Year to 20 days after that. In a study about the impact of COVID-19 on NO_2 concentration changes using TROPOMI data over Southern Ontario, NO_2 levels were shown to have reduction by an average of 40% in Toronto and Mississauga, with much larger decreases in the city center (Griffin et al., 2020). A study in East Asia showed reduction in NO_2 (83%), SO_2 (71%), HCHO (11%), CO (4%) in Wuhan and an increase in SO_2 in Seoul and Tokyo (Ghahremanloo et al., 2021).

In addition, the nighttime light (NTL) has changed during the COVID-19 lockdowns in many countries (Jechow and Hölker, 2020). NTL data is a new generation of remote sensing data that measures the total amount of light produced at night. This data can be used in different types of businesses like aviation and airlines to keep an eye on presence, improvement, and the consequences of natural and civil unrest and economic recovery in a short time (Hudecheck et al., 2020). In addition to interfering with clouds, sun and moonlight, NTLs can detect artificial light, industrial premises, and roads with a maximum resolution of 750 km (Elvidge et al., 1997; NOAA, 2015). It can also be used instead of low accuracy data to determine when and where industry-related activities are set to change. NTL is being detected and measured by several satellites. The most advanced OLS sensor on the American satellite DMSP has been collecting data since 1992 ~ 2012, which includes time series datasets, calibrated luminosity datasets, daily and monthly data sets. Later, the Suomi NPP satellite was developed by the National Oceanic and Atmospheric Administration (NOAA) and NASA which is equipped with VIIRS (Visible Infrared Imaging Radiometer Suite) instrument, whose data can be retrieved from 2012 until present in order to capture the night light. Study on NTL by VIIRS data in China showed a large decrease in economic activities which was caused by COVID-19 outbreak (Hudecheck et al., 2020). The results of studying NTL changes in the period of one month before and after the date of lockdown, have shown that Asian cities had the most NTL reduction. In particular, the monthly average NTL in Mumbai, India, has decreased by nearly 20% compared to the previous month. However, no significant reduction in NTL was observed in European cities. African cities have also experienced sustainment NTL change. Moreover, the results have shown that the urban centers have become darker than the suburbs (Xu et al., 2021).

Liu et al. (2020) have examined spatiotemporal changes of NTL and air quality index before and during the epidemic in China. This study has divided NTL into three categories: residential area, transportation, and commercial area. The results have shown a decrease in NTL which belongs to commercial centers, an increase in NTL which belongs to residential areas and a stability in the NTL related to transportation. Bustamante-Calabria et al. (2021) have studied the NTL changes by using VIIRS data in Granda, Spain. A considerable reduction has been observed which is because of both the reduction of light emission from the city and the reduction of human aerosol content in the atmosphere. Zheng et al. (2021) have studied the changes in spatial and temporal of NTL by VIIRS images and air pollutants during the COVID-19 lockdown in Wuhan. As a result of fewer human activities, the radiance of NTL reduced in eight districts, largely in the city center, but increased in the five neighboring districts as a result of people staying at home. In addition, they found a positive correlation between SO_2, NO_2, CO, and particulate matter, but O_3 did not have the same correlation. There are some studies which have shown the correlation between NO_2 and NTL. In a study by Toenges-Schull et al. (2006), a correlation coefficient of 0.79 has been reported between the global NTL (NTL) images and NO_x emissions which has been estimated by the EDGAR inventories. In addition, Zheng et al. (2019) have reported a positive correlation between NO_2 data from TROPOMI sensor and NTL data from VIIRS sensor. These previous studies have analyzed NTL changes around the world but a distinctive study in Iran does not exist.

Iran, like the other countries in the world, set lockdowns in 2020, with the two most crucial times being the beginning of spring, i.e., March and April because of the transportation restriction during Nowruz Holiday (20 March until 11 April) and the beginning of autumn (14 October until 13 November), which i.e., October and November because of the schools and universities close. In this study, by extracting the NO_2 column density value of TROPOMI sensor product which belongs to Sentinel-5p satellite, we investigated the annual and monthly change of NO_2 emission during the years 2019, 2020, and 2021 on the national scale of Iran. For the better evaluation of NO_2 pollutant changes, we have used NTL data of VIIRS explore as an approximate measure of human activities dynamics and for the first time, the relationship between NO_2 emission and NTL is quantified over Iran.

2. Materials and Methods

2.1. Study Area

Iran is located at 44º ~ 64º eastern longitude and 25º ~ 40º northern latitude. Area of Iran is 1.648 million km² and the population is estimated more than 85 million people in the year 2021 according to UN data. The study is concentrated on crowded and industrial cities such as Tehran, Isfahan, Mashhad, Shiraz, Qom, Sari, Bandar Abbas, Bushehr, Ahvaz, Tabriz, Zahedan, Yazd, Kerman, Kermanshah. Tehran is between the Alborz mountains range and the Persian Plateau with an area of 1,300 square kilometers and a population of 9,259,009 in 2021. Mashhad has cold and dry weather and has first rank in tourism among Iranian cities because of Imam Reza shrine. Isfahan is the third most populous metropolis in Iran after Tehran and Mashhad with a population of 2,177,000 in 2021. Iranian aircraft companies, Mobarakeh Steel, Isfahan Oil Refinery, and Isfahan Steel Company are active industries in Isfahan. Tabriz is the largest economic hub of Azerbaijan region in Iran and the largest metropolis of Iran after Tehran. The climate of Tabriz is dry steppe with hot and dry summers and cold winters. Shiraz is the fifth most populous city in Iran with the population of 1,566,000. Shiraz, with its temperate climate in the spring, hosts countless Nowruz travelers. Qom is the religious capital of Iran and has a warm and semi-arid climate. Kerman is one of the

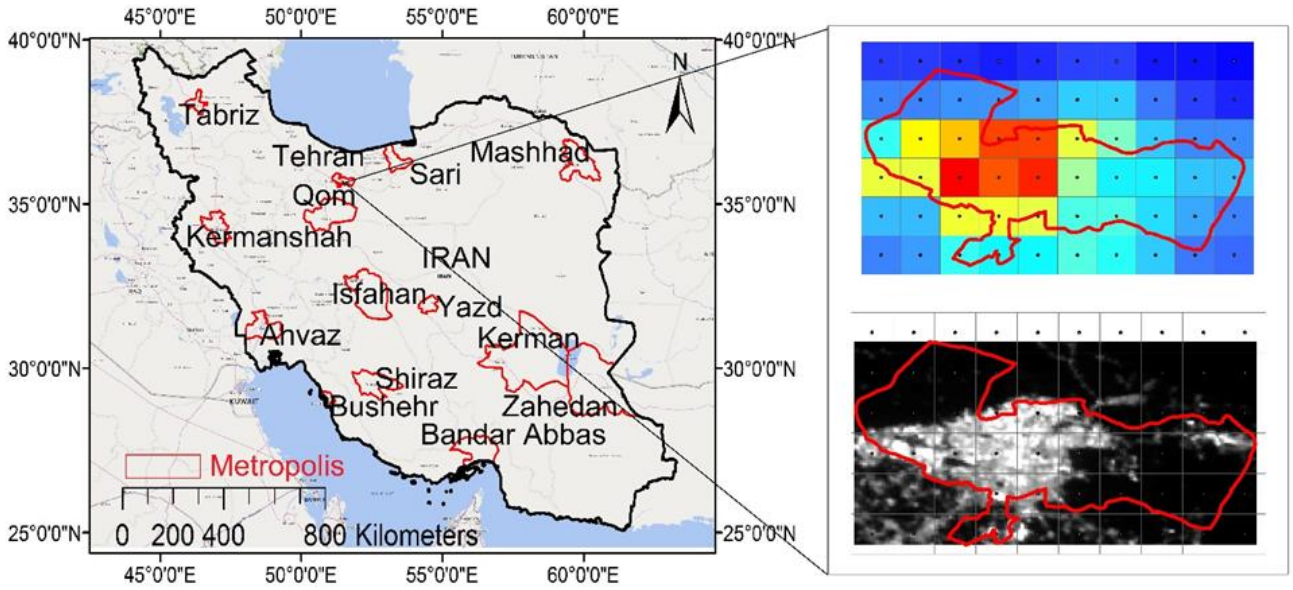

Figure 1. The study area with a fishnet polygons and points over Tehran metropolis (TROPOMI data in top and VIIRS data in down).

most important tourism centers in Iran due to its special historical, geographical, and cultural location and hosts a large number of domestic and foreign tourists every year. Bushehr is a seaport city in southwestern Iran. Bandar Abbas is the largest seaport of Iran with humid weather which is located in southern Iran. Ahvaz is the eighth most populous city in Iran. Ahvaz after Tehran and Isfahan has been identified as one of the most polluted cities of Iran. Kermanshah is located in western Iran and has an area of 95.97 km^2 and population of 1,046,604. Zahedan is the capital of Sistan and Baluchestan province and its climate is hot and dry. Large industries such as textile carpets, steel and iron ores, coal mines, tile factories and food industries are located in Yazd and About 53% of electricity consumption spends in the stone industry. Sari is located in northern Iran and is one of the most populous cities in north of Iran. The location of 14 metropolises of Iran was indicated in Figure 1.

2.2. Remotely Sensed Data

TROPOMI NO_2 columns density are obtained by spectra of UV and VIS in the 405 ~ 465 nm wavelength range (Van Geffen et al., 2019) and measured in a swath width of 3.5 × 5.5 km. The DOAS method is used to calculate the total NO_2 slant column density from the Level 1b UV–VIS radiance and solar irradiance spectra (Platt and Stutz, 2008).

Daily NO_2 column density images have been projected and selected the tropospheric band in SNAP (version 8) by Graph-Builder. Later the monthly mean of NO_2 tropospheric column density has been calculated by Level-3 binning function. Values of each pixel have been extracted in GIS by Fishnet function and Extract values by point. The values of metropolises have been extracted for all months of 2019, 2020 and 2021 and have been gotten average of all pixels related to each metropolis. The values have multiplied by 6.02214×10^{19} to convert the unit of mol/m^2 to mol/cm^2 (Eskes et al., 2020).

Monthly NPP-VIIRS data were obtained from https://eogdata.mines.edu/products/vnl/ for the years of 2019 and 2020. Whereas VIIRS data is not available completely for 2021, so, we just applied VIIRS data for 2019 and 2020. In this research the "vcmsl" version of NTL data was used, that includes the stray-light corrected data (Elvidge et al., 2021). Paired Sample *t*-test and correlation coefficient were used for statistical analysis of NO_2 and NTL variation in metropolises of Iran. Figure 2 shows the flow chart of research process.

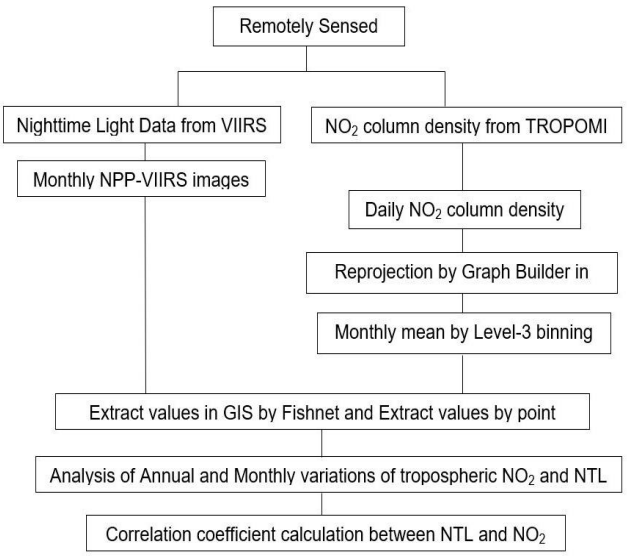

Figure 2. Flow chart of research.

3. Results and Discussion

3.1. The Variation of NO_2 Tropospheric Column Density

Results have provided annual and monthly outputs for all 12 months of the year which our analysis is more on lockdown months in Iran (March-April-October-November). In this research we have considered the years 2019, 2020, and 2021 because there weren't complete 2018 TROPOMI data for Iran.

Tehran as the capital of Iran has shown the highest annual mean reduction (30%) of NO_2 concentration in 2020 compared to 2019. In 2021, the next year after lockdown, Tehran has shown a significant increase (55%) of NO_2 than 2020 and a 35% increase compared to 2019 that means NO_2 concentration have had an upward annual trend which has been restrained by 2020 closures. The amount of NO_2 concentration changed from 24.3 (mol/cm^2) in 2019 to 16.9 (mol/cm^2) in 2020 and 36.9 (mol/cm^2) in 2021.

The highest annual increased change of NO_2 value has been observed in Mashhad (18%) and Yazd (11%) in 2020 compared to 2019 while the changes in the other cities were under 10%. Bushehr, Zahedan, Isfahan, Shiraz and Kerman haven't experienced the annual average change in NO_2 concentration in 2020.

Mashhad has shown an increase from 1.9 (mol/cm^2) in 2019 to 2.3 (mol/cm^2) in 2020 and to 3 (mol/cm^2) in 2021. The amount of NO_2 concentration has boosted 18% higher in 2020 than 2019 and 37% higher in 2021 than 2019 which has shown an upward trend of NO_2 emission in Mashhad and lockdowns were not effective in 2020. Yazd has had an annual upward trend. The NO_2 concentration has increased 11% in 2020 and 27% in 2021 compare to 2019. Bandar Abbas like Mashhad and Yazd has shown a 7% increase in 2020 and a 28% increase in 2021 compare to 2019.

Zahedan has shown 25% annual increase of NO_2 in 2021 than 2019 and 2020. The amount of NO_2 concentration has changed from 0.6 (mol/cm^2) in 2019 and 2020 to 0.8 (mol/cm^2) in 2021. Although Kerman haven't had any changes in NO_2 concentration in 2020 than 2019, the concentration increased from 0.9 (mol/cm^2) to 1.1 (mol/cm^2) in 2021. In addition, Isfahan have shown 22% increase in NO_2 in 2020. Shiraz has had 35% increase in 2021 compared to 2019 and 2020, and the amount of NO_2 has changed from 1.9 (mol/cm^2) to 2.9 (mol/cm^2). Bushehr Like Zahedan, Shiraz, Isfahan and Kerman, have shown an increase (60%) in 2021 compared to 2019 and 2020 and the amount of NO_2 has changed from 0.6 (mol/cm^2) to 1.5 (mol/cm^2).

Tabriz has showed 45% increase of NO_2 concentration in 2021 than 2019 and 2020 which has changed from 2.7 and 2.8 (mol/cm^2) to 5 (mol/cm^2). Sari has not experienced a significant annual change in 2020 and 2021. The amount of NO_2 concentration decreased from 2.2 (mol/cm^2) in 2019 to 2 (mol/cm^2) in 2020 and increased to 2.4 (mol/cm^2) in 2021. NO_2 concentration has increased 5% in 2020 and 15% in 2021 in Qom which changed from 4.1 (mol/cm^2) in 2019 to 4.3 in 2020 (mol/cm^2) and to 4.8 (mol/cm^2) in 2021.

Kermanshah have had an increase in 2020 (7%) and 2021 (34%) compared to 2019 which values have changed from 1.5 (mol/cm^2) in 2019 and 1.6 (mol/cm^2) in 2020 to 2.4 (mol/cm^2) in 2021. Ahvaz has shown 8% increase in NO_2 in 2020 and 14% increase in 2021 than 2019. The values have from 2.6 (mol/cm^2) to 2.4 (mol/cm^2) and 3 (mol/cm^2). Generally, the results showed all the metropolises had an annual and monthly increase in NO_2 concentration in 2021, the year after lockdown.

Table 1 shows the annual mean change of NO_2 in the metropolises. According to the annual mean of tropospheric NO_2, Tehran is the most polluted metropolis, whereas Bushehr and Zahedan are the least polluted cities of Iran.

Majority of cities has shown an annual growth or a low drop in 2020 compared to 2019, however the amount of monthly NO_2 concentration has decreased in April and November which has been issued lockdowns in Iran. Iranian New Year, Nowruz, is at the beginning of spring which is accompanied by high traffic of tourist trips, nature tour and visiting relatives. Iranian New Year lockdown started in 20 March until 11 April, 2020 in whole of Iran. Among 14 metropolises, 10 metropolises have shown an increase of NO_2 in March in both 2020 (+6 ~ 24%) and 2021 (+9 ~ 59%) compared to 2019 which have shown a higher percent increase in 2021. Sari has shown a de-

Table 1. Annual Mean Variation of NO_2 Values over the Metropolises of Iran Due to COVID 19 Lockdown

Metropolises	NO_2 value (2019) (mol/cm^2)	NO_2 value (2020) (mol/cm^2)	NO_2 value (2021) (mol/cm^2)	Change (%)	*P* value
Tehran	24.3	16.9	36.9	–30	0.00
Sari	2.2	2.0	2.4	–10	0.00
Ahvaz	2.6	2.4	3.0	–8	0.00
Isfahan	2.2	2.2	2.8	-	0.00
Shiraz	1.9	1.9	2.9	-	0.71
Bandar Abbas	1.4	1.5	2.2	+7	0.00
Kermanshah	1.5	1.6	2.4	+7	0.00
Tabriz	2.7	2.8	5.0	+4	0.00
Qom	4.1	4.3	4.8	+5	0.00
Kerman	0.9	0.9	1.1	-	0.00
Yazd	2.5	2.8	3.4	+11	0.00
Mashhad	1.9	2.3	3.0	+18	0.00
Zahedan	0.6	0.6	0.8	-	0.00
Bushehr	0.6	0.6	1.5	-	0.06

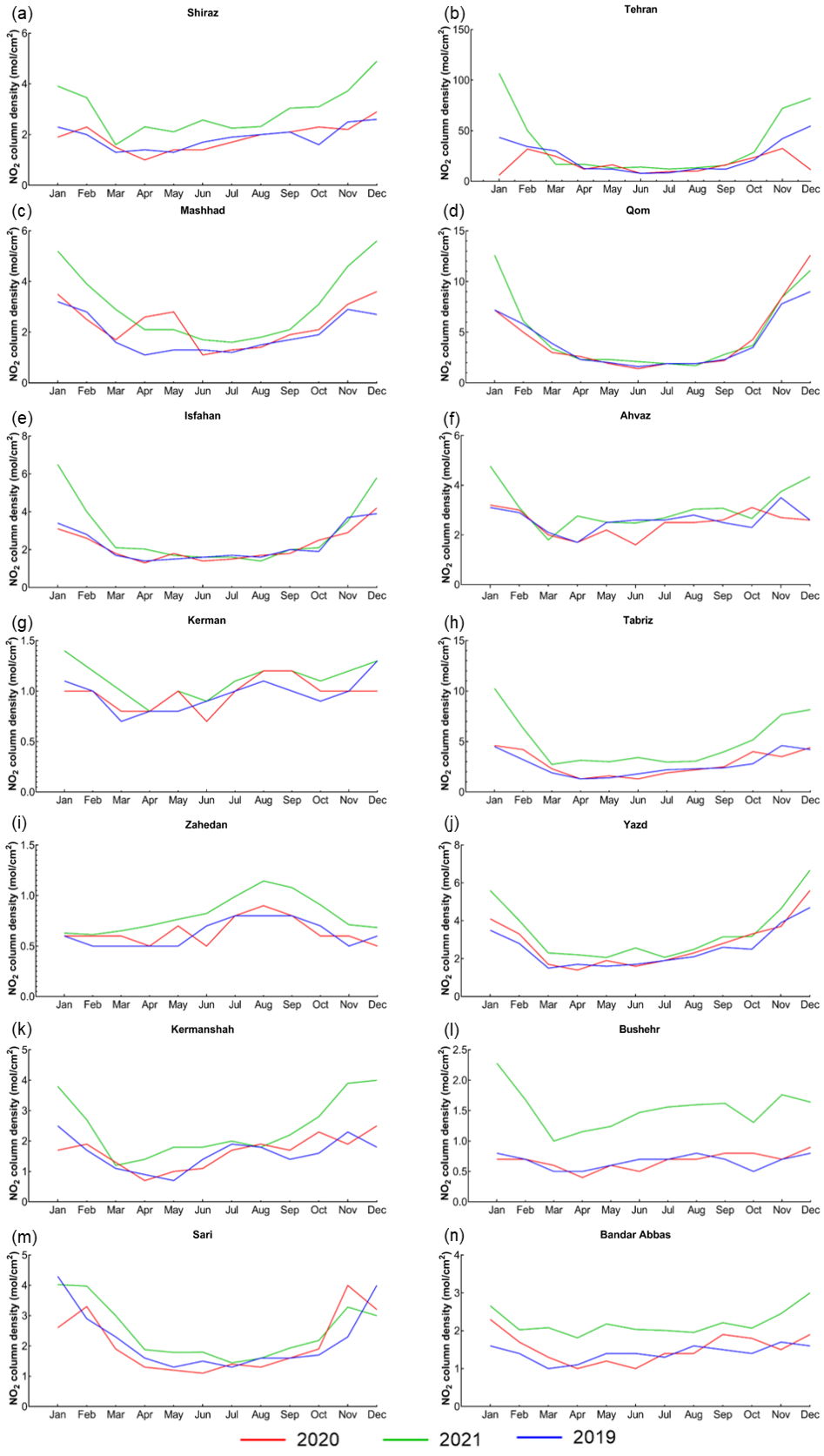

Figure 3. The monthly variation of NO_2 concentration in the metropolises of Iran.

crease in 2020 but an increase in 2021. Tehran, Ahvaz and Qom have shown a decrease in both 2020 and 2021. Most the metropolises have had decrease of NO_2 in April 2020 (–5 ~ 29%) compare to April 2019. Ahvaz, Kerman, Tabriz and Zahedan haven't experienced change in April, 2020. All the metropolises have shown an increase of NO_2 in April 2021 (+12 ~ 59%) compare to 2019 and 2020. By contrast, Qom has shown an increase in April, 2020 and a decrease in 2021.

The other lockdown related to starting autumn and the second wave of epidemic in Iran, was implemented in 14 October, 2020 and it took around a month. Regarding autumn lockdowns, most the metropolises have shown an increase in October (+10 ~ 31%) and a reduction in November 2020 (–6 ~ 24%). In the next year, most of the metropolises have shown a significantly increase in October (+6 ~ 62%) and November (+8 ~ 59%) compare to 2019. Mashhad, Qom, and Sari have shown an increase in October and November of 2020 and 2021 compared to that of 2019. Figure 3 shows the NO_2 monthly change for the metropolises.

Lockdown has been accompanied by a decrease in traffic volume. According to Iran Road Management Center, the number of vehicles at city entrances has decreased in lockdown period. In this research according to data availability, five metropolises including Tehran, Mashhad, Isfahan, Ahvaz and Shiraz were analyzed in the study months (March, April, October, and November). The amount of vehicles has reduced in March (45 ~ 61%), April (29 ~ 46%), October (4 ~ 15%), and November (9 ~ 29%) in these metropolises. The result has shown that number of vehicles reduced by about 50% in Nowruz lockdown related months but has shown under 30% vehicle reduction in fall lockdown, 2020. Table 2 shows the changes in the number of vehicles at entrance of metropolises in the months related to the lockdown.

During the lockdown, NO_2 emissions in Tehran, Sari, and Shiraz were probably reduced as a result of reducing vehicles and traffic volume in these cities and suburbs. High traffic cities such as London (71.1 ~ 80.8 %), Paris (65.7 ~ 79.8 %) and Milan (8.6 ~ 42.4%) have been showed the same descending trend for NO_2 levels during COVID-19 lockdowns (Collivignarelli et al., 2021). In a study on air pollution changes by OMI data in Iran during one month (March to April), which has issued Nowruz lockdown, a reduction has shown in NO_2 in Tehran and Iran (Broomandi et al., 2020). The result has had similarity to the result of NO_2 reduction in Tehran in our study.

In our findings, Mashhad has shown around 50 and 30% reduction of vehicles in March and April, respectively, while the NO_2 concentrations has been increased in these months. Although the reduction in traffic volume was observed, most the cities of Iran have not shown an effective reduction in tropospheric NO_2 column density. Isfahan, Ahvaz and Mashhad have had a decrease in the number of vehicles but they have not shown a significant decrease in NO_2 concentration, which shows that transportation is not the main source of NO_2 emission in these cities. In cities such as Tabriz and Bandar Abbas where the contribution of mobile sources in air pollution is higher than stationary sources, the increase in nitrogen dioxide after traffic

Table 2. Number of Vehicles at the Entrance of Five Metropolises in 2019 and 2020

Mashhad (Average of three main roads)	Number of vehicles in 2019	Number of vehicles in 2020	Reduction (%)
March	30,760	17,182	–45
April	26,777	18,428	–32
October	28,164	25,255	–11
November	24,354	19,954	–19
Tehran (Average of three main roads)			
March	40,357	20,924	–49
April	43,389	23,572	–46
October	40,657	39,218	–4
November	30,659	27,939	–9
Shiraz (main road)			
March	35,391	19,634	–45
April	35,239	20,781	–42
October	36,995	33,413	–10
November	33,607	23,506	–31
Isfahan (Average of two main roads)			
March	13,325	5,317	–61
April	10,134	6,110	–40
October	11,321	4,669	–59
November	9,570	4,127	–57
Ahvaz (Main east road)			
March	17,972	9,551	–47
April	16,315	11,610	–29
October	16,586	14,215	–15
November	14,620	11,453	–22

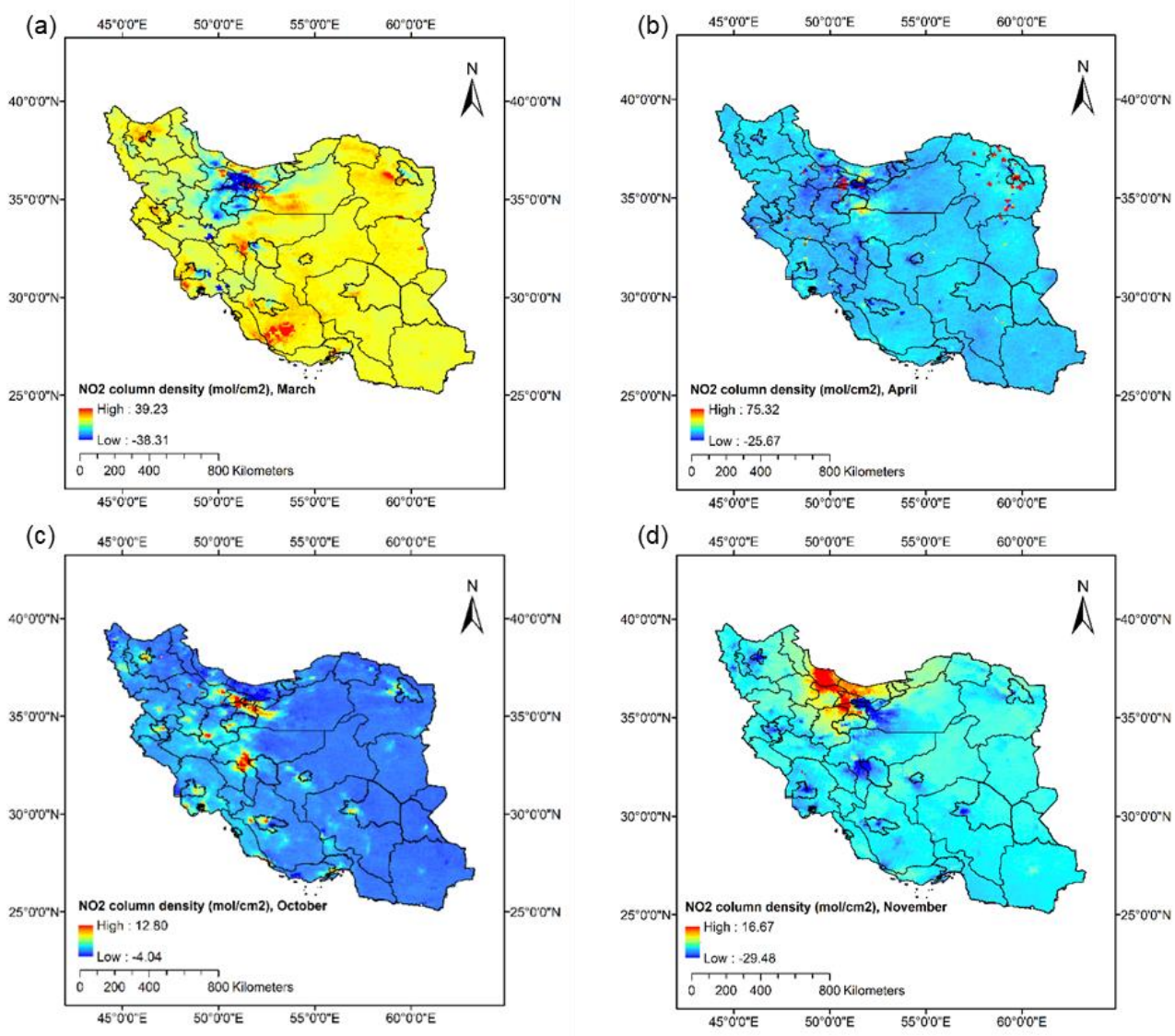

Figure 4. NO_2 column density differences in March, April, October, and November between 2019 and 2020.

restrictions is due to the fact that most of the transport volume was done in suburb roads before CORONA lockdown. But in during CORONA restriction, the volume of intra-city transport has been increased significantly. The urban managers in Isfahan mentioned that the contribution of stationary sources is more than the mobile sources, so the reduction traffic volume has not shown reduction in air pollution in 2020 than that of 2019. The study on the states of America such as New York, Illinois, Florida, Texas and California, showed a decrease in NO_2 affected by lockdown and reduction of traffic. Although in New York and Florida which traffic is the main pollution source, air quality improved significantly, in Illinois, Texas and California which the other pollution sources are dominant, the reduction of air pollution was not effective (Elshorbany et al., 2021).

In order to substantiate our findings, we gathered the air quality station (AQS) data from department of environment Islamic republic of Iran. It is important to mention that only six metropolises' AQS data is accessed to us for this analysis (Theran, Mashhad, Shiraz, Isfahan, Ahvaz, and Bandar Abbas). The monthly correlation between the values obtained from Sentinel 5p images and the values obtained from all cities' AQS data was 0.63 and 0.56 in 2019 and in 2020, respectively.

Figure 4 shows variation of NO_2 column density in March, April, October and November. The NO_2 change map is obtained by diffrencing maps between 2020 and 2019. After subtraction, the positive values show increasing NO_2 of 2020 emission and the negative values show a redution of NO_2 emission. Most area of the country have shown an increase in March except for Tehran and Qom provinces. The NO_2 distribution maps have shown more reduction in April in comparison to March. In October and November, most regions have shown a reduction in atmospheric NO_2.

Table 3. Annual Mean NTL Variation in the Metropolises

	NTL 2019	NTL 2020	Changes (%)	*P* value		NTL 2019	NTL 2020	Changes (%)	*P* value
Tehran	33.16	32.48	–3	0.006	Tabriz	21.63	23.36	+8	0.003
Sari	12.49	11.86	–6	0.116	Qom	26.79	25.28	–6	0.008
Ahvaz	33.27	27.46	–18	0.003	Kerman	23.65	24.00	–2	0.582
Esfahan	24.66	24.05	–3	0.026	Yazd	17.14	17.15	0	0.964
Shiraz	21.26	20.79	–3	0.326	Mashhad	26.76	27.82	+4	0.003
Bandar Abbas	38.53	26.97	–31	0.019	Zahedan	14.13	14.83	+4	0.044
Kermanshah	19.34	18.49	–5	0.015	Bushehr	16.22	16.85	+4	0.045

Table 4. Monthly NTL Changes in the Metropolises of Iran

November	NTL 2019	NTL 2020	Changes (%)	*P* value		NTL 2019	NTL 2020	Changes (%)	*P* value
Tehran	30.38	24.69	–19	0.000	Tabriz	22.06	21.88	–1	0.670
Sari	12.53	12.45	–1	0.919	Qom	24.11	19.51	–20	0.106
Ahvaz	28.09	29.37	–5	0.835	Kerman	23.59	21.00	–11	0.043
Esfahan	23.98	21.55	–11	0.002	Yazd	16.41	14.99	–9	0.086
Shiraz	21.40	20.05	–7	0.034	Mashhad	22.67	24.82	+9	0.015
Bandar Abbas	21.98	27.19	+20	0.274	Zahedan	14.11	12.30	–13	0.092
Kermanshah	18.53	16.28	–13	0.036	Bushehr	17.32	15.32	–12	0.027
April									
Tehran	36.01	31.95	–2	0.000	Tabriz	21.67	22.37	+4	0.121
Sari	11.42	12.25	–7	0.188	Qom	28.82	24.09	–17	0.170
Ahvaz	54.43	24.65	–55	0.053	Kerman	23.31	23.96	–3	0.001
Esfahan	26.84	23.71	–12	0.002	Yazd	17.62	16.67	–6	0.181
Shiraz	22.36	19.47	–13	0.019	Mashhad	23.50	28.88	+19	0.010
Bandar Abbas	52.90	27.89	–48	0.225	Zahedan	13.88	14.69	+6	0.012
Kermanshah	21.51	18.36	–15	0.058	Bushehr	16.38	15.27	–7	0.216
March									
Tehran	38.09	37.65	–2	0.661	Tabriz	21.35	22.64	–6	0.144
Sari	13.66	9.38	–32	0.237	Qom	31.08	29.32	–3	0.386
Ahvaz	36.43	25.86	–30	0.015	Kerman	26.34	24.71	–7	0.435
Esfahan	29.38	25.04	–15	0.002	Yazd	18.93	17.66	–7	0.100
Shiraz	24.77	20.34	–18	0.023	Mashhad	27.05	24.21	–11	0.020
Bandar Abbas	30.13	25.87	–15	0.366	Zahedan	13.55	13.83	+3	0.038
Kermanshah	22.95	19.16	–17	0.093	Bushehr	17.94	16.66	–8	0.256

Table 5. Correlation Coefficient between NTL and NO_2 Concentration

2019	*R*	2019	*R*	2020	*R*	2020	*R*
January	0.72	July	0.74	January	0.67	July	0.75
February	0.71	August	0.73	February	0.66	August	0.72
March	0.69	September	0.74	March	0.74	September	0.75
April	0.71	October	0.73	April	0.71	October	0.71
May	0.73	November	0.70	May	0.70	November	0.72
June	0.74	December	0.69	June	0.73	December	0.70

3.2. The Variation of Nighttime Light (NTL) Radiance

NTL data has been used to investigate the relationship between nitrogen dioxide and reduced human activities during the lockdown. The annual average of NTL showed a decrease in Bandar Abbas (31%), Ahvaz (18%) and the other metropolises (under 10% decrease) while Tabriz (8%), Mashhad (4%), Zahedan (4%), Bushehr (4%) and Kerman (2%) have shown an increase. Table 3 shows the annual mean changes of NTL in the metropolises.

Generally, most of the metropolises have shown an increase in NTL radiance in October and a reduction in March (2 ~ 32%), April (2 ~ 55%) and November (1 ~ 20%) especially in Tehran and Sari. Ahvaz has shown a significant reduction in March (30%) and April (55%) which have had the most NTL changes among all metropolises. Figure 5 shows the reduction of NTL in Ahvaz in April 2020 compared to April 2019. NTL radiance

have shown 19% growth in April and 9% growth in November in Mashhad. Furthermore, NTL radiance has increased in Zahedan in March (3%) and April (6%), and in Tabriz in April (4%), in Bandar Abbas in November (20%). Table 4 shows NTL changes in all metropolises with emphasis on March, April, and November.

Other places in the world have shown a similar reduction of NTL in 2020 during COVID-19 pandemic. The decrease in NTL was especially noticeable in Asian cities. As the decline of human activities, the NTL decreased in industrial regions in January and February compared to pre-pandemic (Hudecheck et al., 2020). The monthly average NTL in Mumbai, India decreased about 20% in 2020 due to lockdown (Xu et al., 2021). Increasing trend of NTL in Tabriz, Mashhad, Zahedan and Bushehr were observed in pixels that located in urban periphery. Spatial analysis of NTL variation in each city can help to better understanding of decrease or increase nighttime light in comercial or residential zones.

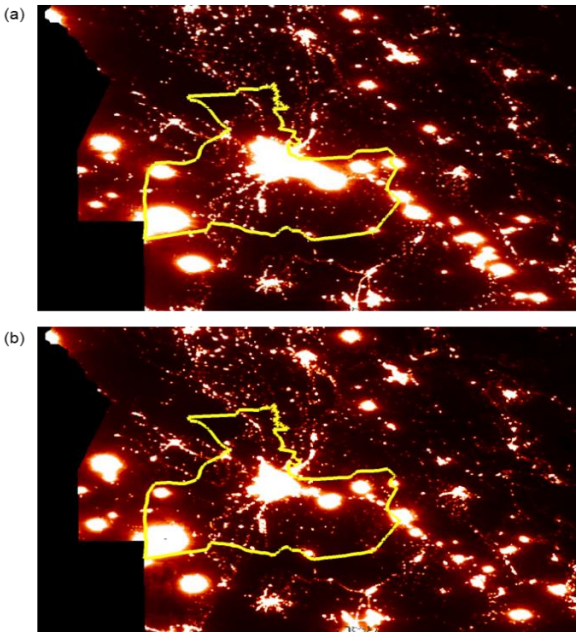

Figure 5. NTL image for Ahvaz Metropolis in April 2019 (a) and April 2020 (b).

3.3. The Relationship between Nighttime Light and NO_2

Night Day Band (NDB) images provide an important perspective of the large-scale effects of CORONA virus on the world, from the impacts of the pandemic on businesses and transportation networks to monitoring the gradual recovery of cities on the earth. So, for finding this relationship it is necessary to calculate the correlation between NO_2 as air quality and NDB as economic and transportation activities.

The correlation coefficient between NO_2 concentration and NTL was calculated for all metropolises in 24 months of 2019 and 2020, separately. Because of the large number of graphs, only four graphs of each year as the representative of each season have been shown in Figure 6. The range of R value is from 0.66 related to February 2020, to 0.75 related to July and September of 2020. Toenges-Schull et al. (2006) have indicated the correlation coefficient between NO_x concentrations and NTL is 0.79. The relationship between NO_x and NTL has shown very strong correlation in China (R^2 = 0.93) (Jiang et al., 2016). Table 5 shows the correlation coefficient between NO_2 concentration and NTL.

In several cities, such as Mashhad, Tehran, Sari, Ahvaz, Isfahan, and Tabriz, the annual mean of NTL and NO_2 concentrations follow a similar pattern. It means that the decreasing trend in NTL is associated to decreasing trend in NO_2 value. This finding emphasizes the decreasing in human activities such as transportation and industrial activities had main role in air quality in majority of metropolises. But in Zahedan and Bushehr which haven't showed any changes in NO_2 concentration, nighttime light also showed just a 4% decrease. Bushehr is an industrial city and many oil and gas industries are located there, so decreasing transportation did not have a significant effect on air quality in this area. Bandar Abbas city showed different behavior compared to other cities, it had a 4% increase in NO_2 levels but showed 31% decrease in nighttime light radiance. The results have not showed any changes in Yazd nighttime light radiance but showed a 11% decrease in NO_2 concentration in the study time.

4. Conclusions

In this research, the TROPOMI air pollutant data and Suomi NPP nighttime light data was used for investigation of NO_2 column density variation in COVID-19 pandemic in 14 metropolices in Iran. The NO_2 concentration reduced in April and November of 2020 which issued lockdown in the majority of metropolises. In some metropolises the changes were opposite or has been remained unchanged. The results have shown a significant annual and monthly increase in NO_2 concentration in 2021 compared to 2019 and 2020 which can explain an upward trend of NO_2 emission in Iran. Annual NTL reduced but it was under 10% in the most the metropolises. Ahvaz, Sari and Theran showed most significant reduction in the months of lockdown. Prohibition of transportation and reducing industrial activities probably are the reasons of reduction in NTL. NO_2 column density and NTL radiance showed a correlation (0.66 ~ 0.75) in the months of 2019 and 2020 which R value is the same as previous studies (Toenges-Schull et al., 2006; Jiang et al., 2016). Mashhad, Tehran, Sari, Ahvaz, Isfahan, and Tabriz follow a similar pattern in NO_2 levels and NTL changes. The reduction of number of vehicles in 2020 due to COVID-19 pandemic, determined that the amount of NO_2 is not so related to traffic, the number of vehicles and tourism industry in some metropolises of Iran. In the other hand, mobile sources of NO_2 emission inside the stationary sources has important role in air quality in metropolises in our country. The effect of industries as stationary sources and other human activities must be studied. We recommend, the effect of industries as stationary sources and other human activities will be considered before making any policy to reduce air pollution in metropolises. So, we can use this result in future researches in about air quality and urbanization.

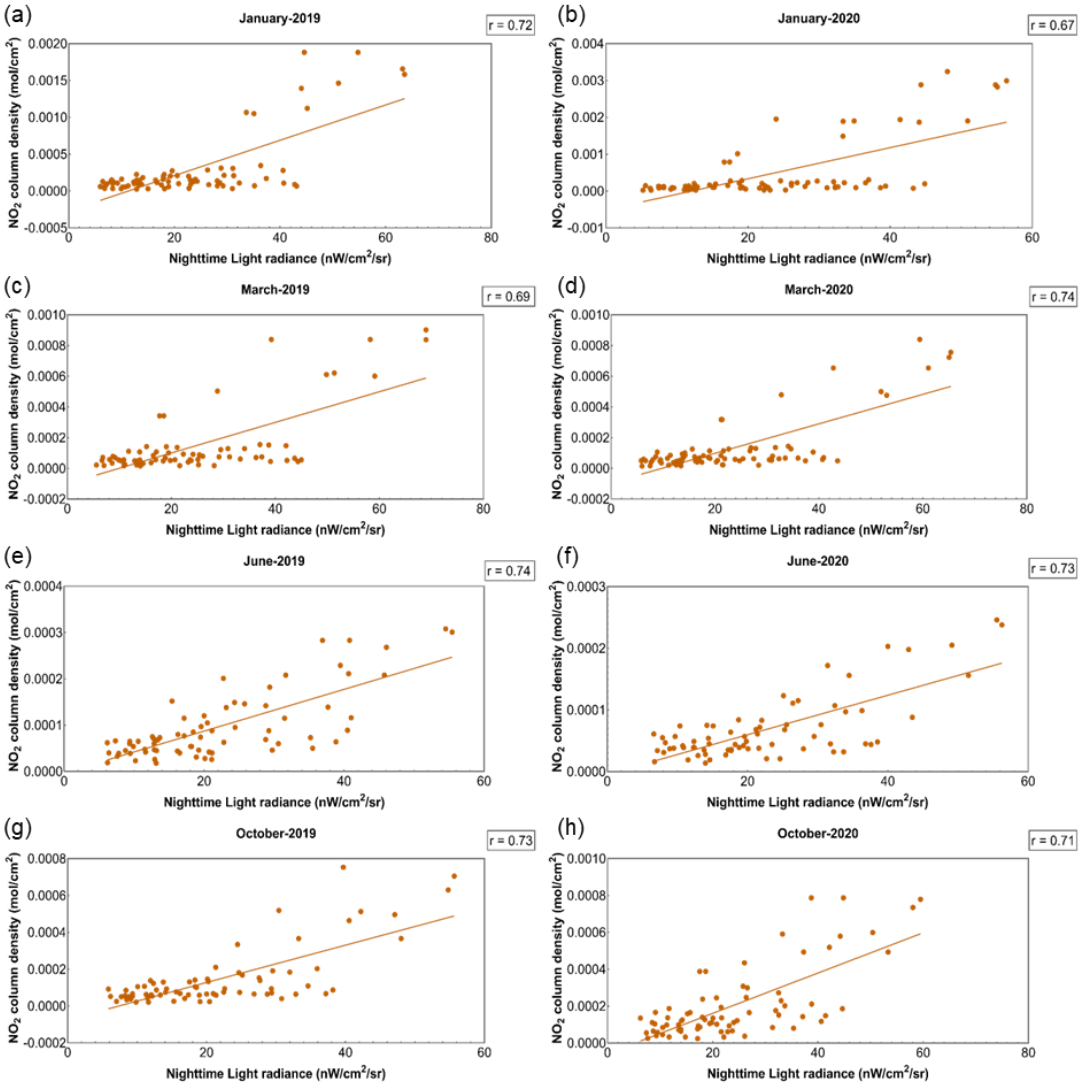

Figure 6. The correlation between NO_2 concentrations and NTL.

Acknowledgements. The authors acknowledge the European Space Agency, United States National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration and the Netherlands Space Office for providing dataset of research. This Study was supported by Iran National Science Foundation (grant number: 9901 2652).

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