JAEHR
Journal of Advances in Environmental Health Research
J Adv Environ Health Res 2026;14(1):42-48. doi:10.34172/jaehr.1437
http://jaehr.muk.ac.ir

Original Article

Air Quality Assessment Before and During COVID-19 Using Sentinel-5P Satellite and Ground Station Data in Ahvaz, Bushehr, and Bandar Abbas

Mokhtar Kavoosi[1*], Hossein Mohammed Asgari[2]

[1]Department of Environment, Faculty of Natural Resources, Khorramshahr University of Marine Sciences and Technology, Khorramshahr, Iran
[2]Department of Environment, Khorramshahr University of Marine Sciences and Technology, Khorramshahr, Iran

Article history:
Received: July 8, 2025
Revised: August 22, 2025
Accepted: August 31, 2025
ePublished: March 29, 2026

***Corresponding author:**
Mokhtar Kavoosi,
Email: Kavoosi m.19@gmail.com

Abstract

Introduction: The current study investigated temporal variations in six air pollutants: $PM_{2.5}$, PM_{10}, SO_2, NO_3, O_3, CO in the cities of Ahvaz, Bandar Abbas, and Bushehr during 2018–2022, with a focus on the pre- and during-COVID-19 periods.

Methods: SO_2, NO_2, CO, and O_3 data were obtained from the TROPOMI sensor onboard Sentinel-5P (7 × 7 km resolution) using Google Earth Engine (GEE). $PM_{2.5}$ and PM_{10} concentrations were estimated from Aerosol Optical Depth (AOD) data derived from MODIS MCD19A2 (1 km resolution) using a regression model calibrated with ground-based monitoring data. Records with > 30% cloud cover or missing values were excluded, and monthly and annual means were calculated. Satellite observations were bias-corrected via linear regression against ground-based data and downscaled using bilinear interpolation. Inter-city comparisons were conducted using independent t-tests, while pre- vs. during-pandemic differences were assessed using paired t-tests.

Results: Ahvaz recorded the highest mean concentrations of $PM_{2.5}$, PM_{10}, SO_2, and CO. In most cases, pollutant concentrations were higher before the COVID-19 pandemic, particularly for $PM_{2.5}$ and PM_{10} in Ahvaz and Bushehr ($P < 0.05$). Correlations between satellite-derived and ground-based measurements of $PM_{2.5}$ and PM_{10} were strong and statistically significant in Ahvaz and Bushehr, but weak or non-significant for SO_2, NO_2, and O_3.

Conclusion: The integration of satellite observations with ground-based monitoring systems provides a reliable and cost-efficient approach to air quality assessment. Reductions in certain pollutants, especially particulate matter, were associated with decreased industrial activity and transportation during the pandemic.

Keywords: Air quality, Sentinel-5 satellite, Air pollutants, COVID-19

Please cite this article as follows: Kavoosi M, Asgari HM. Air quality assessment before and during COVID-19 using sentinel-5P satellite and ground station data in Ahvaz, Bushehr, and Bandar Abbas. J Adv Environ Health Res 2026;14(1):42-48. doi:10.34172/jaehr.1437

Introduction

The COVID-19 pandemic, with its unprecedented global reduction in human activities such as industrial production, transportation, and social gatherings, provided a rare opportunity to study the direct impact of anthropogenic activity on urban air quality.[1,2] This "natural experiment" allows for a clearer understanding of how human-induced emissions influence the concentrations of key pollutants, including particulate matter ($PM_{2.5}$, PM_{10}), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3). Monitoring and assessing air quality in such fields requires strong, high-resolution data.[3,4] Although ground-based monitoring stations provide accurate, site-specific measurements of pollutant concentrations, they are often limited in spatial coverage, particularly in large urban or industrial areas. To overcome this problem, satellite remote sensing has emerged as a complementary approach, offering consistent, broad-scale observations of atmospheric pollutants. Sentinel-5P, launched by the European Space Agency, is particularly valuable as it delivers daily high-resolution data for multiple pollutants across wide geographic regions. The integration of satellite-derived observations with in situ measurements from ground stations allows for more comprehensive monitoring, validation of data, and improved understanding of spatial and temporal pollutant patterns. Previous studies have demonstrated that combining these two data sources can enhance the accuracy of air quality assessments and help identify pollution hotspots, trends, and anomalies, especially during periods of atypical human activity such as pandemic lockdowns. For instance, in 2022 Shikwambana et al analyzed changes in SO_2 and NO_2 levels in South Africa from December 2018 to September 2019, illustrating that wind patterns influenced pollutant dispersion—reducing levels in summer and increasing them in winter.[5] Also, in 2019 Schneising et al developed an operational algorithm to simultaneously retrieve carbon monoxide (CO) and methane (CH_4) from Sentinel-5 TROPOMI data using the WFM-DOAS method. Their results showed random errors of 5.7% (CO) and 0.8% (CH_4), and systematic errors of 1.2% and 0.2%, respectively. The satellite data accurately captured natural variations, with correlation coefficients ranging from R = 0.91 to 0.97 based on daily averages.[6] Pham et al (2024) examined the impact of the COVID-19 pandemic on air quality in Ho Chi Minh City, Vietnam, using Sentinel-5P and MODIS satellite data. The results indicated a significant decrease in the concentrations of pollutants such as NO_2, SO_2, and $PM_{2.5}$ during the lockdown compared to the same period in previous years.[7] Singh et al (2025) identified air pollution hotspots at the micro level and analyzed changes in air quality in the National Capital Region of India using Sentinel-5P satellite data. The results showed significant variations in pollutant concentrations during the COVID-19 pandemic.[8] Amiri et al investigated air pollution changes in Ahvaz, Iran, using Sentinel-5P satellite data and the Google Earth Engine platform. The findings indicated a notable reduction in the concentrations of pollutants such as CO, NO_2, SO_2, and HCHO during the COVID-19 pandemic.[9]

Despite these advancements, significant gaps remain in the literature. In Iran, few studies have systematically combined satellite and ground-based data to evaluate air quality changes across multiple coastal cities. Most existing research focuses on single pollutants, limited temporal spans, or individual cities, leaving a critical need for integrated, multi-parameter, spatially explicit analyses. Furthermore, limited attention has been given to understanding the differential impact of reduced anthropogenic activity on various pollutants and across diverse urban and coastal contexts. Identifying these patterns is essential not only for scientific understanding but also for informing environmental management, urban planning, and public health policies. The present study dealt with these gaps by investigating the changes in concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3 in Ahvaz, Bushehr, and Bandar Abbas before and during the COVID-19 pandemic. This research specifically aimed to (1) analyze spatial and temporal variations in pollutant concentrations, (2) validate satellite-derived measurements against ground-based observations, and (3) identify cities and regions most affected by air pollution.

By focusing on multiple pollutants and integrating high-resolution satellite data with ground-based measurements, the study provided a comprehensive assessment of urban air quality in the context of significant reductions in human activity. Moreover, the research highlights the utility of Sentinel-5P imagery in monitoring air quality across heterogeneous urban environments and emphasizes the indispensable role of ground-based stations in data validation and local-scale analysis. Ultimately, this study contributed to a more coherent understanding of the relationship between human activities and air pollution, addressed a clear research gap in the Iranian coastal context, and offers practical insights for evidence-based interventions to mitigate pollution and improve public health. By elucidating how reductions in anthropogenic emissions during the COVID-19 pandemic affected multiple air quality parameters, this research reinforced the importance of integrated monitoring strategies and data-driven policies for sustainable urban environmental management.

Materials and Methods

Study area

In this study, satellite data were obtained from the Sentinel-5P TROPOMI (Tropospheric Monitoring Instrument) via the Google Earth Engine (GEE) platform, including daily Level-3 datasets for six air pollutants ($PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3) with a native spatial resolution of approximately 7 × 7 km at nadir. Ground-based measurements from fixed monitoring stations in Ahvaz, Bushehr, and Bandar Abbas were used for validation. Daily satellite data from January 2018 to December 2022 were processed and aggregated to monthly and annual averages for comparative analyses. The "before COVID-19" period was defined as January 2018 to February 2020, and the "during COVID-19" period as March 2020 to December 2022. All the satellite data were pre-processed in GEE, including cloud masking and spatial subsetting to the study area. Pollutant values were extracted over each city's boundaries, matched with the corresponding ground station observations, and prepared for statistical analysis. The map of the study area has been presented in Figure 1.

Data Analysis

In this study, satellite data were obtained from the Sentinel-5P TROPOMI (Tropospheric Monitoring Instrument) via the Google Earth Engine (GEE) platform. The products used included daily Level-3 datasets for SO_2, NO_2, CO, and O_3 (total column density in mol/m^2) with a native spatial resolution of approximately 7 × 7 km at nadir. Since $PM_{2.5}$ and PM_{10} are not directly measured by Sentinel-5P, Aerosol Optical Depth (AOD) data were retrieved from the MODIS product (MCD19A2) at 1 km resolution and converted to PM concentrations using a multiple linear regression model calibrated with ground-based measurements from monitoring stations in Ahvaz, Bushehr, and Bandar Abbas.

Figure 1. Location of the stations studied: Ahvaz, Bushehr and Bandar Abbas

The satellite datasets had a daily temporal resolution covering the period from January 2018 to December 2022. For statistical analyses, daily values were aggregated to monthly and annual means. The "before COVID-19" period was defined as January 2018 to February 2020, and the "during COVID-19" period as March 2020 to December 2022. Data pre-processing in GEE included cloud masking (removing pixels with more than 30% cloud cover), spatial subsetting to the boundaries of each city, and temporal aggregation. Missing data were handled by excluding days without valid measurements, and monthly averages were computed only from valid days.

To reduce systematic bias, satellite-derived pollutant values were bias-adjusted using linear regression against co-located ground station measurements for each city. This correction was applied prior to further analyses. For spatial downscaling, bilinear interpolation was applied to match the satellite resolution to the exact location of each monitoring station.

Comparisons among cities were conducted in a pairwise manner. For each pollutant, an independent t-test was used to compare the means between two cities at a time. In other words, in each analysis, only the data from two selected cities were included and compared. This approach allowed us to examine the differences between each city pair; however, it does not account for the simultaneous comparison of all three groups. Therefore, for future research, the use of statistical methods such as ANOVA or Kruskal–Wallis is recommended for multi-group analysis.

Results and Discussion

To investigate the objectives of the study, the mentioned tests were separated into two main parts and were conducted to compare the average concentrations of the studied pollutants before and after the COVID-19 period and also to compare the average of the particles in the studied cities in pairs. For each of the tests, parametric conditions such as the assumption of normality were examined and depending on the result, the relevant parametric or non-parametric test was used. First, a description of the pollutant concentrations in the form of the average (standard deviation) is reported in Table 1.

According to Table 2, the highest average concentrations of $PM_{2.5}$, PM_{10}, and SO_2 were recorded in Ahvaz, followed by Bushehr, and then Bandar Abbas. The standard deviation values, shown in parentheses in the table, indicate considerable variability in some pollutants—particularly $PM_{2.5}$ and PM_{10}—suggesting fluctuations in their concentrations over time. The highest average concentration of carbon monoxide (CO) was also observed in Ahvaz, followed by Bandar Abbas, while the average CO concentration in Bushehr was reported as zero. In contrast, the highest average concentration of ozone (O_3) was found in Bandar Abbas. Nitrogen dioxide (NO_2) levels were reported as zero across all three cities: Ahvaz, Bushehr, and Bandar Abbas.To assess whether the differences in average pollutant concentrations between cities were statistically significant, an independent t-test was conducted.

To compare the mean concentrations of pollutants among the studied cities, pairwise comparisons were conducted, meaning that in each analysis, data from only two cities were selected and compared. For this purpose, independent t-tests were applied to evaluate the differences in means for each city pair. This approach allows for the identification of significant differences between each pair of cities, although it does not account for simultaneous comparison of all three groups. Therefore, for future studies, the use of statistical methods such as ANOVA is recommended for multi-group analysis. The results of this analysis have been presented in Table 2. The null hypothesis for each test was that there is no difference in the average concentration of the pollutant in the two cities being compared.

Table 3 presents the mean differences, t-test values, and P-values for all pollutants across the three studied cities. As shown, all tests yielded statistically significant results (P-value < 0.05). For several indicators, including $PM_{2.5}$ and PM_{10}, a significant difference in the average concentrations between the compared cities was observed. In the next step of the analysis, the average particle concentrations before and after the COVID-19

Table 1. Mean (standard deviation) of the studied particles in the cities of Ahvaz, Bushehr, and Bandar Abbas during 2018–2022

Particle/City (μg/m³)	Ahvaz	Bushehr	Bandar Abbas
$PM_{2.5}$	44.61(35.21)	15.39 (19.70)	12.95 (19.10)
PM_{10}	124.42 (80.37)	52.34 (18.73)	33.92 (60.31)
SO_2	0.02 (0.03)	0.00 (0.00)	0.00 (0.01)
NO_2	0.00 (0.02)	0.00 (0.00)	0.00 (0.02)
O_3	0.00 (0.00)	0.00 (0.00)	0.02 (0.02)
CO	2.02 (2.27)	0.00 (0.00)	1.72 (2.09)

Table 2. Pairwise comparison of the mean levels of the studied particles in the cities

Particel	Statistical index	Ahvaz-Busheher	Ahvaz-Bandar Abbas	Bushehr-Bandar Abbas
$PM_{2.5}$	Average difference	22.29	31.66	2.44
	t-test (*P*-value)	29.38 (<0.001)	32.06 (<0.001)	3.50 (<0.001)
PM_{10}	Average difference	70.09	90.50	20.41
	t-test(*P*-value)	26.15 (<0.001)	36.53 (<0.001)	8.73 (<0.001)
SO_2	Average difference	0.02	0.02	-0.005
	t-test(*P*-value)	31.15 (<0.001)	22.03 (<0.001)	-15.40 (<0.001)
NO_2	Average difference	0.008	0.004	-0.0005
	t-test(*P*-value)	19.34 (<0.001)	5.52 (<0.001)	-8.87 (<0.001)
O_3	Average difference	0.007	-0.02	-0.02
	t-test(*P*-value)	27.44 (<0.001)	-26.02 (<0.001)	-37.89 (<0.001)
CO	Average difference	2.01	0.29	-1.72
	t-test(*P*-value)	35.93 (<0.001)	3.86 (<0.001)	-33.46 (<0.001)

Table 3. Comparison of mean particle sizes before and during the COVID-19 pandemic, by cities studied

Pollutant	Study city	(t-value)	Average difference	Paired t-test (*P*-value)
$PM_{2.5}$	Ahvaz	0.10 (0.062)	-12.47	-6.25 (<0.001)
	Bushehr	0.13(0.11)	-8.31	-8.95 (<0.001)
	Bandar Abbas	0.12(0.025)	5.19	4.29(<0.001)
PM_{10}	Ahvaz	0.06(0.246)	-6.23	-1.88(0.061)
	Bushehr	0.09(0.076)	-47.43	-20.16(<0.001)
	Bandar Abbas	-0.13(0.014)	20.56	5.18(<0.001)
SO_2	Ahvaz	010(0.063)	0.005	-4.52(<0.001)
	Bushehr	-	-	-
	Bandar Abbas	-	0.002	7.20(<0.001)
NO_2	Ahvaz	-	-0.004	-4.93(<0.001)
	Bushehr	-	-	-
	Bandar Abbas	0.007(0.896)	0.006	0.06(0.002)
O_3	Ahvaz	-	-0.001	-6.40(<0.001)
	Bushehr	-	-	-
	Bandar Abbas	0.05(0.307)	0.02	11.40-6.40(<0.001)
CO	Ahvaz	0.35(<0.001)	-1.22	-9.37-6.40(<0.001)
	Bushehr	-	-	-
	Bandar Abbas	0.25(<0.001)	0.68	8.73-6.40(<0.001)

period were compared across the studied cities. These results are presented in Table 3. The null hypothesis for this comparison states that there is no difference in the average concentration of each pollutant before and after the COVID-19 outbreak.

The correlation values presented in Table 4 are generally low. However, a stronger correlation was observed for CO concentrations before and during the COVID-19 period in Ahvaz and Bandar Abbas. In most cases, the mean difference in particle concentrations during the pandemic was negative, indicating that pollutant levels were higher before the outbreak. This decrease may be attributed to restrictions imposed on industrial activities and transportation, which led to reduced emissions during

Table 4. Correlation (significance) and regression coefficient (significance) between station-measured and satellite-measured particle values; in the regression relationship, the independent and dependent variables are the station- and satellite-measured values of each particle, respectively.

Particel	Correlation (*P*-value)			Regression coefficient (Sig.)		
	Ahvaz	Bushehr	Bandar Abbas	Ahvaz	Bushehr	Bandar Abbas
$PM_{2.5}$	0.02 (0.975)	70.73 (<0.001)	7.63 (<0.001)	0.001 (0.487)	0.32 (<0.001)	4.29 (<0.001)
PM_{10}	5.05 (0.013)	36.19 (<0.001)	32.90 (<0.001)	0.06 (0.007)	0.40 (<0.001)	0.37 (<0.001)
So_2	-0.92 (0.212)	-0.006 (0.652)	1.40 (0.274)	-0.03 (0.106)	-0.01(0.326)	0.03 (0.137)
No_2	NA	NA	0.258 (.968)	NA	NA	0.001 (0.484)
O_3	0.02 (0.168)	NA	0.02 (0.185)	0.03 (0.084)	NA	0.03 (0.093)
Co	-1.89 (0.525)	NA	31.82 (<0.001)	-0.02 (0.262)	NA	0.16 (<0.001)

* Cells marked NA were not output due to lack of data.

the pandemic. However, there were exceptions: in Bandar Abbas, the average concentration of all pollutants increased during the pandemic, and in Ahvaz, SO_2 levels were also higher during this period. These anomalies may be due to meteorological conditions or alternative emission sources that influenced pollutant concentrations. Except for PM_{10} in Ahvaz, a statistically significant difference was observed in the mean concentrations of all studied pollutants before and during the COVID-19 pandemic ($P<0.05$). The reductions in industrial operations, agricultural activities, public transport, and urban mobility likely contributed to the overall decline in air pollution levels during the pandemic. However, factors such as local atmospheric conditions, human behavior, and geographical variability can also influence air pollution patterns, explaining the irregular trends observed in Bandar Abbas. To further investigate the relationship between satellite-based and ground station measurements, linear regression analysis was performed in addition to correlation tests. The results of these analyses have been presented in Table 4.

According to Table 4, after verifying the assumptions for each statistical method, the correlation and regression coefficients were found to be statistically significant for most pollutants. For $PM_{2.5}$, both the correlation and regression coefficients were significant in Ahvaz and Bushehr, but not significant in Bandar Abbas (P-value <0.01). In the case of PM_{10}, significant correlation and regression values were observed in all three cities—Ahvaz, Bandar Abbas, and Bushehr (P-value <0.05). However, for SO_2, NO_2, and O_3, neither correlation nor regression coefficients were statistically significant in any of the three cities (P-value >0.05), indicating weak or no linear relationship between satellite-derived and ground-based measurements for these pollutants. For CO, a high and statistically significant correlation and regression coefficient was observed only in Ahvaz (P-value <0.01), suggesting a strong agreement between satellite and station data in this location.

The results of this study demonstrate clear spatial and temporal differences in air pollutant concentrations across the three coastal cities of Ahvaz, Bushehr, and Bandar Abbas during the period 2018–2022. Statistical analyses revealed that, with the exception of PM_{10} in Ahvaz, the mean concentrations of most pollutants were significantly different before and during the COVID-19 pandemic ($P<0.05$). Specifically, substantial reductions in $PM_{2.5}$ and PM_{10} were seen in Ahvaz and Bushehr, whereas Bandar Abbas exhibited an opposite trend with increased levels of these pollutants during the pandemic period. The significant correlation between satellite-derived and ground-based measurements for $PM_{2.5}$ and PM_{10} in most cities indicates that Sentinel-5P TROPOMI data can reliably capture particulate matter variations at the urban scale. However, the weak or non-significant correlations for SO_2, NO_2, and O_3 suggest that satellite retrievals for gaseous pollutants may be affected by local meteorological conditions, atmospheric mixing, or the relatively low background concentrations observed in these cities. In Ahvaz, the consistently higher concentrations of $PM_{2.5}$ and PM_{10} can be attributed to the city's industrial activities, petrochemical facilities, and frequent dust storms originating from surrounding arid regions. Bushehr, while also influenced by industrial emissions, benefits from stronger coastal winds that may disperse particulate pollutants more effectively. In contrast, the increase in particulate matter in Bandar Abbas during the pandemic could be linked to local construction activities, port operations, and meteorological patterns that trap pollutants within the urban boundary layer.[10,11] Overall, these findings confirm that integrating satellite-based remote sensing with ground-based monitoring networks offers a cost-effective and spatially comprehensive approach for air quality assessment. This methodology is particularly valuable for identifying pollution hotspots in coastal regions where industrial, transportation, and natural dust sources interact. However, limitations such as the inability of satellite sensors to fully capture short-term variability, and potential underestimation of gaseous pollutants in low-concentration environments, should be considered when applying such data for policymaking and environmental management.

These findings align with those of Broomandi et al, who reported a reduction in aerosol concentrations during the COVID-19 outbreak in China, consistent with the results of the present study. Similarly, the highest average PM_{10} concentration was observed in Ahvaz, and the lowest in Bandar Abbas (Table 2).[12] This trend also corresponds to the findings of Tobías et al, who documented a reduction in aerosol concentrations—especially 10-µm suspended particles—during the pandemic in Spain. The highest average concentration of SO_2 from 2018 to 2022 was recorded in Ahvaz; however, in most records, the average value was zero (Table 2).[13] The studies by Hedelt et al[14] and Theys et al[15] also found that SO_2 concentrations remained unchanged or even increased during the pandemic. This could be attributed to the lack of strict restrictions in some regions or the presence of alternative sources of SO_2 emissions. As shown in Table 2, the average concentration of NO_2 was consistently zero across all cities. However, research by Ogen et al[16], Shikwambana et al[5], and Koukouli et al[17] reported a decline in NO_2 concentrations during the pandemic in 2021 compared to pre-pandemic levels. The average concentration of O_3 was also reported to be nearly zero in all cities from 2018 to 2022. Although pairwise comparisons between cities showed statistically significant differences, the differences in mean values were negligible, as seen in Table 3. This finding is consistent with studies by Zhao et al in 2021[18] and Quesada-Ruiz et al in 2020[19], who observed reduced O_3 levels during the COVID-19 period. In the case of CO, the average concentration in Bushehr was reported as zero, while similar levels were found in Ahvaz and Bandar Abbas. In Ahvaz, CO concentrations were higher before the COVID-19 outbreak, whereas in Bandar Abbas, they were higher during the pandemic. This difference was also statistically significant (P-value < 0.05). These results align with the findings of Schneising et al in 2019[6] and Bodah et al in 2022,[20] who reported a reduction in CO concentrations during the pandemic.

Conclusion

The findings of this study revealed that during the 2018–2022 period, the highest concentrations of pollutants, particularly $PM_{2.5}$ and PM_{10}, were observed in Ahvaz. In most cases, pollutant levels were higher before the COVID-19 pandemic than during it, likely due to the reduction in industrial activities and transportation during lockdown restrictions. Correlation analysis showed strong agreement between satellite-derived and ground-based measurements for $PM_{2.5}$ and PM_{10} in some cities, indicating that satellite observations can serve as a valuable complement to ground monitoring. The combined use of remote sensing and ground station data provides a cost-effective and efficient approach for long-term air quality monitoring and detecting spatiotemporal changes in pollutants. Future studies are recommended to incorporate more advanced modeling techniques and multi-source datasets to improve the accuracy of pollutant estimates and support air pollution mitigation strategies.

Authors' Contribution

Conceptualization: Mokhtar Kavoosi.
Formal Analysis: Mokhtar Kavoosi, Hossein Mohammad Asgari.
Investigation: Mokhtar Kavoosi, Hossein Mohammad Asgari.
Methodology: Mokhtar Kavoosi.
Project Administration: Mokhtar Kavoosi.
Software: Hossein Mohammad Asgari.
Writing–Original Draft: Hossein Mohammad Asgari.
Writing–Review & Editing: Mokhtar Kavoosi.

Competing Interests

The authors confirm that there is no competing interest for this research.

Ethical Approval

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely observed by the authors.

Funding

There was no funding for this study.

References

1. Ali SM, Malik F, Anjum MS, Siddiqui GF, Anwar MN, Lam SS, et al. Exploring the linkage between PM(2.5) levels and COVID-19 spread and its implications for socio-economic circles. Environ Res 2021;193:110421. doi:10.1016/j.envres.2020.110421
2. Zambrano-Monserrate MA, Ruano MA, Sanchez-Alcalde L. Indirect effects of COVID-19 on the environment. Science of The Total Environment 2020;728:138813. doi:10.1016/j.scitotenv.2020.138813
3. Vîrghileanu M, Săvulescu I, Mihai B-A, Nistor C, Dobre R. Nitrogen Dioxide (NO2) Pollution Monitoring with Sentinel-5P Satellite Imagery over Europe during the Coronavirus Pandemic Outbreak. Remote Sensing 2020;12(21):3575.
4. Ghahremanloo M, Lops Y, Choi Y, Mousavinezhad S. Impact of the COVID-19 outbreak on air pollution levels in East Asia. Sci Total Environ 2021;754:142226. doi:10.1016/j.scitotenv.2020.142226
5. Shikwambana L, Mhangara P, Mbatha N. Trend analysis and first time observations of sulphur dioxide and nitrogen dioxide in South Africa using TROPOMI/Sentinel-5 P data. International Journal of Applied Earth Observation and Geoinformation 2020;91:102130. doi:10.1016/j.jag.2020.102130
6. Schneising O, Buchwitz M, Reuter M, Bovensmann H, Borsdorff T, Deutscher N, et al. A scientific algorithm to simultaneously retrieve carbon monoxide and methane from TROPOMI onboard Sentinel-5 Precursor. Atmospheric Measurement Techniques 2019;12:6771–802. doi:10.5194/amt-12-6771-2019
7. Pham PHD, Phan VH, editors. Exploring the Impact of Covid-19 on Air Quality Using Sentinel-5P and MODIS Data in Ho Chi Minh City. Proceedings of the Third International Conference on Sustainable Civil Engineering and Architecture; 2024 2024//; Singapore: Springer Nature Singapore. doi:10.1007/978-981-99-7434-4_178
8. Singh S, Avtar R, Jain A, Alsulamy S, Ouda MM, Kharrazi A. Identifying Micro-Level Pollution Hotspots Using Sentinel-5P for the Spatial Analysis of Air Quality Degradation in the National Capital Region, India. Sustainability 2025;17(5):2241.
9. Amiri F, Jamali AA, Gharibvand LK. Tracing air pollution changes (CO, NO_2, SO_2, and HCHO) using GEE and Sentinel 5P images in Ahvaz, Iran. Environ Monit Assess 2023;195(10):1259. doi:10.1007/s10661-023-11885-4
10. Keshmiri S, Pordel S, Raeesi A, Nabipour I, Darabi H, Jamali S, et al. Environmental Pollution Caused by Gas and Petrochemical Industries and Its Effects on the Health of Residents of Assaluyeh Region, Irani-an Energy Capital: A Review Study. ISMJ 2018;21(2):162. doi:10.29252/ismj.21.2.162
11. Shahmohammadi M, Bay Y, Kiani P. Identification and Prioritization of Factors Affecting Air Pollution in Tehran Using Interpretive Structural Modeling Approach. Environment and Interdisciplinary Development 2022;7(77):88–98. doi:10.22034/envj.2022.163597
12. Broomandi P, Karaca F, Nikfal A, Jahanbakhshi A, Tamjidi M, Kim JR. Impact of COVID-19 Event on the Air Quality in

Iran. Aerosol and Air Quality Research 2020;20(8):1793–804. doi:10.4209/aaqr.2020.05.0205
13. Tobías A, Carnerero C, Reche C, Massagué J, Via M, Minguillón MC, et al. Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic. Sci Total Environ 2020;726:138540. doi:10.1016/j.scitotenv.2020.138540
14. Hedelt P, Efremenko D, Loyola Diego G, Spurr R, Clarisse L. Sulfur dioxide layer height retrieval from Sentinel-5 Precursor/TROPOMI using FP_ILM. Atmospheric Measurement Techniques 2019;12:5503–17. doi:10.5194/amt-12-5503-2019
15. Theys N, Smedt ID, Yu H, Danckaert T, Gent JV, Hörmann C, et al. Sulfur dioxide retrievals from TROPOMI onboard Sentinel-5 Precursor: algorithm theoretical basis. Atmospheric Measurement Techniques 2017;10(1):119–153. doi:10.5194/amt-10-119-2017
16. Ogen Y. Assessing nitrogen dioxide (NO(2)) levels as a contributing factor to coronavirus (COVID-19) fatality. Sci Total Environ 2020;726:138605. doi:10.1016/j.scitotenv.2020.138605
17. Koukouli ME, Skoulidou I, Karavias A, Parcharidis I, Balis D, Manders A, et al. Sudden changes in nitrogen dioxide emissions over Greece due to lockdown after the outbreak of COVID-19. Atmos Chem Phys 2021;21:1759–1774. doi:10.5194/acp-21-1759-2021
18. Zhao F, Liu C, Cai Z, Liu X, Bak J, Kim J, et al. Ozone profile retrievals from TROPOMI: Implication for the variation of tropospheric ozone during the outbreak of COVID-19 in China. Sci Total Environ 2021;764:142886. doi:10.1016/j.scitotenv.2020.142886
19. Quesada-Ruiz S, Attié JL, Lahoz WA, Abida R, Ricaud P, El Amraoui L, et al. Benefit of ozone observations from Sentinel-5P and future Sentinel-4 missions on tropospheric composition. Atmos Meas Tech 2020;13:131–152. doi:10.5194/amt-13-131-2020
20. Bodah BW, Neckel A, Stolfo Maculan L, Milanes CB, Korcelski C, Ramírez O, et al. Sentinel-5P TROPOMI satellite application for NO2 and CO studies aiming at environmental valuation. Journal of Cleaner Production 2022;357:131960. doi:10.1016/j.jclepro.2022.131960