

Effect of Anthropogenic Activities on the Presence of Nitrogen Dioxide (NO₂) Through Remote Sensing and Ground Based Observations over Emirate of Fujairah, UAE

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Abstract: Air pollution is one of the biggest problems of this age, not only it contributes to climate change but also it has a negative effect on public and individual health due to rising morbidity and mortality. There are various contaminants that play a significant role in human disease. Numerous toxins are released into the environment as a result of anthropogenic activities including burning fossil fuels for transportation and electricity generation. In order to assist decision-makers in finding a long-term solution for improving environmental quality and population health status, NO₂ pollution monitoring and regulation is an essential task. Moreover, efforts to reduce NO₂ emissions are important for improving air quality and public health. Based on data acquired from Sentinel-5P, the study presented a comparison of NO₂ measurements in Sentinel-5P and ground-based stations over the urban area of Fujairah during 2021 and comparison analysis of the tropospheric NO₂ column spatial configuration over urban area of Fujairah during comparable periods of pre, mid and post COVID-19 pandemic era as 2019, 2020 and 2021, respectively. These findings demonstrate remarkable tropospheric NO₂ column number density decreases even of 85% in the busier areas of emirate of Fujairah during the pandemic era. Sentinel-5P measurements draw attention to the significant reduction in NO₂ pollution over Fujairah during the COVID-19 lockdown where we had less traffic, which is supported by ground stations-based calculations.

Keywords: Atmospheric Pollution, NO₂, Air Quality, Sentinel-5p, TROPOMI, Remote Sensing Data, COVID-19, Pandemic, Outbreak

1. Introduction

Urban air pollution is made of extremely complex mixture of gaseous and particulate substances [1]. Anthropogenic activities such as combustion of fossil fuels for energy production and transportation entails as the major cause of releasing various pollutants in the environment. These pollutants cause atmospheric composition change which negatively impact human health and its ecosystem [2]. Vehicle emissions are anticipated to worsen from what they are now by 2030. Numerous studies have reported the

negative influence of vehicle emissions like hydrocarbons, nitrogen oxide, carbon monoxide, and particulates which are anticipated to worsen by 2030 [3]. Nitrogen dioxide (NO₂) is the air pollutant species that is most critical to human health of its direct respiratory irritation, exacerbation of existing health conditions, long-term negative health impacts, and contribution to other harmful pollutants. Air quality guideline by World Health Organization (WHO) suggests NO₂ level shouldn't exceed 10 µg/m³ annual mean and 25 µg/m³ 24-hour mean. In 2019, 99% of the world population was living in places where these criteria were not met [4]. According to WHO, 91 percent of the world population breathe air with

high levels of pollutants which results in death of 7 million people/year [5]. According to epidemiological studies, bronchitis symptoms increased in asthmatic children due to long-term exposure of NO₂ [5]. NO₂ has capacity to create secondary pollutants like nitric acid and ozone (O₃), which help to create smog, acid rain, and the greenhouse effect [6]. Therefore, global warming increases when greenhouse gas concentrations rise in the atmosphere. The cumulative warming effect to the earth's atmosphere from greenhouse gases increased by 45 percent from 1990 to 2019 [7]. Lowering anthropogenic emissions of air pollutants and atmospheric particles from sources like vehicle traffic may help to enhance the world's air quality [8].

Monitoring air quality has become a crucial public health and environmental protection activity. In addition to ground-based monitoring stations, satellites are increasingly utilised for tracing air pollution sources and monitoring air quality. Satellite-based data are incredibly useful for monitoring air pollutants and the physical conditions of the Earth's surface due to the increasing availability of remotely sensed data derived from sophisticated sensors with high resolutions. In addition, metrological and satellite-based derivatives are incorporated into a variety of studies to elucidate the spatiotemporal patterns of air pollutants, biophysical parameters, and respiratory disease [9].

The COVID-19 outbreak, which was first reported in late December 2019 in Wuhan, China, has become one of the most grievous health crises of the 21st century, posing grave risks to all nations. Diverse drastic measures were taken on a global scale to control and mitigate the virus's rapid spread and to reduce its mortality rate. Particularly, the transport sector was severely impacted by curfews imposed as a result of the adoption of remote work systems by educational institutions, public and private sectors [10]. As a consequence, during the first few months of the pandemic, people's mobility changed drastically as the majority stayed at home during working hours. In addition, researchers began to report improvements in air quality based on information acquired from satellite images and monitoring stations on the ground. Using Sentinel-5 satellite data, numerous studies evaluated the changes in various air pollutants during the 2020 COVID-19 lockdown (March to June 2020) in 21 metropolitan cities spanning 14 Middle Eastern nations. Significant decreases in various air pollutants including NO₂ levels were observed primarily in minor cities and, to a lesser extent, in metropolitan cities. Other researchers analysed the effect of the COVID-19 lockdown on air quality in the Middle East, including Saudi Arabia, Kuwait, Iraq, Iran, and the United Arab Emirates [11-13].

However, the available regional studies primarily concentrated on the early phases of the pandemic and did not adequately represent the recovery phase or provide comprehensive and quantitative analyses of the changes in various air pollutants and mobility patterns. The Fujairah emirate is not investigated extensively in the United Arab Emirates, and very little effort has been made to monitor environmental pollution here. This study documents the

impact of the COVID-19 lockdown and subsequent resuming on mobility and air quality in the Fujairah region of the United Arab Emirates, compares the impact of the lockdown on air quality as reflected by satellite data and ground-based observations, and correlates the mobility patterns of people with the observed changes in air quality during the lockdown and subsequent recovery.

The data mining process will be applied to collect data from satellite and four different ground-based station located in the Fujairah. The point-based ground measurements will be taken and applied in spatial modelling to accurately quantify the amount of air pollution. The distribution modelling of NO₂ is useful for epidemiological studies, management of the urban air which further helps in government planning and regulations [14]. These efforts will assist the government in finding a long-term solution for improving environmental quality and the health of the population.

2. Materials and Methods

2.1. Study Area

Fujairah is one of the seventh Emirates in the United Arab Emirates. It is the only Emirate to be located on the eastern side of the UAE, near to Gulf of Oman. The total area of Fujairah is 1450 Km² which covers 1.8% of the whole area of UAE [15]. The population of the Emirate of Fujairah is reported as 292,358 in 2020, according to the Fujairah Statistics Centre [16]. Our analysis focuses on the urban area of Fujairah in 2021 which covers 450.05 Km² as shown in Figure 1.



Figure 1. The selected study area in Fujairah.

2.2. Data Mining

The data has been collected from ground-based stations in urban Fujairah provided by Fujairah Environment Authority

(FEA) and satellite Sentinel-5 Precursor (Table 1). These ground-based weather stations are equipped with Analyzer sensors capable of capturing a diverse array of atmospheric constituents, including NO_2 . These sensors are strategically positioned at heights ranging between 5 to 10 meters above ground level, facilitating the collection of accurate and representative air quality measurements.

2.3. Nitrogen Dioxide (NO_2) Data from Ground-Based Stations

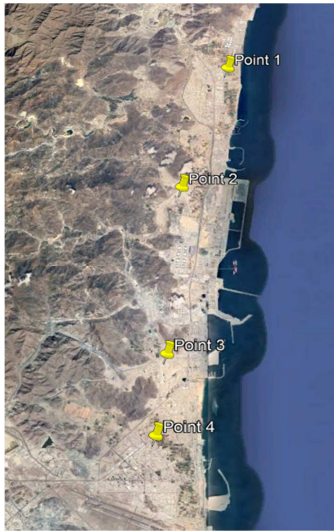


Figure 2. The stations under study are marked on the map using GPS coordinates in the Google Earth Pro.

These data include NO_2 concentrations in microgram per cubic meter ($\mu\text{g}/\text{m}^3$) measured hourly through day and night and average temperature in Celsius ($^{\circ}\text{C}$) during each month at four different stations in the selected Fujairah urban area in 2021 (Table 1, Figure 2). An algorithm written in python has been applied to measure the mean of the concentration in each

day. These data were used as reference to identify the differences in NO_2 levels in various stations and compare it to the Sentinel-5P data.

Table 1. Location and classification of spatial nature of the Areas where ground based stations are installed.

Station Name	Classification Of Spatial Nature
Point 1	Residential – Industrial
Point 2	Residential – Industrial
Point 3	Residential – Industrial
Point 4	Residential – Urban

2.4. Sentinel-5 Precursor Satellite

The data of Sentinel-5P has been collected via Sentinel Hub using EO Browser in near real time (NRTI). Sentinel-5P is an atmospheric monitoring satellite and has only one sensor called TROPOspheric Monitoring Instrument (TROPOMI), which is the most developed multispectral imaging spectrometer. It monitors the sunlight that is reflected to space from the earth's surface and atmosphere and finds the special fingerprints of different gases in various regions of the electromagnetic spectrum. The gases accounted for special fingerprints include nitrogen dioxide, ozone, formaldehyde, methane, carbon monoxide, etc, and aerosols [17]. The Sentinel-5 Precursor satellite contributes valuable information for a wide range of applications related to environmental protection, public health, climate change mitigation, and scientific research. The data of NO_2 tropospheric column in the unit of mol per square meter (mol/m^2) has been collected for 2021. The images of spatial distribution of NO_2 concentration over the study area has been downloaded for the following dates: 26/11/2019, 29/12/2019, 21/1/2020, 9/2/2020, 17/3/2020, 27/3/2020, 12/1/2021 and 27/3/2021 based on Mohammed bin Rashid space centre survey on NO_2 concentration before and during the lockdown [18] (Figure 3).



Figure 3. The NO_2 tropospheric column along with study area using Sentinel-5P.

3. Results

3.1. Comparison of NO₂ Measurements in Sentinel-5P and Ground-Based Stations

Based on the column number density and concentrations of NO₂, the underlying results highlight that the NO₂ pollution is recorded higher in the colder months (January–May) and (October–December) than the hotter months (June–September) (Figures 4–7). In-line with that average lowest temperature has been recorded as 21.6°C in January and highest as 36.5°C in July as shown on (Figure 8). The highest value of Sentinel-5P column number density of NO₂ is recorded as 2.19E-04 mol/m² on 13/01/2021 and the lowest value equals to 1.25E-05 mol/m² on 06/06/2021. Similarly, the average column number density of NO₂ is 6.06E-05 mol/m². The highest NO₂ concentration extend to 75.91 µg/m³ on 31/10/2021 while the lowest values remain at 5.26 µg/m³ on

07/06/2021 from Point 3 station (Figure 4). Moreover, the NO₂ concentration values get as far as 71.47 µg/m³ on 5/03/2021 and as low as 13.4 µg/m³ on 13/07/2021 for Point 4 station (Figure 5). Similar calculation has been done for Point 2 station where highest value of NO₂ concentration reached to 76.71 µg/m³ on 8/04/2021 and lowest stayed on 9.85 µg/m³ on 24/09/2021 (Figure 6). The results demonstrate higher values of NO₂ concentration in Point 1 station which reaches up to 107.12 µg/m³ on 23/10/2021 and lowest recorded levels as 5.7 µg/m³ on 4/06/2021 (Figure 7). The average recorded values of NO₂ concentration for all four stations including Point 1, Point 2, Point 3 and Point 4 appeared as 33.24 µg/m³, 32.33 µg/m³, 30.32 µg/m³ and 23.12 µg/m³, respectively. These results significantly indicate highest recorded values of NO₂ concentration in Point 1 station while comparatively lower NO₂ concentration has been recorded in Point 4 station among all.

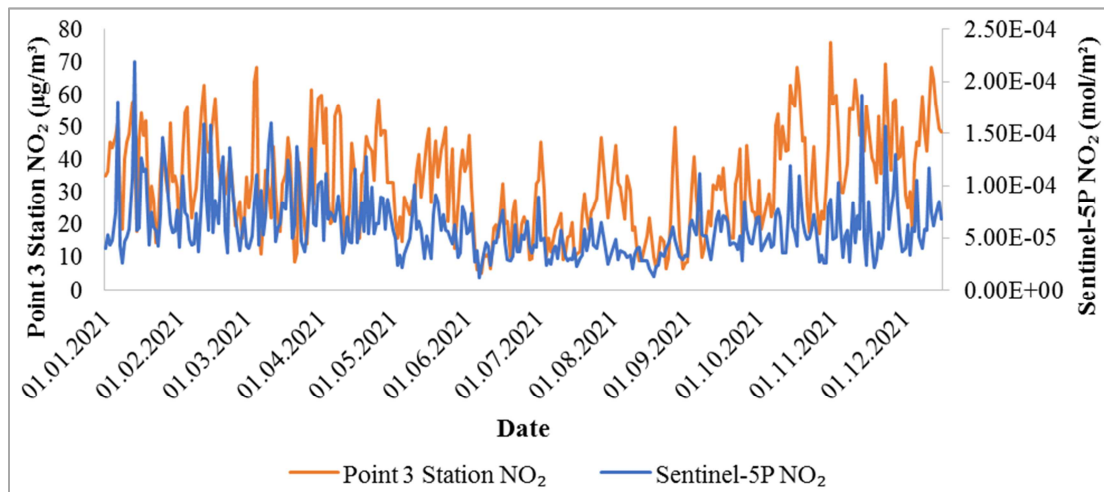


Figure 4. Comparative dynamics of NO₂ daily values for the year 2021 in Fujairah urban area, Point 3 ground-based station measurements are mentioned as orange line in µg/m³, Satellite data (Sentinel-5P) mentioned as blue line in mol/m against the dates on horizontal axis.

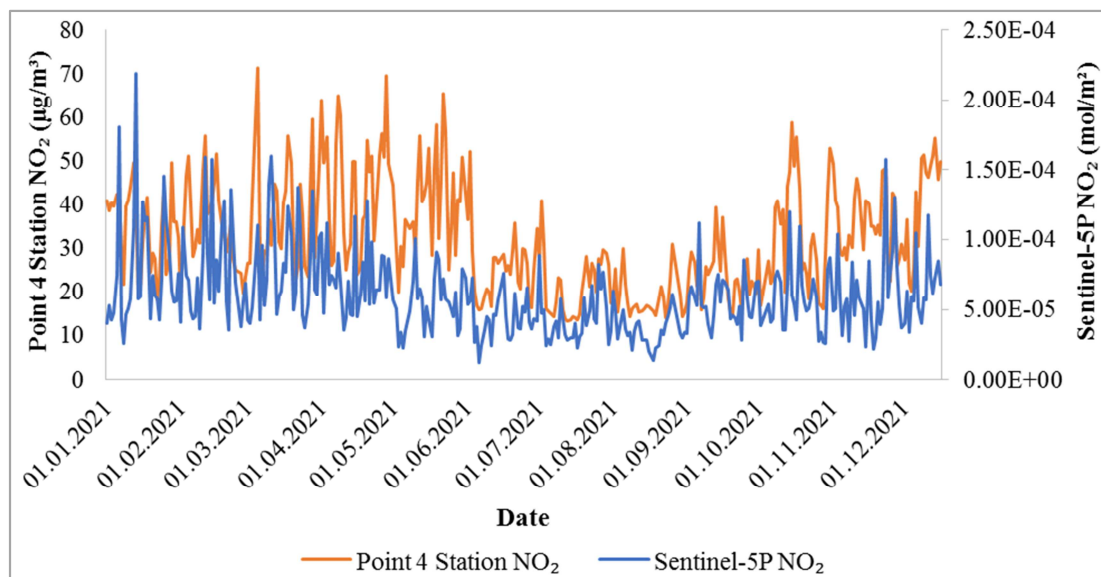


Figure 5. Comparative dynamics of NO₂ daily values for the year 2021 in Fujairah urban area, Point 4 ground-based station measurements are mentioned as orange line in µg/m³, Satellite data (Sentinel-5P) mentioned as blue line in mol/m against the dates on horizontal axis.

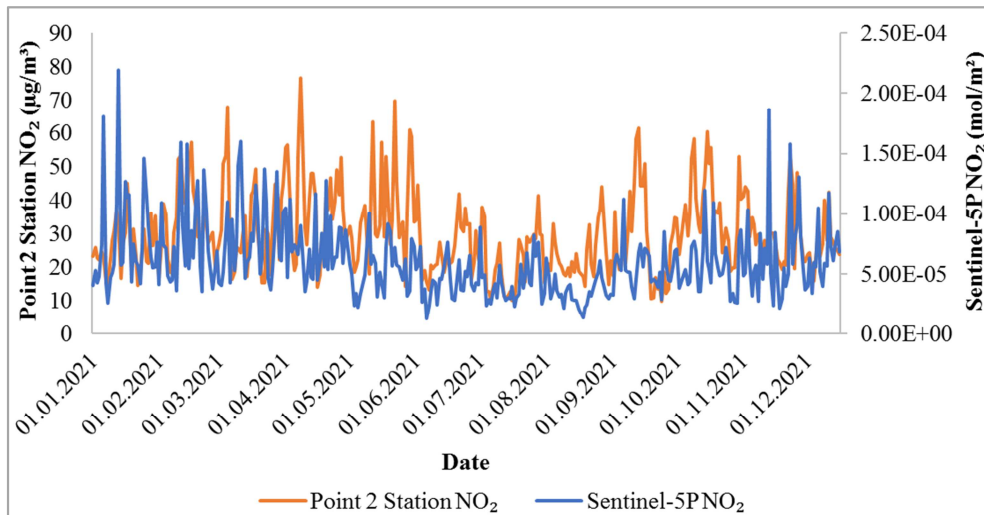


Figure 6. Comparative dynamics of NO₂ daily values for the year 2021 in Fujairah urban area, Point 2 ground-based station measurements are mentioned as orange line in µg/m³, Satellite data (Sentinel-5P) mentioned as blue line in mol/m against the dates on horizontal axis.

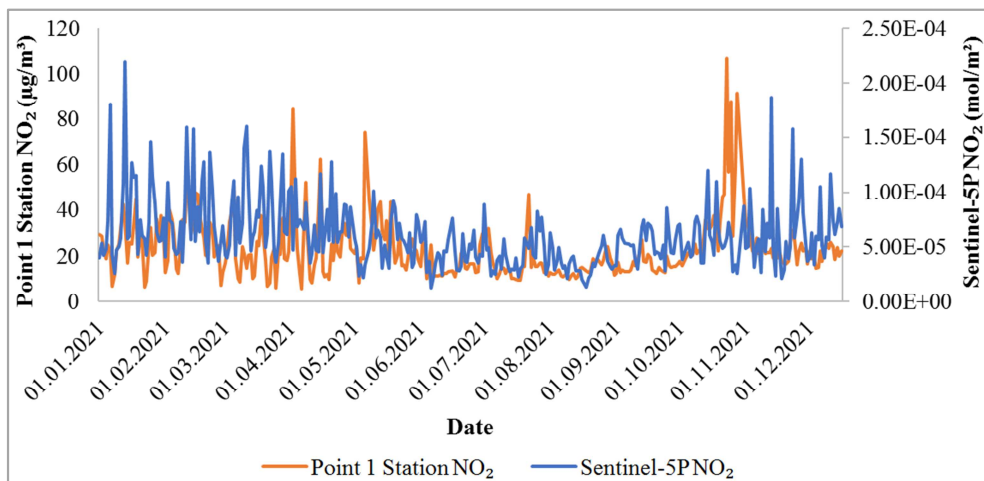


Figure 7. Comparative dynamics of NO₂ daily values for the year 2021 in Fujairah urban area, Point 1 ground-based station measurements are mentioned as orange line in µg/m³, Satellite data (Sentinel-5P) mentioned as blue line in mol/m against the dates on horizontal axis.

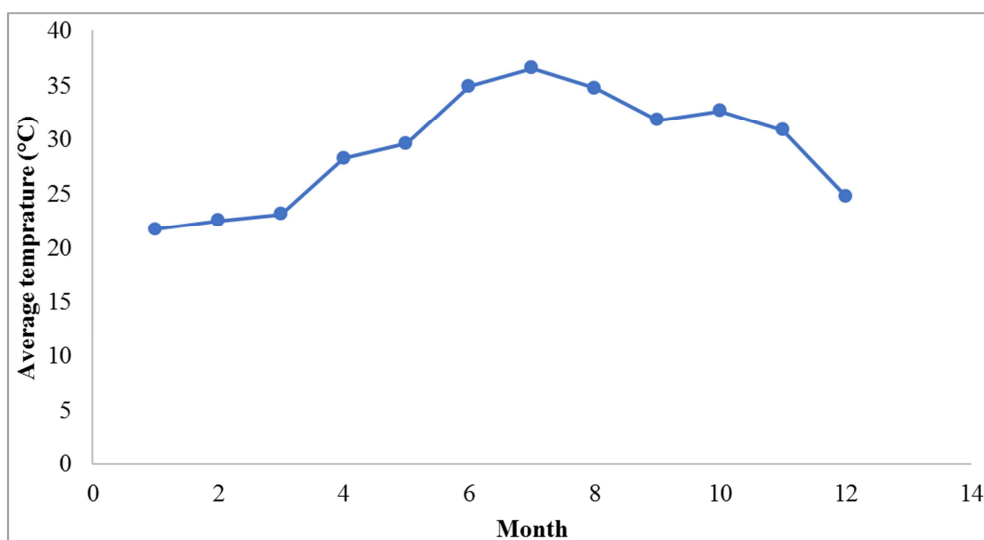


Figure 8. Average temperature in Celsius for each month of 2021 retrieved from Skamkam station data, Average temperatures in Celsius (°C) are shown in vertical axis and the months of 2021 on horizontal axis.

3.2. Comparison of NO₂ Pollution and COVID-19 Pandemic Lockdown

The COVID-19 pandemic led to significant and temporary reductions in NO₂ emissions and concentrations due to lockdowns, reduced economic activity, and changes in transportation patterns. The episode provided valuable insights into the relationship between human activities and air quality and prompted discussions on future strategies for achieving cleaner and healthier urban environments. The spatial distribution of NO₂ concentrations from Sentinel-5P is presented here for different dates to compare average tropospheric NO₂ column number density (Figure 9). Each colour represents various levels of concentration. The dark red colour indicates the highest values of NO₂ concentrations which

equals to $1.0\text{E-}4 \text{ mol/m}^2$ and the dark blue represents the least concentration of NO₂ which equals to 0 mol/m^2 (Figure 9). NO₂ concentration is highest in the east, then the north and west shows less concentration of NO₂, and the south has the least concentration in the pre Covid-19 era presented here as the date of 26/11/2019. In contrast to that, on 29/12/2019 the north, northeast and northwest have higher NO₂ concentration and the south and southwest shows less NO₂ concentration. During 2020 pandemic, the level of NO₂ decreased dramatically although the north, northwest and northeast yet had higher NO₂ concentration compared to other locations on the map as seen on 27/3/2020 had the lowest level of NO₂. The dark red colour for the southeast, the centre and east displayed for the day 27/3/2021 depicts the highest NO₂ concentration.

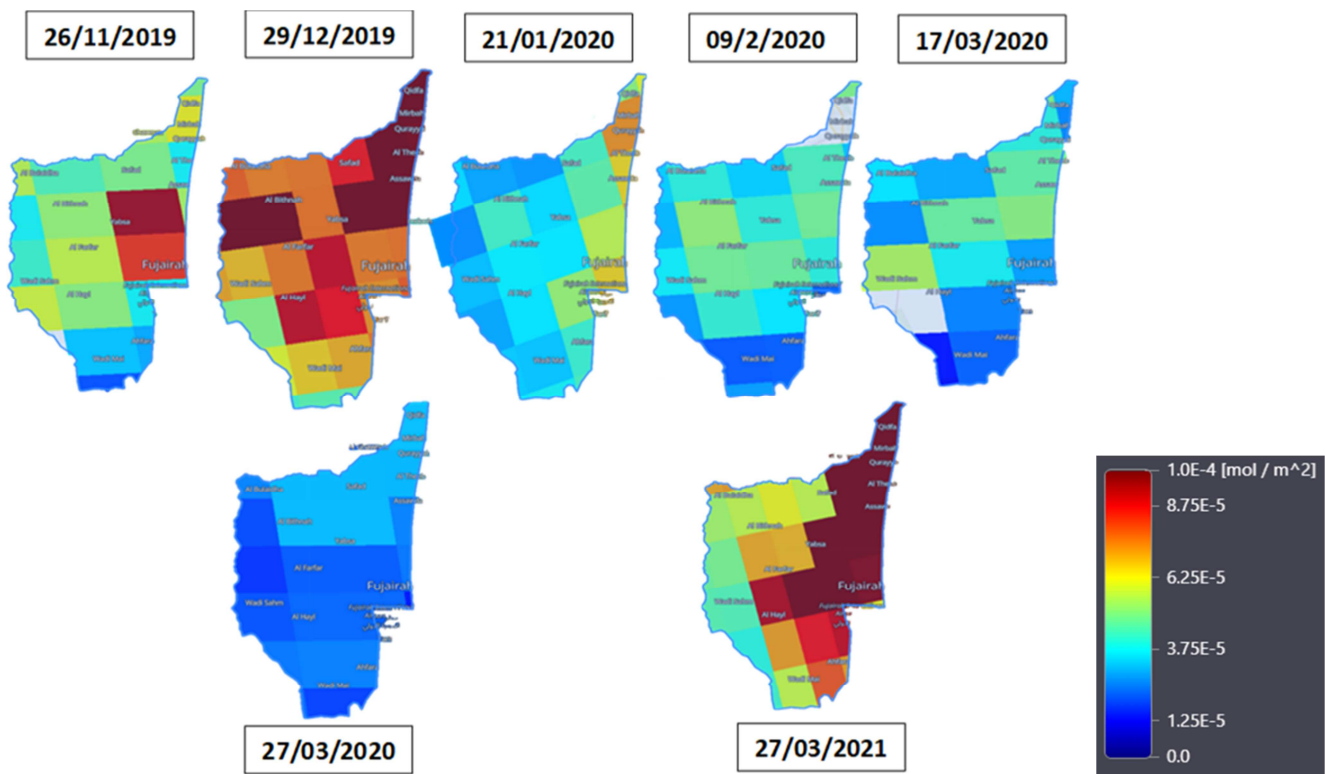


Figure 9. Spatial distribution of NO₂ concentrations from Sentinel-5P. comparative maps on selected dates of average tropospheric NO₂ column number density over Fujairah urban area. On the right it shows the average tropospheric NO₂ column number density index.

4. Discussion

The comparison of NO₂ concentration measurements acquired from Sentinel-5P as well as from ground-based stations reveals the significant impact weather has on NO₂ levels. The results exhibit pattern of NO₂ concentration which falls lower in the hotter months and higher in the colder months. Explanation may encompass on the increased traffic in colder months, as for UAE, the weather is much pleasant with average temperature in winters falling up to 19 °C as opposed to summer where average temperature may increase up to 41.3°C. Point 3 station exhibit the highest average concentration level of NO₂ which equals to 33.24µg/m³. The

area is known to have dense zone with schools, offices, and industries. Consequently, pulling more traffic of motor vehicle including loader trucks towards this area during the daytime. Point 1 station had the least average concentration level of NO₂ which equals to 23.12µg/m³. Point 1 area has less traffic compared to the other areas. The results highlighted that the traffic has huge impact on the NO₂ levels which bring above the speculation of motor vehicles as being the principal urban anthropogenic source of primary NO₂. A greater percentage of primary NO₂ is present in the exhaust from diesel-fuelled vehicles compared to petrol-fuelled vehicles. Primary NO₂ is created through high combustion, from ground-level emissions connected to the burning of fossil fuels in automobiles [19]. While comparing results of NO₂

pollution with pre, mid and post pandemic era, we must point out that at the time of COVID-19 pandemic lockdown in 2020, significantly lower levels of NO₂ concentrations has been recorded where we have less traffic compared to 2019 and 2021. The result shows that the COVID-19 pandemic indeed had a positive effect on air governance which was beneficial for human health.

The distribution of the NO₂ pollution can be affected by the local climatic conditions. For example, pollutants can be spread and moved away from their source by strong winds and temperature is another climatic parameter to consider [20]. Which can tell that the emissions of NO₂ can be distributed to near areas of the original source.

5. Conclusion

In conclusion, this study represents the inaugural analysis of its kind conducted in the Fujairah region, UAE. The findings underscore the noteworthy environmental implications of diminished nitrogen dioxide (NO₂) levels observed during the pandemic. The discernible reduction in NO₂, particularly in densely populated regions characterized by heightened vehicular activity and proximity to industrial zones, exemplifies the tangible positive outcomes attainable through rapid interventions. The implications of this research suggest the feasibility of achieving substantial and swift environmental improvements, emphasizing the importance of strategic measures in mitigating air pollution, particularly in urban settings with pronounced sources of NO₂ emissions.

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Conflicts of Interest

The authors declare that they have no conflict of interests.

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