Comparative Analysis of Pollutant Levels during Lockdowns Across Different Land-Use over the Emirate of Abu Dhabi, United Arab Emirates

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The outbreak of the COVID-19 pandemic has had a significant effect on people all over the world, posing health, economic, and social threats to the entire human population. As a part of preventive measures, at the end of March 2020 the UAE promulgated various lockdown measures to reduce the risk of the pandemic, which have a major impact on its local air quality levels. This research investigates the effect of the lockdown measures on the levels of the air pollutants like NO2 and PM2.5in Abu Dhabi Emirate using air quality stations data for the months of March and April 2020. Overall, NO2 levels have fallen dramatically by a range of 19% to 60% across all land use areas within the Emirate. Conversely, PM2.5 levels varied during the lockdown in April 2020, with increases ranging from 31% to 65% in rural and suburban industrial areas and decreases ranging from 2% to 33% in urban and suburban population areas. It can be observed that the lockdown measures had a huge impact on the NO2 levels due to reduced transportation and human activities while PM2.5 levels displayed great variability. The statistical analysis shows a significant moderate positive relationship (rs 0.476) at 0.05 level between NO2 and traffic volume crossing Musaffah Bridge.

Keywords: Nitrogen Dioxide, Particulate Matter 2.5, Transportation Pollution, Lockdown Measures, Air Quality

Introduction

An outbreak of the novel coronavirus (COVID-19) was reported in January 2020 and the UAE government implemented strict national lockdown measures across the country to control the transmission of COVID-19. As a consequence, these precaution measures caused the reduction in human activities and associated emissions that contribute to environmental air pollution. Air pollution has become as a major concern all over

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the world, particularly in developing nations like the UAE. The exploration of enormous oil resources in the UAE has enabled the nation to progress significantly within the past years. Simultaneously, economic and social changes have been accompanied by great achievements; however, concern exists that the rapid national growth may have created certain harmful impacts on environmental air quality. Environmental impacts are particularly severe in developed regions due to increased population, traffic levels, intense vehicle use, vehicle characteristics, driving patterns and complex urban geometry (Mishra et al. 2016). In the past decades, regulations worldwide have increasingly established the restrictive thresholds for air pollutant concentrations. This has led to improvements in the road transport sector, such as promotion of public vs. private transport, vehicle fleet turnover, fuel improvement and an increase in the share of electric/hybrid vehicles, serving to considerably reduce the rate of air pollutant emissions (Gualtieri et al. 2014). The construction of high-speed rail and advanced public transportation infrastructure will significantly improve the environmental air quality which has been noted in previous studies (Fu and Gu 2017; Laliveet al. 2018; Liang and Xi 2016; Mérel et al. 2014; Sunet al. 2019). Air pollution monitoring has a key role in management activities which lead to controlling severe air pollution in the country. and this which helps to reduce the health risks. According to Piotrowska (2010) and Aneja (2001), air pollution is considered to be responsible for more than five million deaths annually. The United States Environmental Protection Agency (UAEPA) described the major air pollutants: nitrogen dioxide (NO2), particulate matter (PM), sulfur oxide, carbon monoxide, ozone, particulate matter and lead (Pb). Besides gaseous pollutants, the atmosphere also was polluted due to particles. These particles are in the form of suspension, fluid or in solid state, which has a divergent composition and size. They are often catalogued as "floating dust," and known as particulate matter (PM). Particulate matter, such as PM10, PM2.5, PM1 and PM0.1 is defined as the fraction of particles with an aerodynamic diameter smaller than 10, 2.5, 1 and 0.1 µm resp. There is growing concern about potential health risks from exposure to PM2.5(fine particulate matter). PM2.5 is a category of solid and liquid particles with an aerodynamic diameter ≤2.5 µm (Crist et al., 2008; Castro et al. 2010). It can pass through the respiratory system into deeper parts of the lungs causing harmful effects (Castro et al. 2010).The level of exposure to PM2.5 is determined by considering a variety of factors such as size, shape, chemical composition of the particle, human characteristics (e.g., age, gender, socioeconomic status, nutritional status), weather conditions and other factors (Wallace 1996; Pope et al. 2004; Riediker et al. 2004; Gutierrez–Castillo et al. 2006; Gualtieri et al. 2011; Myatt et al. 2011; Osornio–Vargas et al. 2011; Wang et al. 2013; Cachon et al. 2014).

Beside the natural sources (e.g., dust and sand storms), human activity sources (industrial, commercial, and residential) also contribute to the PM 2.5 in urban areas in an unsystematic manner, and it is associated with various chemical compositions (Monn 2001; Abu Dhabi Environment Agency 2018). Researchers have studied in depth the chemical composition of PM2.5 to identify the major source of this pollutant. Past studies have revealed that major sources of ambient PM2.5 in cities or urban regions include secondary sulfate (SO4 2–), nitrate (NO3 –), (secondary aerosols), industrial emissions, coal combustion, motor vehicle exhaust, biomass burning and road dust (Almeida et al. 2005; Song et al. 2006; Jorquera and Barraza 2012; Minguillon et al. 2012; Choi et al. 2013). In addition, the minor sources such as sea salt, soil dust (Jorquera and Barraza 2012; Choi et al. 2013), and domestic heating (Kertesz et al. 2010) play a role. NO2 is the major cause of air pollution, and the present paper thus examines NO2 concentration during the period of lockdown phase from March-April 2020, basically the month prior to lockdown and the lockdown period. The NO2 gas is released from combustion processes such as motor vehicles, electric utilities and other industrial, commercial and residential sources that burn fossil fuels. USEPA (1998) and World Bank Group WBG (1998) considered NO2 to be a significant pollutant in the troposphere. NO2 also has diverse negative impacts such as formation of acid rain, deterioration of water quality, formation of toxic chemicals, reduction of visibility, and rising earth temperature, as described in previous studies (Hashim et al. 2004; Kalabokas et al. 2002; USEP 1998; WBG 1998; WHO 2000). The EU has established limit values for NO2 which is noted in EC Directive (2002), and considering hourly average mass concentrations, the NO2 limit for protecting human health is 200 μg m-3 (WHO 2000).

The COVID-19 global pandemic has likely impacted on air quality due to human activities that are largely restricted by taking lockdown measures in many regions in the UAE. The authorities announced that transportation movements were strictly prohibited except when absolutely essential during the lockdown phase. Transportation is an important area where measures are needed to control air pollution. The NO2 pollutant is released from combustion processes associated with motor vehicles, electric utilities and other industrial, commercial and residential sources that burn fossil fuels. The main aim of this research was to investigate the impact of the lockdown measures and the reduced human activities on the concentration levels of pollutant NO2 and particulate matter PM2.5 in the Emirate of Abu Dhabi.

NO2 and PM2.5 concentration data collected from the Environment Agency - Abu Dhabi air quality monitoring stations during the period March-April 2020 were used for the study. A comparative analysis of pollutant levels of NO2 and PM2.5 during the lockdown period over different land use areas in the Emirate of Abu Dhabi is examined. The basic premise is that both levels should be significantly lower in April 2020 in comparison to similar levels in March 2020 due to the reduced human activities during the lockdown period.

Study Area and Air Quality Data

The UAE is located in the western part of the Asian continent, along with other six countries constituting what is geographically known as the Arabian Peninsula. The UAE borders on Saudi Arabia from the west, the Sultanate of Oman from the east and south and the Arabian Gulf from the north. The country is a federal union comprised of seven emirates. The Emirate of Abu Dhabi is the largest in terms of land size and is also the country's capital and political center (Figure 1). The Emirate of Abu Dhabi is located in the western part of the country. The overall landscape of the Emirate comprises massive desert areas along with various sand dune fields. Extending towards the south and eastern side are mountainous regions along the borders of Oman. Large hydrocarbon industry fields of gas and oil are located in the western part of the Emirate.

Being the largest Emirate, it contains large metropolitan cities such as the capital city of Abu Dhabi, Al Ain city in the southeast and Madinat Zayed in the western area. The metropolitan cities are major hubs for economic activities of various services, including trade and banking, industrial production and limited agricultural activities in the southeastern area, consisting of vegetable and palm plantations. With deserts covering a major portion of the Emirate landscape, dust storms are of frequent occurrence, especially in the spring and summer.

The Environment Agency - Abu Dhabi (EAD) (https://www.ead.gov.ae/en) has a large network of air quality stations (https://www.adairquality.ae/) scattered throughout the Emirate, with a primary focus on major urban population centers, suburban areas of low population and industrial zones. Data used in this study were acquired from EAD and cover the months of March and April 2020. The data comes from twenty stations and consists of hourly measurements of different air pollution parameters (Table 1).

Figure 1 shows the location and spatial distribution of the air quality monitoring stations within the study area. The air quality stations in the Emirate of Abu Dhabi are well distributed spatially so as to provide a complete coverage of the different land uses and land cover in the Emirate (Abuelgasim and Farahat 2020; Farahat and Abuelgasim 2021; Abuelgasim et al. 2021). Urban traffic stations are located roadside in two cities at busy traffic intersections. The urban background stations are

TABLE 1
Air Quality Monitoring Stations

Station ID	Name	Land Cover – Land Use	Latitude	Longitude
1	Hamdan Street	Urban Traffic	24.49	54.36
2	Khadejah School	Urban Background	24.48	54.37
3	Khalifa School	Suburban Background	24.43	54.41
4	Mussafah	Suburban Industrial	24.35	54.50
5	Baniyas School	Suburban Background	24.32	54.64
6	Al Ain Islamic Institute	Suburban Background	24.22	55.73
7	Al Ain Street	Urban Traffic	24.23	55.77
8	Bida Zayed	Suburban Background	23.65	53.70
9	Gayathi School	Suburban Background	23.84	52.81
10	Liwa	Rural Background	23.10	53.61
11	Ruwais	Suburban Industrial	24.09	52.75
12	Habshan South	Rural Industrial	23.75	53.75
14	Bain Al Jessrain	Suburban Background	24.40	54.52
15	Khalifa City A	Suburban Background	24.42	54.58
16	Al Mafraq	Suburban Industrial	24.29	54.59
17	Sweihan	Suburban Background	24.47	55.34
18	Al Tawia	Suburban Background	24.26	55.70
19	Zakher	Urban Background	24.16	55.70
20	Al Qua'a	Rural Background	23.53	55.49

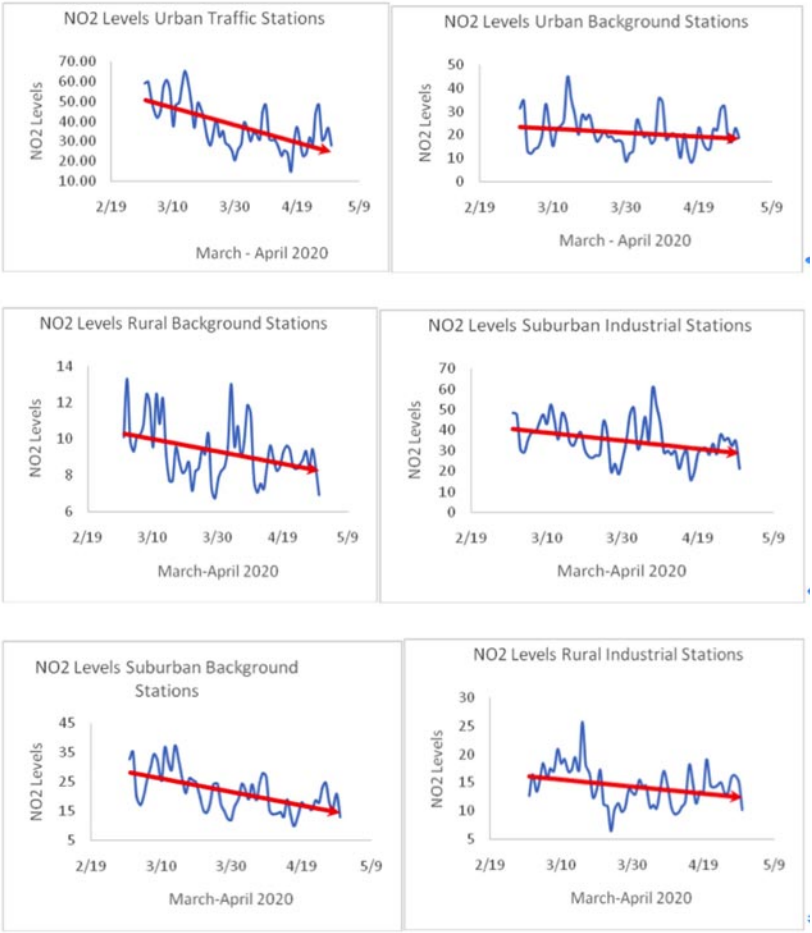
located in major vibrant urban centers with rather high populations and a multitude of human activities. The suburban background stations are mostly located within residential neighborhoods with sizable populations. The suburban industrial stations are located within light/heavy industry areas, mostly outside the main cities. The rural background stations are located in small towns with low population and in the main surrounded by deserts, large fields of sand dunes and local palm and vegetable plantations. One station, rural industrial, is located in close proximity to the major hydrocarbon industries.

In addition to the NO_2 and $PM_{2.5}$ levels, traffic volume data were acquired from Abu Dhabi Police Department. The traffic data represented an hourly measurement of the number of vehicles passing over major bridges entering the island of Abu Dhabi. These bridges represent the main routes of entrance and exit from the island of Abu Dhabi. The traffic data collated stems from selected days within the months of March-April 2020 (Table 2).

Methods

The data obtained from EAD comprises hourly measurements of NO_2 and $PM_{2.5}$ from the air quality monitoring stations for the period March 1st to April 30th, 2020. The measurements are recorded hourly allowing

FIGURE 1
Study Area and Air Quality Monitoring Stations



a full 24-hour view of the temporal variability of air pollutants in the area each day. It is generally considered that air pollutant concentration levels are strongly influenced by the local and regional land use and land cover within the geographic region where the measuring stations are located. Impacts due to transboundary pollutants and meteorological conditions are ignored in this study. EAD classifies the station geographic regions into six categories as can be seen in Table 1. It should be expected that the levels measured at each station and its variability would be different given the different land use and land cover around each station's geographic location.

This study classifies the air quality stations into six distinctive

TABLE 2
Traffic Volume Dates

Observation	Traffic volume date
1	March 5 2020
2	March 15 2020
3	March 25 2020
4	April 4 2020
5	April 14 2020
6	April 24 2020

groups as per the classification provided by EAD. The first group, urban traffic, consists of two stations, station 1 and 7 located in Abu Dhabi city and Al Ain city at major traffic crossings. This group represent traffic core urban centers with no industrial activities. The second group, urban background, consists of 2 stations (stations ID 2 and 19) are located within urban neighborhoods in both Abu Dhabi and Al Ain cities. Group 3, suburban background, has 9 stations located in small urban areas with a low population, with some stations surrounded by major concentrations of open desert and sand dune fields. Within these small towns there are major residential areas, business centers, and transportation networks. Group four, suburban industrial, consists of three stations located within major industrial areas such as the Industrial City of Abu Dhabi (ICAD) (https://www.zonescorp.com/en/zones/industrial-zones/industrial-city-of-abu-dhabi). Group five, rural background, consists of two stations with towns of low population; some of these towns are surrounded by scattered agricultural palm and vegetable plantations owned and operated in the main by the local town residents. Group six, rural industrial, consists of only one station, which is located in proximity to the major hydrocarbon industry of the Emirate of Abu Dhabi.

The hourly measurements of NO2 ,and PM2.5 were averaged to daily values for each station. Statistical analysis was performed on the daily values for the months of March and April to investigate the variability of the NO2 and PM2.5 levels in the Emirate pre- and during the lockdown measures. Time series graphs portraying the daily variations of NO2 and PM2.5 were developed for each station group. Similarly, the traffic volume data were summed to represent the daily traffic at bridge crossings during the study period.

In addition, a Spearman rank-order correlation coefficient (r_s) was applied using IBM SPSS software to test the relationship for both NO_2 and $PM_{2.5}$ hourly levels for station 14 (Bain Al Jessrain, located in the Al Maqta area) with the total hourly traffic volume crossing the nearby Musaffah Bridge for a selected working day (Tuesday April 14, 2020) during the lockdown. Musaffah Bridge has a total of ten lanes, five lanes on each side of the bridge, linking Abu Dhabi Island to the mainland. Therefore, it is assumed that there is a relationship between NO_2 and human activities and movement crossing over Musaffah Bridge during the day in the lockdown period.

Results and Discussions

Descriptive Statistics: Station Groups

The average fluctuations in NO_2 levels at the different station groups throughout the period March-April 2020 are shown in Table 3 and Figure 2.

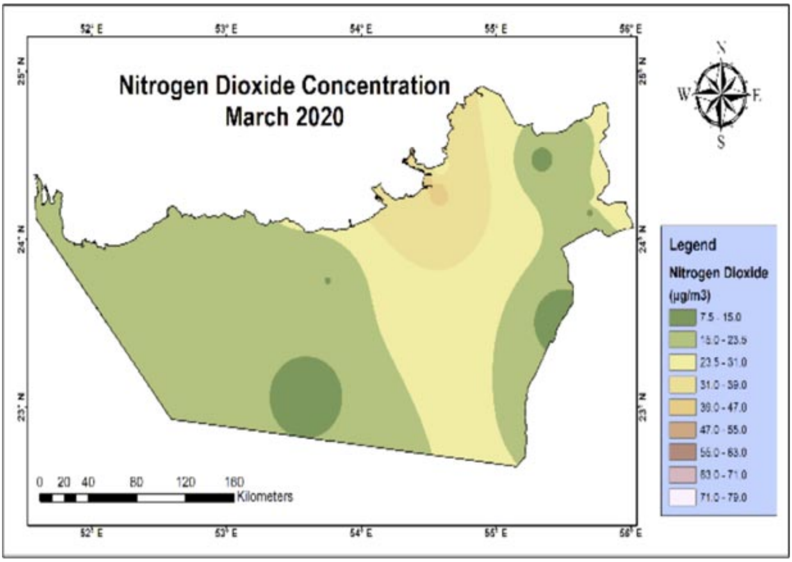
TABLE 3
NO2 Percentage Change

Stations Land Use	Percentage Change in NO2 Levels (March - April 2020)
Urban Traffic	-52.74
Suburban Industrial	-56.48
Urban Background	-40.54
Suburban Background	-59.76
Rural Background	-31.54
Rural Industrial	-18.99

NO2 Variability

The absolute magnitude of the percentile drops in NO_2 levels between March and April 2020 are shown in Table 3. Negative percentages refer to drop in the levels while positive percentages refer to an increase in the pollutant concentration levels. The highest levels of drop in NO_2 levels were registered by the suburban background stations (~ 60%) followed by the stations in the groups suburban industrial and urban traffic stations (52%-56%). These stations are located within suburban residential areas where motor vehicle movement was significantly reduced during April 2020. This suggests that most of the NO_2 emissions sources are from vehicles within the different cities and towns in the Emirate. Further, it confirms the

FIGURE 2
NO2 Levels Variations between March-April 2020 at Different Station Groups

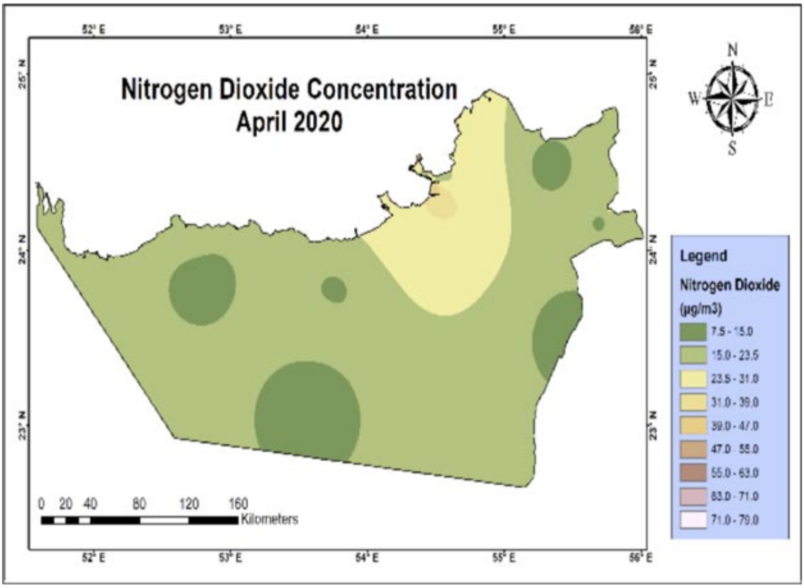


initial presumption of the research that NO_2 levels should drop significantly due to the lockdown measures which greatly reduced vehicle traffic volume in April 2020 in the Emirate of Abu Dhabi. It should be noted that lockdown measures in the emirate were started in the last week of March 2020 and this explains that the percentage changes in the month of April 2020 are usually higher than those in March 2020 across all station groups. Figure 2 shows that the trends of the NO_2 levels were decreasing between March and April 2020 for all station groups, further confirming the previous results.

The spatial distribution of the NO_2 concentrations across the Emirate in March and April 2020 are shown in Figure 3. The maps were generated using the inverse distance weighting (IDW) interpolation method, including all individual stations monthly means for March and April 2020.

FIGURE 3

Spatial Distribution of NO2 Concentrations over the Study Area



Generally, the concentration levels of NO_2 are higher in March in comparison to April 2020, as can be observed in the map. The northeastern part of the Emirate of Abu Dhabi that includes the capital city of Abu Dhabi consistently showed high levels of NO_2 throughout March 2020. This is predominantly due to the large urban population in the city and the massive traffic volume. The western part of the Emirate generally shows low levels of NO_2 concentrations, with desert areas showing medium levels of NO_2. The pattern observed in April 2020 is very different than the pattern of distribution observed in March. In particular, the drop in April 2020 is quite noticeable in the map in comparison with March 2020 due to the lockdown measures that significantly reduced traffic volume and vehicular flow in the Emirate.

An initial presumption of this study was that lockdown measures would lead to less traffic volume which in turn should lead to lower levels of NO_2 concentrations throughout the study areas. In order to correlate changes in NO_2 concentration levels in 2020 with traffic volume measures, the study chose to access transportation data in close proximity to the air pollution stations, in particular on bridges that provide access to Abu Dhabi Island from the east, west and south (Figure 4). The data consisted of the traffic volume, using the number of cars as a measure of volume, entering the island in a 24-hour period on selected days during the period March – April 2020 (Table 3). The data represented traffic volume at four bridges: Sheikh Khalifa Bridge, Sheikh Zayed Bridge, Mussafah Bridge, and Maqta Bridge, all bridges in Abu Dhabi, UAE. Figure4 shows the location map of these four bridges in Abu Dhabi, UAE, where Sheikh Zayed Bridge connects Abu Dhabi Island to the mainland.

FIGURE 4
Bridges Locations in Abu Dhabi, UAE

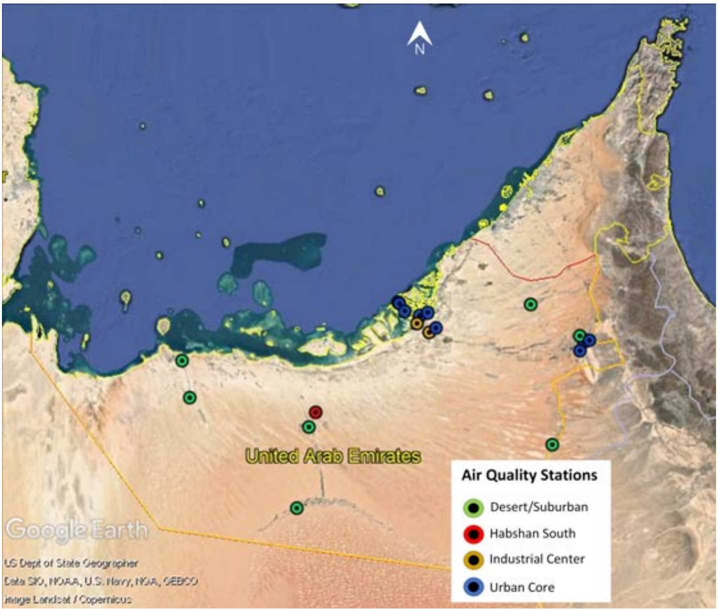
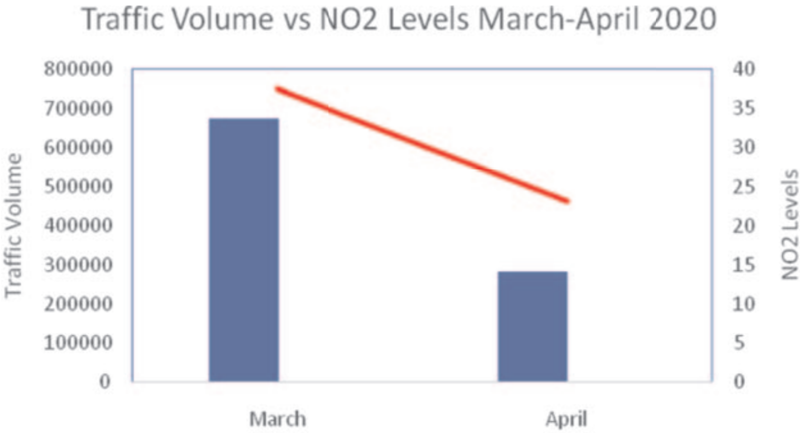


Figure 5 illustrates the changes of incoming traffic volume into Abu Dhabi Island at the bridges in both March and April 2020. The figure

FIGURE 5

Bridges Traffic Volume



shows the average monthly traffic volume of the four bridges along with the average monthly NO_2 levels in Abu Dhabi Island. It can be clearly seen that as the traffic volume decreases the NO_2 levels decrease as well.

Table 4 shows the traffic volume of all four bridges connecting the city of Abu Dhabi to the mainland. There was approximately an average of 60% reduction in the traffic volume across all the bridges in April 2020. From the overall analysis, it is clear that the most significant reduction of traffic volume occurred during the COVID-19 lockdown phase of April 2020.

Table 4

Traffic Volume March – April 2020

Month	Traffic Volume Shiekh Khalifa Bridge	Traffic Volume Shiekh Zayed Bridge	Traffic Volume Mussafah Bridge	Traffic Volume Maqta Bridge
March	81876	92949	295677	202724
April	34586	31733	143945	72060
Percentage Traffic Drop	-58	-66	-51	-64

The Spearman rank-order correlation coefficient between NO_2 hourly levels reported by Bain Al Jessrain air quality station and the traffic volume passing over Musaffah Bridge demonstrate a significant moderate positive association of 0.476 at the 0.05 level of significance (Table 5).

PM2.5 Variability

The present study also focused on the impact of the lockdown measures during the early months of 2020 and the reduced human activities on the levels of the air pollutant PM2.5. Generally, it is believed that PM2.5 air

TABLE 5
Spearman Rank-Order Correlation Coefficient Analysis for NO2, PM2.5, and Traffic Volume crossing Musaffah Bridge on April 14, 2020

		Traffic Volume Crossing Musaffah Bridge
NO2	Correlation Coefficient	.476*
	Sig. (2-tailed)	.019
	N	24
PM2.5	Correlation Coefficient	-.272
	Sig. (2-tailed)	.198
	N	24

*. Correlation is significant at the 0.05 level (2-tailed).

pollution is caused by two main sources: human sources (transportation, oil and gas activities, industry activity) and natural sources such as dust and sand storms (Abu Dhabi Environment Agency, 2018). The PM2.5 levels show very different patterns that were not expected. Initially, it was assumed that PM2.5 levels would follow the same trends as NO2 levels during the lockdown period.

However, Table 6 shows that PM2.5 levels in April 2020 have increased in comparison to March levels in suburban industrial and rural background stations. This increase in suburban industrial and rural background stations can only be explained as being due to cross-boundary transport and meteorological natural processes which significantly impacted PM2.5 levels. This is likely as both areas have witnessed a significant drop in human activity and a drop in NO2 levels, and it was expected that PM2.5 should show some level of drop.

TABLE 6
PM2.5 Percentage Change, March - April 2020

Stations Landuse	Percentage Change in PM2.5 Levels (March - April 2020)
Urban Traffic	-1.92
Suburban Industrial	65.55
Urban Background	-33.58
Suburban Background	-15.74
Rural Background	30.96
Rural Industrial	-33.12

Reduced anthropogenic activities are not necessarily a prerequisite to reduced air pollution (Wang et al. 2020a; Wang et al. 2020b), particularly in arid and semi-arid regions such as in the case of Abu Dhabi. Meteorological conditions can be unfavorable leading to increased dust activity. In spite of the lockdown measures, the industrial areas continued to operate, albeit at a reduced rate in certain areas, so PM2.5 levels would not have been expected to drop. The statistical analysis of the Spearman rank-order correlation coefficient between PM2.5 and traffic volume crossing Musaffah Bridge shows no significant relationship at the 0.05 level (Table 5).

Conclusions

This study analyzed the concentrations of air pollutants, including NO_2 and $PM_{2.5,}$ before and during the implementation of the COVID-19 national lockdown periods in suburban, industrial, urban and rural areas in the Emirate of Abu Dhabi. Statistical analysis was performed on the daily data to investigate the variability of pollutant levels in the Emirate during the period March-April 2020. Graphs with spatio-temporal variations of NO_2 and $PM_{2.5}$ levels were developed from the daily data for each station group. It was found that the pollutant NO_2 levels significantly decreased during the lockdown period, in the range of 19% to 60%. This lower concentration level of NO_2 has been found to be strongly associated with a significant reduction of 60% in traffic volume in the Abu Dhabi region. A significant moderate positive relationship (r_s 0.476) was found between NO_2 hourly levels reported by the Bain Al Jessrain air quality station and the traffic volume passing over Musaffah Bridge. Future studies should examine similar relationships across a variety of main street networks. $PM_{2.5}$ levels have shown different patterns in comparison to NO_2 levels. $PM_{2.5}$ levels varied between during the lockdown in April 2020, with increases ranging from 31% to 65% in rural and suburban industrial areas and decreases, ranging from 2% to 33% in urban and suburban population areas. It has previously been shown that reduction in anthropogenic activities does not necessarily lead to reduction in the levels of particulate matter, since meteorological natural processes can be unfavorable to lower levels.

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Data Availability Statement

The data that support the findings of this study are available from Environment Agency - Abu Dhabi (EAD). Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the main author with the permission of EAD https://www.ead.gov.ae/en .

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