Assessment of Air Pollutants Levels in Major Jordanian Cities Before and After the COVID-19 Lockdown

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Abstract

This study assessed the impact of the partial COVID-19 lockdown on air pollutant levels in Jordan's three major cities: Amman, Irbid, and Zarqa. The focus was on four key pollutants: Particulate Matter (PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO). Daily pollutants measurements data were collected from air quality monitoring stations of the Ministry of Environment between 17 March and 30 June for the years 2019 to 2024. Analysis of Variance (ANOVA) and Tukey's Honest Significant Difference (HSD) test were used to identify significant differences between means at P $\leq$0.05. The findings revealed that levels of certain pollutants were decreased during the COVID-19 lockdown period in 2020, although long-term trends and recovery patterns varied among cities and pollutants. The results demonstrated a significant decrease in PM_{10}, NO_2, and SO_2 concentrations during the lockdown period in 2020 compared to the pre-lockdown year of 2019, particularly in Amman and Zarqa. PM_{10} levels declined by 33.29% in Amman, 30.44% in Irbid, and 14.20% in Zarqa. Similarly, NO_2 concentrations decreased by 44.18% in Zarqa, 37.42% in Amman, and 22.27% in Irbid. A notable reduction in SO_2 was observed only in Zarqa (77.77%), likely linked to industrial shutdowns, while Amman and Irbid showed minor changes. In contrast, CO levels exhibited variable trends: while Amman and Irbid exhibited relative stability or slight decreases during 2020, Zarqa experienced a consistent and significant increase in CO levels in the years following the lockdown.

Keywords: COVID-19 pandemic; Air pollutants; partial lockdown; Jordan

1. Introduction

At the end of 2019, a third highly pathogenic coronavirus, SARS-CoV-2, emerged in the human population, following the outbreaks of SARS-CoV in 2003 and MERS-CoV in 2012. This virus, responsible for the COVID-19 disease, was officially recognized as a global pandemic by the World Health Organization (WHO) on March 11, 2020.

As of September 21, 2024, over 776 million confirmed cases of COVID-19 have been reported worldwide, resulting in a total of 7.07 million deaths. In Jordan, the virus has affected 1.70 million individuals, underscoring the widespread impact of the pandemic (WHO, 2024).

The COVID-19 pandemic led to unprecedented global lockdowns, profoundly disrupting daily life and reshaping various sectors, including education, healthcare, social interactions, and economic structures (Sohrabi, Alsafi, O'neill, & Joseph, 2020). Countries around the world, including Jordan, implemented measures such as business closures and social distancing to limit the spread of the virus. While the primary focus was on addressing the immediate health crisis, the lockdowns and restrictions also had unintended environmental impacts. A key concern was the potential effect of the pandemic on the air pollutants levels. Understanding this relationship is essential for developing effective strategies to protect public health and mitigate pollution emissions (Burnett et al., 2018; Dabbour, Abdelhafez, & Hamdan, 2021).

Initial evaluations indicated a decrease in human-caused air pollution in countries responding to the COVID-19 pandemic. NASA researchers compared the NO_2 levels measured by the Ozone Monitoring Instrument (OMI) in 2020 with the average levels recorded during the same period from 2005 to 2019. The analysis revealed that NO_2 concentrations in eastern and central China were notably lower in 2020, showing a reduction of 10 to 30% compared to typical levels for that time period (NASA, 2020).

Berman and Ebisu (2020) examined air quality in the United States of America during the COVID-19 pandemic, focusing on $PM_{2.5}$ and NO_2 levels from 8 January to 8 March, 2020 and compared them to data from the same period between 2017 and 2019. Significant NO_2 declines (25.5%, 4.76 ppb) were observed during the COVID-19 period compared to historical data. $PM_{2.5}$ also decreased (4.45%, 0.28 $\mu g/m^3$), especially in urban counties and counties from states that implemented early non-essential business closures.

A study of Nakada and Urban (2020) investigated changes in air quality in São Paulo, Brazil, during the 2020 COVID-19 lockdown. Data from four air quality stations were analyzed and compared with the five-year monthly averages for February, March and April (2015–2020). The results showed a significant decrease in NO, NO_2, and CO levels during the lockdown period, while ozone (O_3) levels increased in areas with heavy traffic. Although the lockdown led to improved air quality, it also had negative social and economic impacts, including job losses and an increase in COVID-19-related deaths."

In Jordan, the COVID-19 pandemic lockdown began on March 17, 2020, when the government enforced strict measures including curfews and closures, to curb the spread of COVID-19 virus. Most strict lockdown measures began to ease by June, 2020 with various intermittent restrictions continuing until the government lifted most of the significant limitations by February 27, 2021 (ESC, 2020).

Although there are a lack of studies regarding the effect of the lockdown during COVID-19 pandemic on air quality in Jordan, Dabbour et al. (2021) explored the real-time effects of the COVID-19 pandemic on air pollution levels in Jordan's three major cities –Amman, Irbid, and Zarqa– from March 15 to June 30 over the years 2016 to 2020. The results showed a statistically significant reduction in the mean concentrations of CO, PM_{10}, SO_2, and NO_2 during the study period. Zarqa experienced the largest reduction in SO_2 and NO_2 levels, while Irbid had the greatest decrease in CO and PM_{10} levels. Additionally, correlation tests, multilayer perceptron analysis, and global sensitivity analysis using Sobol analysis indicated that meteorological factors such as humidity, wind speed, average temperature, and pressure had a direct impact on the concentrations of these pollutants both before and after the COVID-19 pandemic in all three cities.

Meanwhile, Shatnawi and Abu-Qdais (2021) developed an Artificial Neural Network (ANN) model to simulate and predict the concentrations of three air pollutants –NO_2, SO_2, and PM_{10}– in Irbid city, before and during the before and during the spread of the COVID-19 virus in Jordan. The data was obtained from the air quality monitoring station for the year 2019 and the first quarter of the year 2020. One of the key findings indicated that pollutant concentrations decreased by varying percentages during the lockdown, with reductions ranging from 29% for PM_{10} to 72% for NO_2, compared to their levels prior to the pandemic.

The main objective of the current study was to assess the impact of the partial lockdown during COVID-19 pandemic on air quality in Jordan's three major cities: Amman, Irbid, and Zarqa. The analysis focused on four key air pollutants: Particulate Matter (PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO). These pollutants are major contributors to air pollution and have significant adverse health and environmental effects (Hosamane & Desai, 2018). Based on previous research and the anticipated reduction in traffic due to mandated business closures, it is hypothesized that a substantial decline in emissions of PM_{10}, NO_2, SO_2 and CO will be observed during the COVID-19 pandemic.

2. Methodology

2.1. Study area

Jordan is a Middle Eastern country located in the Southern Levant region of West Asia. It is bordered by Syria to the north, Iraq to the east, Saudi Arabia to the south, and the occupied Palestinian territories to the west. The country has a total area of 89,318 km^2 and a total population of 11,516,000 people. Jordan is divided into three main regions: the northern, middle, and southern region. The southern region extends up to 31°12′ N latitude, the middle region extends up to 32°05′ N latitude, and the northern region extends up to 32°35′ N latitude (DoS, 2023).

To study the impact of the COVID-19 pandemic on air pollution in Jordan, the study focused on the country's three major cities –Amman, Irbid, and Zarqa– selected for their importance and the availability of air quality data. These cities offer valuable insights into potential changes in pollution levels during the pandemic in densely populated areas. Table 1 summarizes the estimated population, area, and population density of these major urban centers.

Amman, the capital and largest city of Jordan, has an estimated population density of 637.9 person/km^2 (DoS, 2023). The city experiences a generally mild and dry climate. Summers are moderately long and sunny, with July and August being the hottest months, with an average temperature of 32°C. while January is the coldest, averaging 8°C. Spring is warm and breezy, with high temperatures reaching around 28°C. Spring typically begins between April and May and lasts for about a month. Winter starts around late November and extends from early to mid-March, with temperatures often staying near or below 17°C. The city receives an average annual rainfall of around 300 mm (MoEnv, 2020; Dabbour et al., 2021).

Irbid is the second largest city in Jordan, with an estimated population density of 1359 person/km^2 (DoS, 2023). The city is located approximately 70 km north of Amman and 20 km south of the Syrian border. Irbid has a hot-summer Mediterranean climate, with daytime temperatures reaching approximately 38°C. Winters in Irbid are relatively cool and rainy compared to other Jordanian cities, with winter temperatures comparable to those in Amman, and the city receives an average annual rainfall of around 450 mm (MoEnv, 2020; Shatnawi & Abu-Qdais, 2021).

Zarqa is the third largest city in Jordan, with a population density of nearly 345.8 person/km^2 (DoS, 2023). The city is situated 20 km northeast of Amman. The city has a desert climate characterized by long, hot, and dry summers, and cold, mostly clear winters. Throughout the year, temperatures generally range from 6°C in winter to 34°C in summer. The average annual rainfall is around 182 mm (MoEnv, 2020; Dabbour et al., 2021).

2.2. Data collection

The daily averages readings of four air pollutants – particulate matter with an aerodynamic diameter of ≤ 10 microns (PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO) – were obtained from 11 real-time air quality monitoring stations located in Jordan's largest cities (Amman, Irbid, and Zarqa).

The Ministry of Environment (MoEnv) is the primary agency responsible for monitoring air quality through real-time monitoring stations located in different areas across Amman, Irbid, and Zarqa. Therefore, the data were sourced from the Ministry of Environment's air quality monitoring network distributed as follows: six stations in Amman (GAM, KHG, MAH, TAB, UNI, and YAR), three in Zarqa (HH, HAJ, and MAS), and two in Irbid (BAR and HSC). The location of the air monitoring stations within the three cities is shown in Figure 1, illustrating the spatial distribution of the monitoring sites used in this study.

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Table 1: Estimated population of the Kingdom, area and population density by governorate (Amman, Irbid, and Zarqa) according to DoS (2023).

Governorate	Total Population (%)	Area (km^2)	Area (%)	Pop. Density ($person/km^2$)
Amman	4,834,500 (42.0)	7,579	8.5	637.9
Irbid	2,135,400 (18.5)	1,572	1.8	1358.6
Zarqa	1,646,600 (14.3)	4,761	5.4	345.8

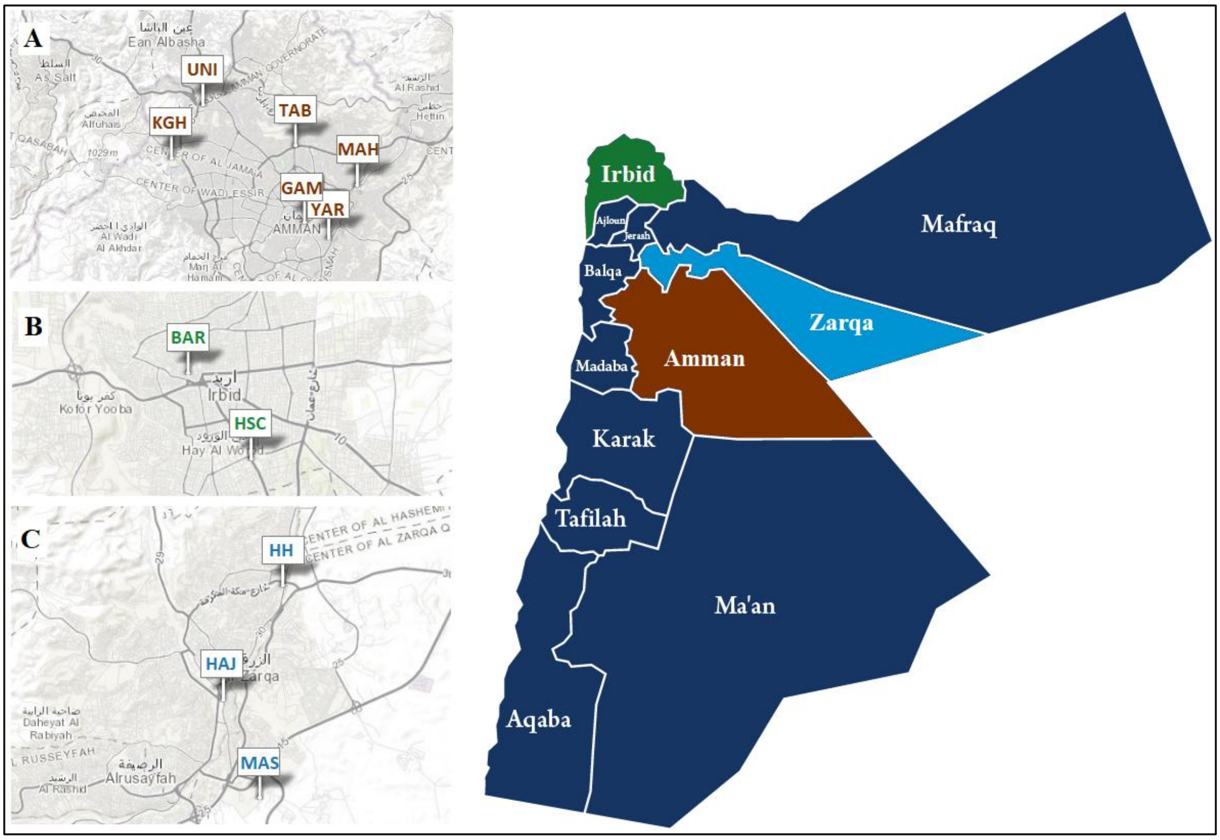

Figure 1: Map of Jordan highlighting the study areas and the location of ambient air monitoring stations in Amman (A), Irbid (B), and Zarqa (C).

The analyzed data of the current study covered the period from March 17 to June 30. This period reflects the partial lockdown phase occurred in 2020, classified as the pre-lockdown period. Similarly, data for the same timeframe in 2020, 2022, 2023, and 2024 was included as part of the post-lockdown phase. However, data from 2021 was excluded due to a lack of sufficient information.

3. Results and Discussion

3.1. Particulate Matter (PM_{10})

The concentrations of emitted PM_{10} in the three studied cities for the years 2019, 2020, 2022, 2023 and 2024, are presented in Figure 2. The results showed that PM_{10} levels in 2019 were relatively high in all three cities, with Amman scoring the highest mean (46.52 µg/m³).

During the lockdown period in 2020, PM_{10} levels dropped in all cities. Amman showed a decrease from 46.52 to 31.03 µg/m³ (33.29 %), Irbid decreased from 35.13 to 24.44 µg/m³ (30.44 %), and Zarqa from 42.95 to 36.85 µg/m³ (14.20 %). This suggests that reduced human activity during the partial lockdown period may have contributed to lower PM_{10} concentrations. However, while PM_{10} levels were generally lower after 2020 compared to 2019, with minor fluctuations between 2022, 2023, and 2024, statistical analysis did not reveal significant differences.

It is worth mentioning that, the Minister of Environment in Jordan reported that PM_{10} levels across monitoring stations in Amman, Irbid, and Zarqa showed a declining trend from 2016 to 2019 (MoEnv, 2020). This suggests that economic factors, possible industrial slowdowns and pre-existing regulatory efforts may have already been influencing the decline in PM_{10} levels. The lockdown in 2020 likely intensified this trend by further reducing industrial activities and human mobility. Therefore, while the lockdown played a role in reducing PM_{10} levels, it should be viewed in the broader context of economic and industrial changes in Jordan (Adebanjo & Shakiru, 2022).

Results in Figure 3 displays the monthly mean concentration of PM_{10} from March 17 to June 30 for the years 2019 to 2024 across the three cities. Results indicated that in 2019, PM_{10} levels exhibited significant fluctuations, with sharp peaks in March and May, reaching 58.51 µg/m³ and 44.50 µg/m³ respectively, marking the highest values observed across all months and years under investigation. From 2020 onward, particularly after April, PM_{10} levels demonstrated a more consistent pattern with minor variations. Notably, during the 2020 COVID-19 lockdown, PM_{10} concentrations in March rose to 36.10 µg/m³, a value higher than those recorded in the same month during 2022 to 2024. The lowest monthly PM_{10} concentration was observed in March 2024, reaching 22.37 µg/m³.

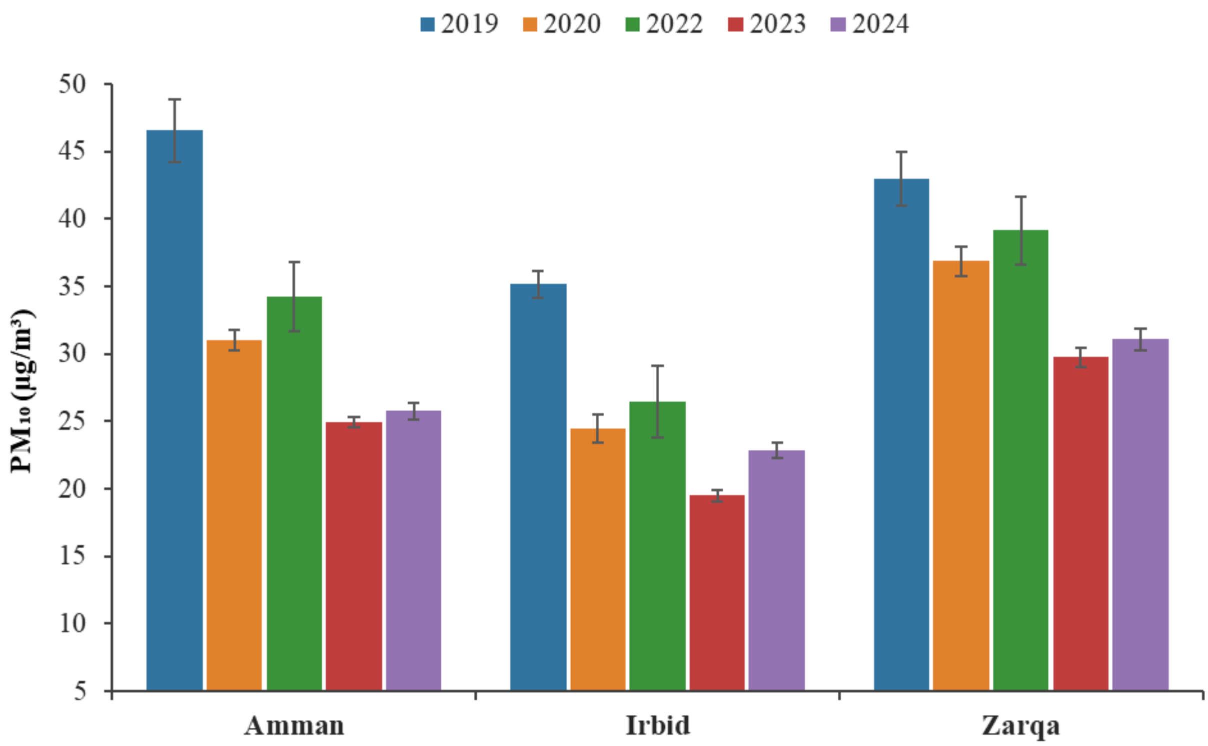

Figure 2: Yearly mean concentration of particulate matter (PM_{10}) in Amman, Irbid and Zarqa.

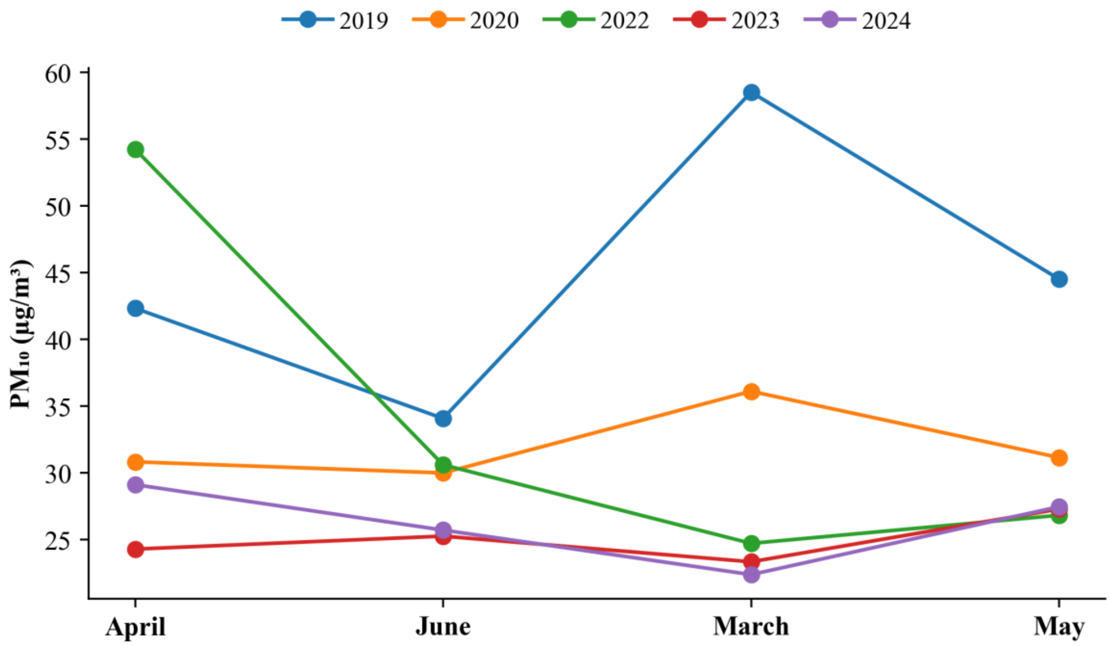

Figure 3: Monthly mean concentration of particulate matter (PM_{10}) from March 17 to June 30 for the years 2019 to 2024.

3.2. Nitrogen dioxide (NO_2)

As shown in Figure 4, a noticeable reduction in NO_2 levels occurred during the partial lockdown in 2020 in Amman and Zarqa compared to pre-lockdown period in 2019, with the maximum reduction in Zarqa and Amman, while a slight decrease was observed in Irbid.

Zarqa showed a significant decrease from 12.78 µg/m³ to 7.13 µg/m³ (44.18 %), Amman from 13.01 µg/m³ to 8.13 µg/m³ (37.42 %), Irbid decreased from 6.47 µg/m³ to 5.03 µg/m³ (22.27 %). This reduction may reflect the decrease in activities that generate NO_2, such as vehicle emissions and industrial processes, during the lockdown period. Dabbour et al. (2021) showed a similar pattern of reduced NO_2 levels in Amman, Irbid, and Zarqa during the partial COVID-19 lockdown compared to the period before the lockdown period. A comparable trend was also reported by Berman and Ebisu (2020) in the U.S., where NO_2 levels significantly declined during the lockdown.

The results in Figure 4 also revealed that, the NO_2 levels fluctuated after 2020, with some cities returning to or exceeding pre-lockdown levels. Amman experienced an increase to 17.08 µg/m³ in 2022 but dropped again in the following years. Irbid and Zarqa also experienced fluctuations, with Irbid's NO_2 levels reaching a peak of 14.08 µg/m³ in 2023, suggesting a possible recovery in businesses and industries activity after the partial lockdown.

Figure 5 illustrates that in 2020, during the partial lockdown, NO_2 levels showed a noticeable reduction across all months compared to other years, specifically in April (6.06 µg/m³) and March (6.22 µg/m³) which had the lowest NO_2 levels, whereas the highest NO_2 levels were observed in May 2022 (15.18 µg/m³), followed by May 2019 (13.57 µg/m³).

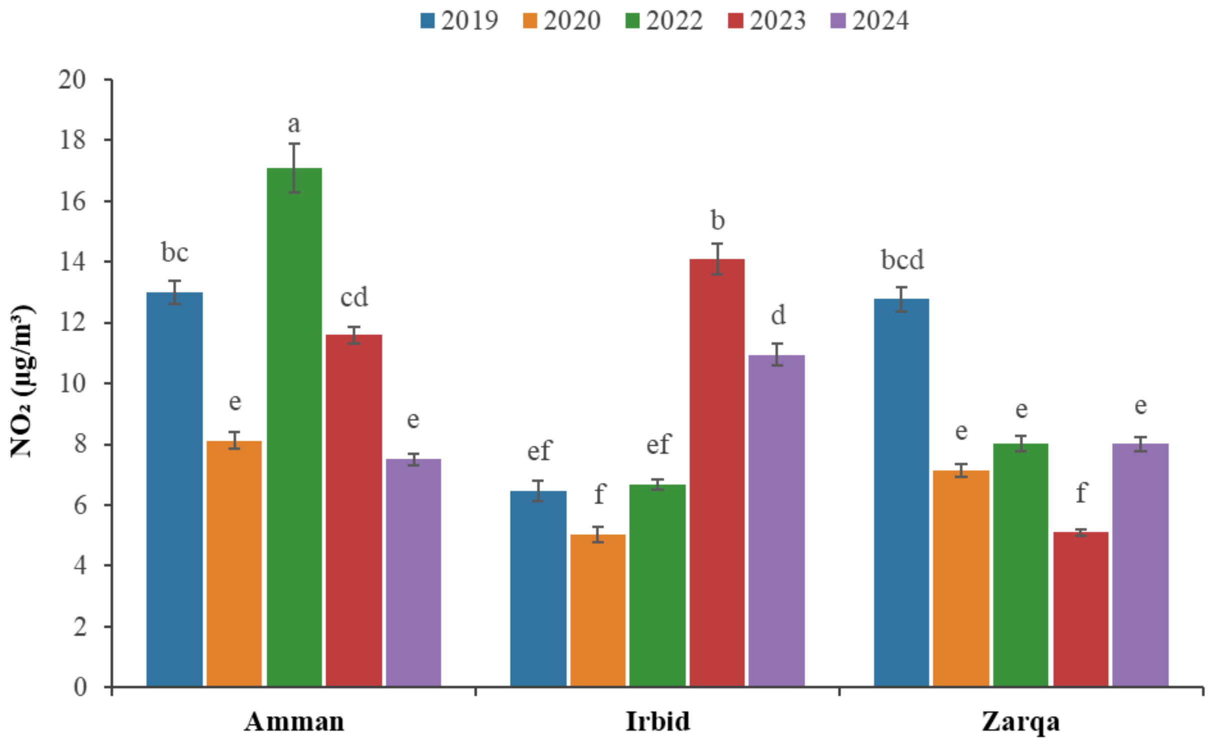

Figure 4: Yearly mean concentration of nitrogen dioxide (NO_2) in Amman, Irbid and Zarqa. Columns with similar letters are not significantly different at $P \leq 0.05$.

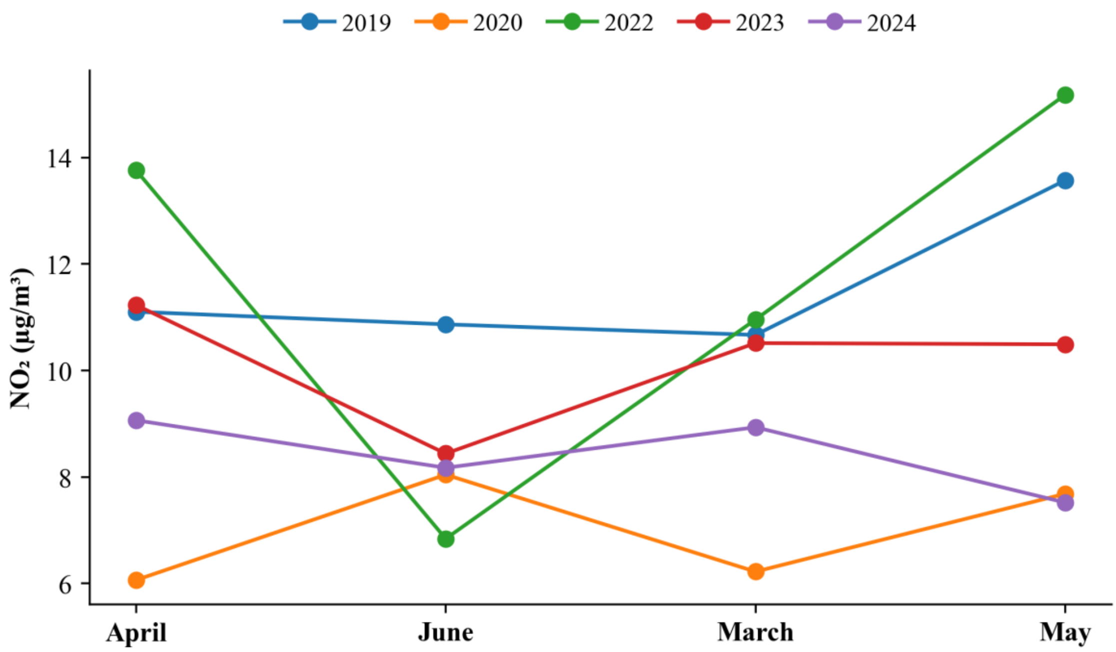

Figure 5: Monthly mean concentration of nitrogen dioxide (NO_2) from March 17 to June 30 for the years 2019 to 2024.

3.3. Sulfur dioxide (SO_2)

Results of the current study exhibited a reduction in SO_2 levels in Zarqa, which dropped significantly from 8.78 µg/m³ to 1.95 µg/m³ (77.77 %). The significant decrease in SO_2 as illustrated in Figure 6, as well as in NO_2 levels (Figure 5), observed in Zarqa city can likely be attributed to the closure of industries during the lockdown period. These industries, which used high-sulfur and high-nitrogen fuels, contributed to the city's air pollution.

Also, the SO_2 results in Figure 6 showed that Amman and Irbid had slight changes in SO_2 levels, with Amman slightly decreasing from 3.03 µg/m³ to 2.65 µg/m³ (12.45 %), and Irbid slightly increasing from 2.75 to 3.19 µg/m³ (15.98 %). After 2020, SO_2 levels began to rise in all cities, though they did not return to pre-lockdown levels in Zarqa by 2024. Amman showed a significant increase, particularly in 2023 and 2024, where levels reached 7.37 µg/m³ in 2024. Zarqa's levels also began rising but remained lower than the pre-pandemic level in 2019, while Irbid had more moderate increases since Irbid has no major industries or airports.

As shown in Figure 7, during the partial lockdown period in 2020, the SO_2 levels were consistently lower across all months compared to the corresponding months in 2019 and the subsequent years. In March 2020, the SO_2 concentration decreased to 2.08 µg/m³, which is the lowest among all years and months under investigation. Conversely, the highest SO_2 concentration was observed in April and June 2024, reaching 6.72 and 6.84 µg/m³ respectively.

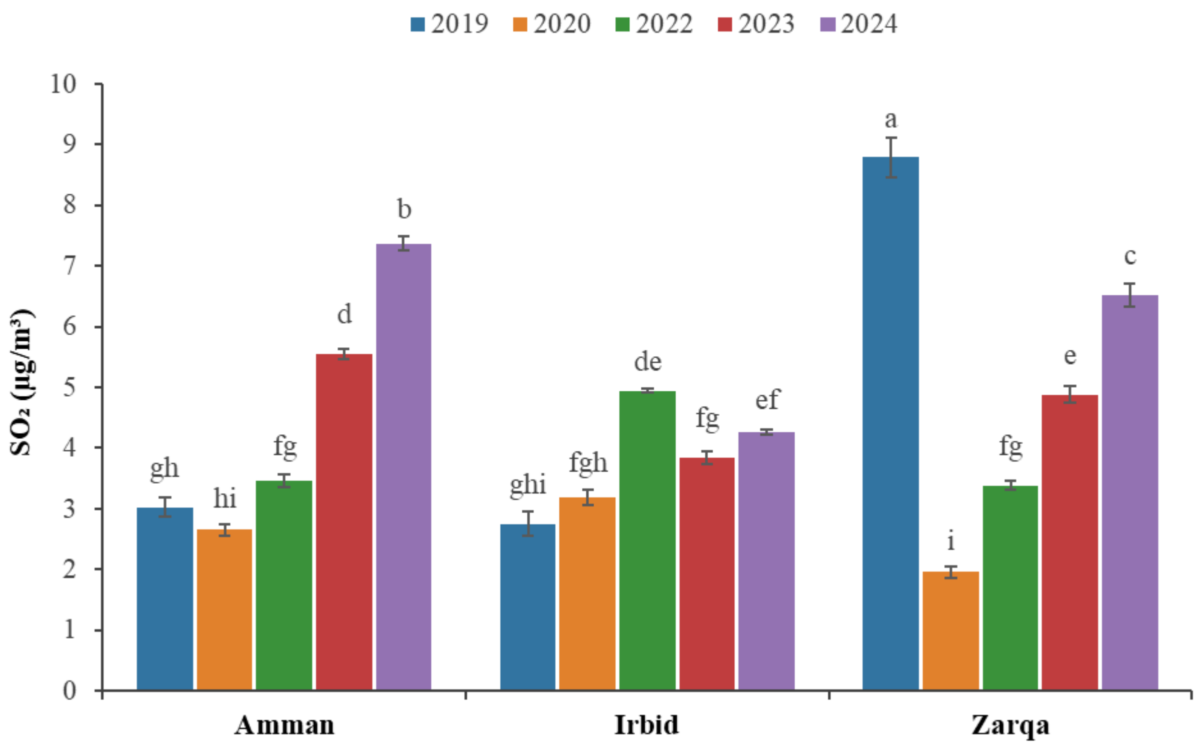

Figure 6: Yearly mean concentration of sulfur dioxide (SO_2) in Amman, Irbid and Zarqa. Columns with similar letters are not significantly different at P≤0.05.

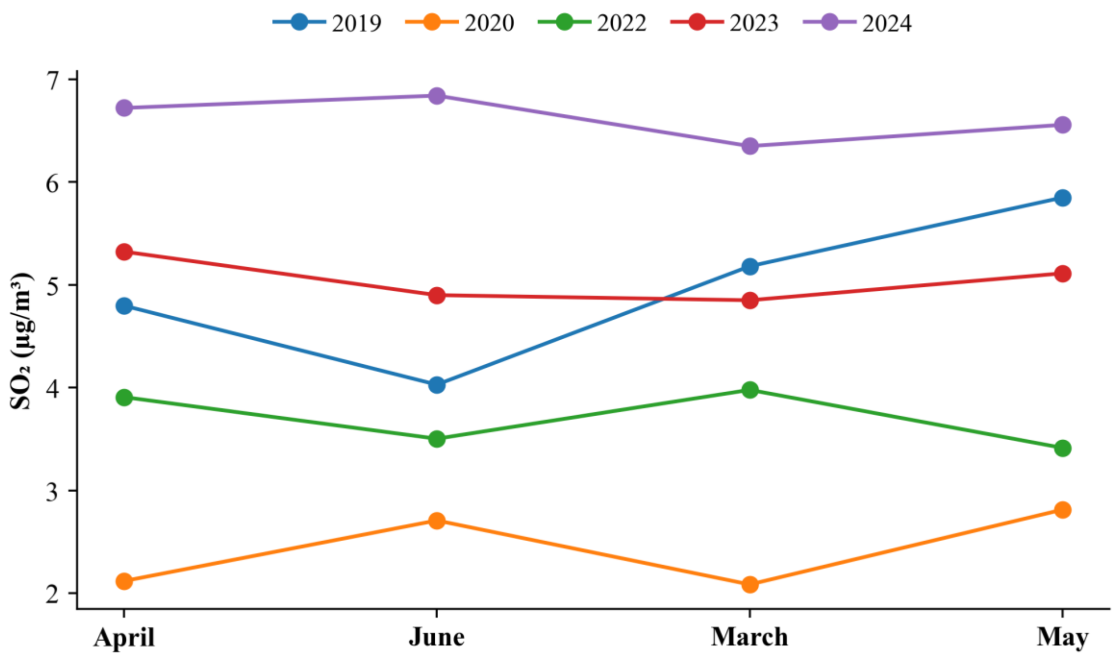

Figure 7: Monthly mean concentration of sulfur dioxide (SO_2) from March 17 to June 30 for the years 2019 to 2024.

3.4. Carbon monoxide (CO)

Results presented in Figure 8 show that the CO levels in Amman were relatively stable from 2019 to 2022, ranging between 20.15 for 2019 and 18.67 for 2022 µg/m³ followed by a moderate increase in CO levels in 2023 (25.53 µg/m³) and 2024 (25.35 µg/m³). In contrast, CO levels in Irbid showed an increase during the lockdown period in 2020 reaching 23.89 µg/m³, before dropping significantly in subsequent years. While, Zarqa showed a continual increase in CO levels after 2020, peaking in 2024 with the highest observed concentrations (52.08 µg/m³) in this study, significantly higher than all years across all cities.

Regarding the CO monthly mean concentrations presented in Figure 9, the results were not significantly different at P-value $\geq$0.05. The results indicated that the CO levels, in the post-lockdown year (2019), were relatively consistent across all months, with values ranging between 17.79 µg/m³ in June and 18.34 µg/m³ in May. During the partial lockdown period in 2020, CO levels increased slightly in March (22.07 µg/m³) and June (20.62 µg/m³) compared to 2019 and 2022, while remained relatively lower in April and May (17.74 and 17.95 µg/m³) respectively compared to all other months and years. Results also showed that the CO monthly means in 2024, followed by 2023 showed the highest CO values across all months. Overall, May 2024 exhibited the highest CO levels scoring 28.79 µg/m³.

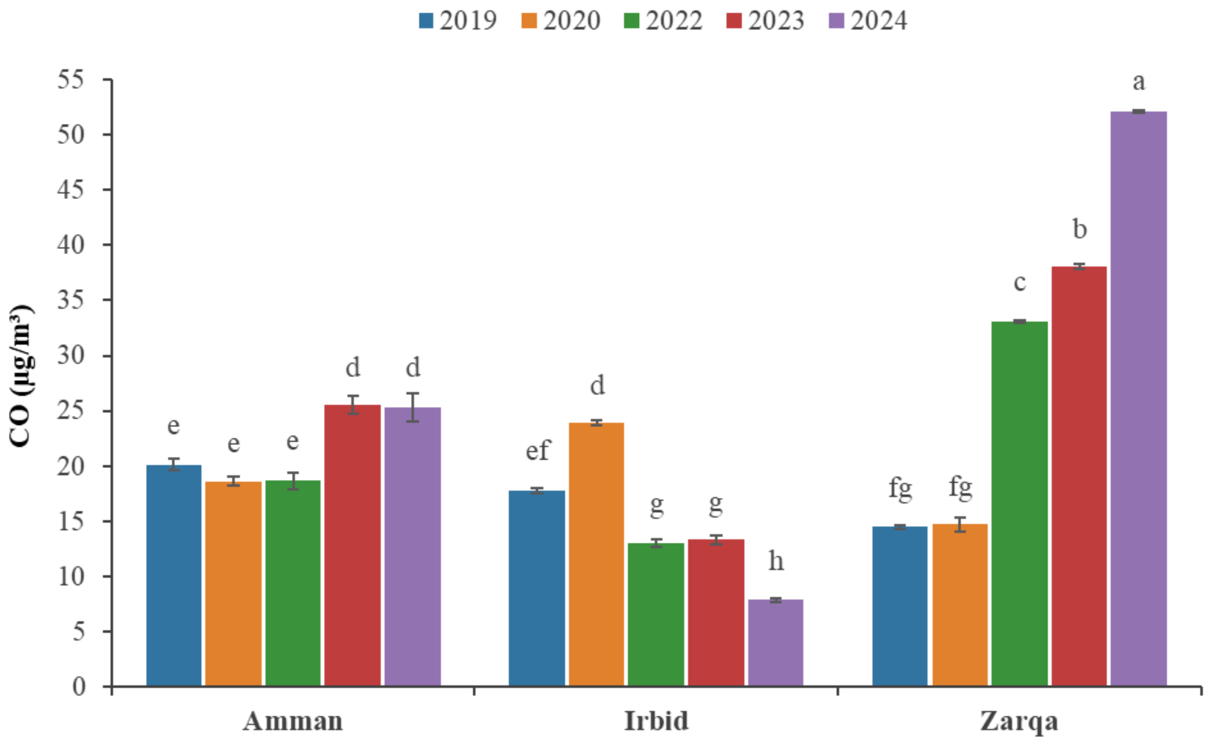

Figure 8: Yearly mean concentration of carbon monoxide (CO) in Amman, Irbid and Zarqa. Columns with similar letters are not significantly different at P≤0.05.

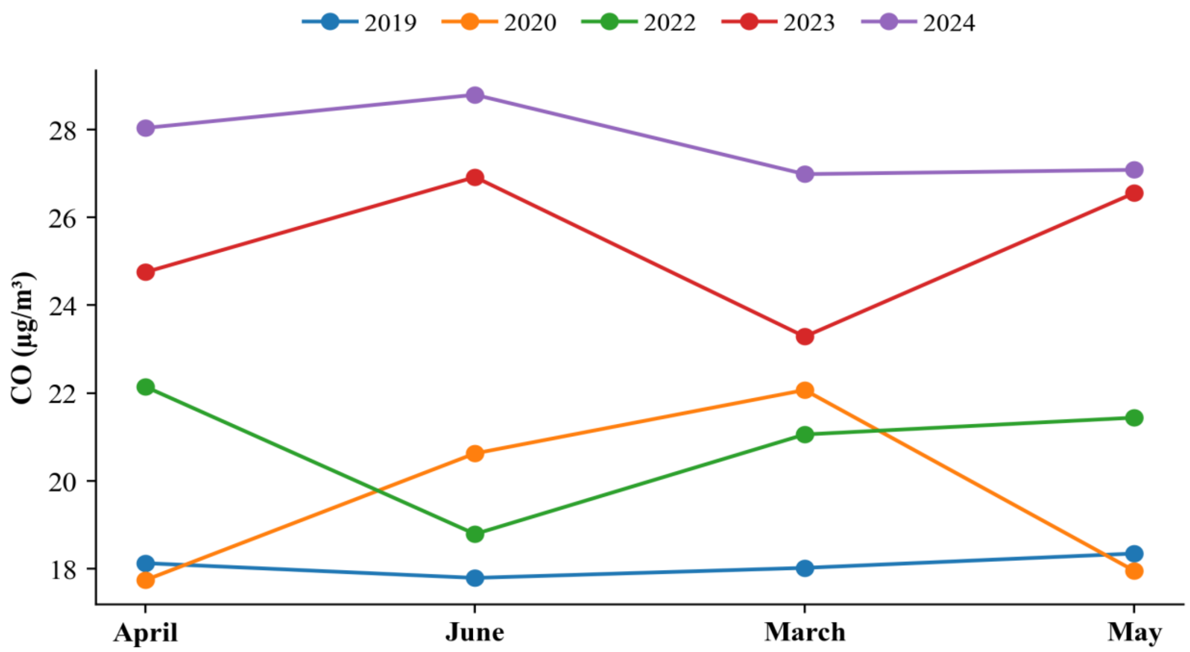

Figure 9: Monthly mean concentration of carbon monoxide (CO) from March 17 to June 30 for the years 2019 to 2024.

4. Conclusions

In this study, the impact of the COVID-19 pandemic on measured air pollution in the three major cities of Jordan (Amman, Irbid and Zarqa) was explored. To achieve this objective, Analysis of Variance (ANOVA) and Tukey's Honest Significant Difference (HSD) test were employed to compare the concertation of four key pollutants (PM_{10}, NO_2, SO_2, and CO).

A notable reduction in certain pollutant levels during the COVID-19 lockdown in 2020, with variations across cities and pollutants. PM_{10}, NO_2, and SO_2 concentrations notably decreased during the lockdown compared to 2019, particularly in Amman and Zarqa. PM_{10} levels dropped by 33.29% in Amman, 30.44% in Irbid, and 14.20% in Zarqa, while NO_2 declined by 44.18% in Zarqa, 37.42% in Amman, and 22.27% in Irbid. A sharp reduction in SO_2 (77.77%) was observed in Zarqa, whereas Amman and Irbid showed minimal changes. In contrast, CO trends varied, with Zarqa experiencing a sustained post-lockdown increase, while Amman and Irbid remained stable or saw slight decreases. These findings highlight the complex relationship between human activity, policy interventions, and air quality, suggesting that targeted measures could effectively reduce specific pollutants.

Further research is needed to assess long-term recovery patterns and the sustainability of such reductions. Additionally, it is important to investigate the underlying causes of the varying responses of different pollutants to the lockdown and to assess the potential health impacts of these changes. By gaining a deeper understanding of these factors, policymakers can develop effective policies to mitigate air pollution and improve public health in Jordan.

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