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Impact of COVID-19 on the Yearly Concentration Reduction of Three Criteria Air Pollutants and Meteorological Parameters' Effects on Aerosol Dispersion

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ABSTRACT

The primary objective of this study is to evaluate the reduction percentage in the yearly concentrations of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and CO before and after COVID-19 in Amman, the capital city of Jordan, which has the highest population and traffic densities, and Zarqa, an industrial area with 55% of different types of industries. Additionally, this study examines the effect of metrological parameters such as temperature, humidity, and wind speed on air pollutant dispersion, particularly particulate matter 10 (PM_{10}), which is considered uncontrollable. Furthermore, this study highlights the critical environmental and health effects of air pollution. The Ministry of Environment measured the yearly concentration of air pollutants (SO_2, NO_2, CO, and PM_{10}) in three areas (Amman, Zarqa, and Irbid) in 12 stations in nearby industrial, urban, and traffic areas using the nitric oxide (NO) NO_2 chemiluminescence analyzer Model 42i, hydrogen sulfide (H_2S) and SO_2 analyzer model 450iQ, and PM_{10} Peta Attenuation analyzer. The few air pollution studies in Jordan have primarily focused on average yearly concentrations of SO_2, NO_2, CO, and PM_{10} without considering the monthly or daily variations that greatly concern health and the environment. The results of the present study reveal that during the COVID-19 pandemic, there was a significant decrease in the annual concentrations of H_2S, SO_2, and NO_2 as the reduction percentage in Amman 70, 58, 87% respectively, and in Zarqa 36, 62, 72% respectively. However, there is a slight reduction in CO and PM_{10} with 39 and 18% at Amman and 19% and 40% at Zarqa. This decrease is attributed to the reduction of primary sources of air pollutants, which are linked to the reductions in traffic volume and industrial activities during the lockdown. Furthermore, the results show that the Jordanian government has implemented regulations to address air pollution in residential areas. These regulations aim to prevent the burning of trees and smoking. The government is also adopting new transportation technologies to reduce the impact of CO_2 and other pollutants produced by diesel and gasoline vehicles. The use of green fuels like synthetic natural gas, green methanol, or ammonia, as well as the increasing use of electric cars, are being encouraged. Implementing the bus rapid transit system, which started in 2021 and includes linked lines in the east and west areas of Jordan, has reduced the number of cars used and solved the main issues in crowded regions. Overall, the country has taken significant steps to address and control air pollution.

INTRODUCTION

Geo-Climatic Situation in Jordan

Jordan is divided into three main geographic and climatic areas: the Jordan Valley, where Amman is located, the Mountain Heights Plateau, and the eastern desert or Badia region. The main desert areas are 200-300 km from Amman. These areas include Safawi, which is filled with dunes and hills (Abu-Sharar et al. 2012), and the Al-Azraq and Rewashed regions in the eastern part of Jordan, which constitute 40% of Jordan's deserts (Khatatbeh et al. 2020). Fig. 1 shows the locations of desert areas in Jordan.

Fifteen percent of the desert area in Amman is located in Qasr Al-Qastal, Al-Muaqar, and Al-Mushatta, which are around 22, 26, and 25 km to the east of Amman. Meanwhile, 10% is located in Al-Halabat (around 25 km from Zarqa to the northeast), and 5% is in Qasr Al-Kharranah and Quseir Amra. Although Jordan's climate can vary from Mediterranean to desert, the country's landscape is typically relatively dry. The desert regions' wintertime temperatures

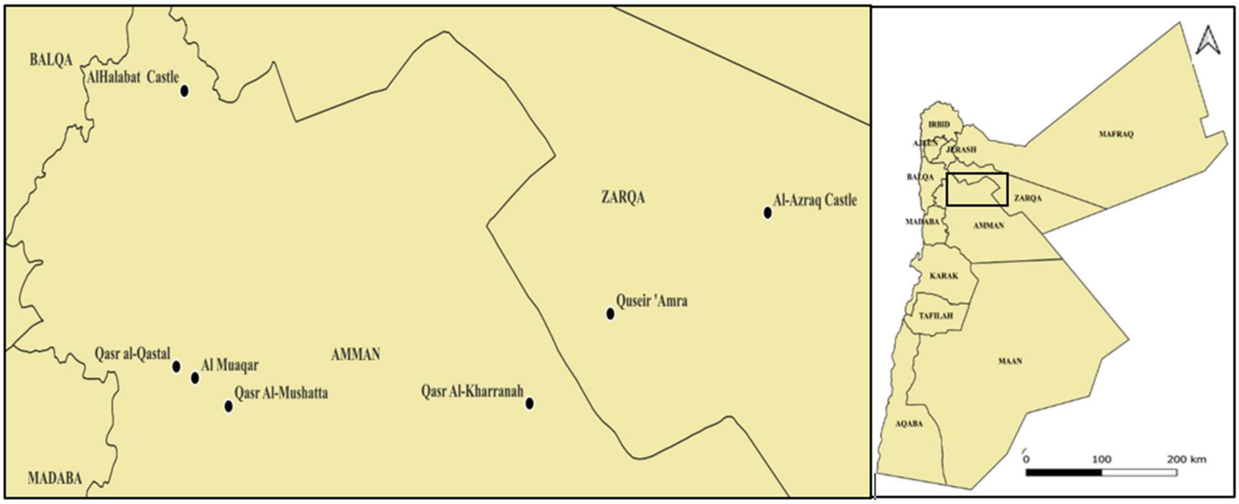

Fig. 1: Locations of desert areas in Jordan.

range from 19 to 22°C, while temperatures in the highlands in the south and north range from 9 to 13°C. Almost 75% of all precipitation occurs in the winter. The dry Sirocco (Khamsin) winds, which impact Jordan's climate and can cause spikes in temperature of up to 15°C, can cause significant temperature anomalies. High daytime temperatures result from the Shamal winds, which blow from the north and northeast (Abdulla 2020).

Current Air Pollution Situation in Jordan

Air pollution in Jordan has a significant impact on public health as (Bdour et al. 2008) identified that health outcomes, including respiratory issues, skin conditions, and malignancies, are consistent with the known health effects of exposure to air pollutants such as PM_{10} and SO_2. For example, 33.7% of people in this region suffer from chronic diseases, 25.6% have aches or infections, and 19.8% have a family history of cancer**,** PM_{10} causes respiratory disorders like bronchitis or asthma damages the immune system (Endale et al. 2024, Rajagopalan et al. 2020, Rozita et al. 2022), CO causes asphyxia at high concentrations (WHO, chronic diseases from air pollution report 2013). NO_2 has an impact on Asthma symptoms and respiratory infections (Muhaidat et al. 2019). SO_2 has an impact on throat and nose irritability and bronchitis.

The sources of air pollutants can be classified into two categories. The first is natural sources, such as dust storms from desert areas that produce a particle known as particulate matter 10 (PM_{10}). Researchers have found that the average number of dust storms in Jordan was 17.22, with a coefficient of variation of 46% (Ghanem 2020). The duration of storms ranged from one to four days, and the majority (54.1%) of them occurred in the spring, particularly in April (22.2%). The yearly numbers of storms in different regions in Jordan are as follows: 13 in Irbid in the north, 182 in Al-Jafar in the south, and 102 in Safawi in the east. The dust storm intensified in the south and east (Bdour et al. 2008).

The second category of air pollutant sources is artificial sources, such as urban and construction pollutants. These pollutants are produced by human activities. The population in Jordan increased from 933,102 in 1960 to 10,302,651 in 2022, which translates to a population growth rate of 1.03%. As a result, the demand for constructing buildings has increased significantly (Department of Statistics Jordan, n.d.). Moreover, transportation significantly decreases the concentration of CO, CO_2 and PM_{10} in the atmosphere, and the number of diesel and gasoline vehicles in three active zones in Jordan (Amman, Zarqa, Irbid) reached 655,323, 30,044, and 56,106, respectively, according to a Ministry of Transportation statistical report (Department of Transportation, 2023). Another important source of air pollution is the industrial sector. For example, a petroleum refinery produced sulfur dioxide (SO_2), CO, and CO_2, an Asmara waste water purification plant produced hydrogen sulfide (H_2S), SO_2, and nitrogen dioxide (NO_2), and the Ramallah iron and steel industry produced SO_2, CO, and CO_2. A petroleum refinery in Zarqa to the north of Amman produced a sulfur concentration of 300 ppb, which decreased to 50 ppb (reflecting a 95% removal efficiency rate) after a sulfur recovery unit was installed (Khatatbeh et al. 2020). A Lafarge concrete factory produced CO and CO_2, and a pottery factory produced different heavy metals, as seen in Fig. 2 below.

The three main air pollution sources in Jordan can also classified as residential, transportation, and industry

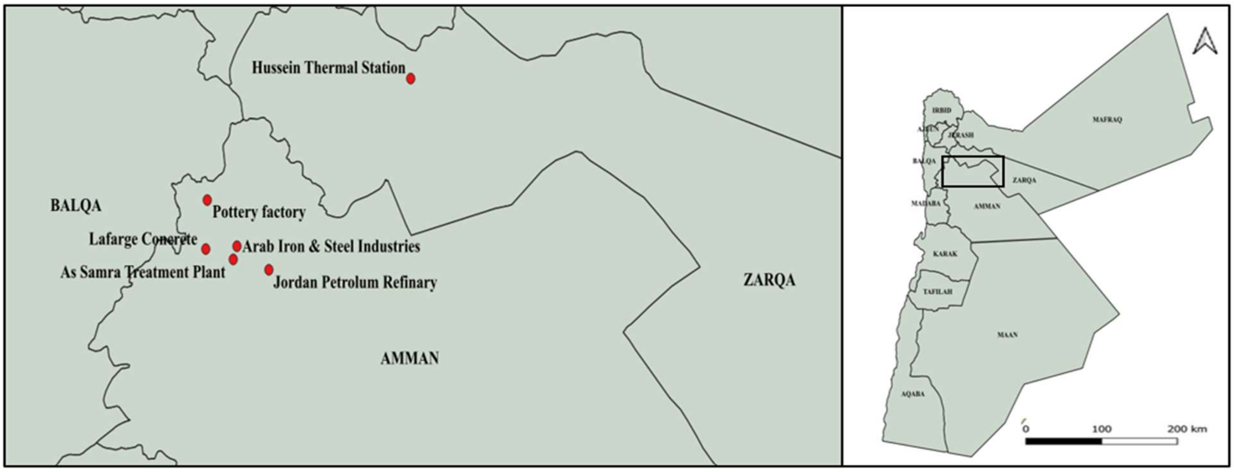

Fig. 2: Locations of industrial areas in Jordan.

Table 1: Sources of major air pollutants in Jordan.

	Sources	Pollutant's Produced	Area/city/ Neighbor	References
Residential	Heating, Burning, Smoking	CO, CO_2	Jerash	(AL-Kurdi & Al Hadidi 2015)
	Construction materials and equipment	NMHC, CO, HAPs, VOCs, PAHs	Amman	(Sa'adeh et al. 2019)
	On-site construction	PM_{10}	Amman	(Rajagopalan et al. 2020)
	Pesticides in plants	NO_X	Amman	(Hamed et al. 2010)
Transportation	Diesel and gasoline vehicles	CO, CO_2, SO_2, NO_2, PM_{10}	Amman, Zarqa, Irbid	(Hamdi et al. 2008)
	Unleaded petrol (90 and 95 octane)	CO, CO_2	Amman, Zarqa	(Alnawaiseh et al. 2015)
	Traffic lights	CO_2, SO_2, NO_2	Amman	(Ministry of Environment Jordan 2019)
	Heating, burning, and smoking	CO, CO_2	Amman, Zarqa	(Saleh 1995)
Industry	Pharmaceuticals factories	Microorganisms and bio-aerosols	Amman	(Zemouri et al. 2017)
	Lime quarries	CO_2, CO, NOx, SOx, $PM_{2.5}$, PM_{10}, CH_4, NMVOCs, NH_3	Abu-Alanda	(US Department of Economic and Social Affairs 2016)
	The burning of lubricating oils	Polycyclic aromatic hydrocarbons (PAH)	Bayader	(WHO, 2019)
	Bakeries	PM_{10}	Amman	(Abu-Allaban & Abu-Qdais, 2011)
	Pottery factories	PM_{10}, NO_X, SO_2, CO, NH_3	Amman	(Khatatbeh et al. 2020)
	Cement industry	SO_2	Zarqa	(Odat 2009)
	Jordan petroleum refinery	CO_2, CO, NOx, SOx, H_2S	Zarqa	(Al-Mashaqbeh et al. 2015)

pollutants. Table 1 displays the pollutants produced in different cities in Jordan according to previous research.

Jordan Current Legislations and Standards Regarding Air Pollution

Several studies and information regarding the sources of air pollution have been produced in Jordan, particularly in the last 10 years (Ghanem 2020). The natural desert and the growth of industrial sectors directly affect human health and the environment. The petroleum industry produces harmful emissions like SO_2, the cement industry produces NH_3 SO_2, CO, and CO_2, and the pharmaceutical industry produces microorganisms and bioaerosols. Some air pollutants are now under control with the use of filters and air scrubbers, while other pollutants are difficult to control, especially when they come from natural sources such as $PM_{10,}$ parallel to the changing of weather and sandstorms. According to the air quality index (AQI), the air pollution situation depends on the human activities and pollutants produced. For instance, the AQI of SO_2, NO_2, and ozone are within the recommended Jordanian limits 1140/2006 for ambient air quality standards and 1189/2006 for the maximum permissible limits of air pollutants emitted from stationary sources. However, the AQI of PM_{10} is always high, especially in Madaba and Tafileh to the south of Jordan, which is an arid area.Table 2 shows the Jordanian limits of the main air pollutants (Ministry of Environment Jordan 2019).

Limited studies investigated the annual and daily concentration of air pollutants and compared the values with Jordanian standards, for instance, Odat (2009) studied the yearly average concentration of these pollutants in various regions in Jordan, revealing that the results met Jordanian standards limits (1140/2006). The exception was PM_{10}, which was 105.2 μg/L in 2014, exceeding the Jordanian standard limit of 70 μg/L (Odat 2009). Another study included the yearly concentration values of SO_2, NO_2, CO, and CO_2 in three regions (Amman, Irbid, and Zarqa) from 2016 to 2019 and after 2020, demonstrating sharp (30-50%) reductions in their concentrations, as was expected after COVID-19. However, this study only focused on the yearly average concentrations of these pollutants and did not consider daily or monthly average concentrations (Dabbour et al. 2021). Moreover, a study on the daily PM_{10} concentration in Amman and Zarqa cities from March 6 to May 28, 2014, revealed high values (up to 150 μg) exceeding the Jordanian standard limit for PM_{10}, which is 120 μg/L. This study aims not only to evaluate the yearly concentrations of pollutants in Jordan but also to highlight the sharp decrease in their monthly concentrations during COVID-19 (i.e., from March 2020 to August 2020) because of the lake use of transportation methods and the industrial sector.

MATERIALS AND METHODS

Study Sites

Amman is the capital of Jordan with coordinates (31.9544° N, 35.9106° E), Fifteen percent of the desert area in Amman is located in Qasr Al-Qastal, Al-Muaqar, and Al-Mushatta, which are around 22, 26, and 25 km to the east of Amman. Meanwhile, 10% is located in Al-Halabat around 25 km from Zarqa to the northeast of Amman with coordinates (32.0608° N, 36.0942° E), and 5% is in Qasr Al-Kharranah and Quseir Amra. These areas are considered to be the main natural source of PM_{10} as seen in Fig. 1.

The main artificial source of air pollution in Amman is the industry as the Ramallah iron and steel industry produces SO_2, CO, and CO_2, A Lafarge concrete factory produces CO and CO_2, and a pottery factory produces different heavy metals, the Ramallah iron and steel industry produced SO_2, CO, and CO_2. For example, a petroleum refinery produced sulfur dioxide (SO_2), CO, and CO_2, an Asmara waste water purification plant produced hydrogen sulfide (H_2S), SO_2, and nitrogen dioxide (NO_2), and A petroleum refinery in Zarqa to the north of Amman produced a sulfur concentration of 300 ppb, which decreased to 50 ppb (reflecting a 95% removal efficiency rate) after a sulfur recovery unit was installed (Khatatbeh et al. 2020). As seen in Fig. 2.

Table 2: Jordanian ambient air quality limits (1140/2006).

Air pollutants	Sampling time	Maximum allowable limit	Number of limit breaches
Sulfur Dioxide (SO_2)	1 hour	0.3 ppm	Three times during any of the 12 months in a year
	24 hours	0.14 ppm	Once a year
	1 year	0.04 ppm	---------------------
Nitrogen Dioxide (NO_2)	1 hour	26 ppm	Three times during any of the 12 months in a year
	8 hours	9 ppm	Three times during any of the 12 months in a year
Carbon monoxide (CO)	1 hour	0.21 ppm	Three times during any of the 12 months in a year
	24 hours	0.08 ppm	Three times during any of the 12 months in a year
	1 year	0.05 ppm	-
Hydrogen sulfide (H_2S)	1 hour	0.03 ppm	Three times during any of the 12 months in a year
	24 hours	0.01 ppm	Three times during any of the 12 months in a year
	1 year	8 μg/L	-
	1 year	70 μg/L	-
Particulate matter (PM_{10})	24 hours	120 $μg/m^3$	Three times during any of the 12 months in a year
	1 year	70 $μg/m^3$	-

Data Collection and Instruments

This study analyzes the daily, monthly, and annual records of air pollutant concentrations in Amman and Zarqa using Excel and maps drawn using QGIS. The considered air pollution data was obtained from the Ministry of Environment. The records include measurements of H_2S, SO_2, NO_2, CO, and PM_{10}. Nitric oxide (NO) and NO_2 concentrations were measured using a chemiluminescence analyzer (Model 42i), while SO_2 and H_2S concentrations were determined using an SO_2 analyzer (Model 450i Q). Particulate matter (PM_{10}) was measured using a Beta Attenuation Analyzer. The meteorological parameters were measured at the same period as wind speed, the direction of the wind, as well as the temperature and humidity levels measured by retractable telescopic mast 8-10 meters and ultrasonic metrological sensors. Seven monitoring stations in Amman and three stations in Zarqa were considered as shown in Table 3. Although these monitoring stations provide valuable data, they may not fully represent the air quality across the country. Some areas with high air pollution levels might not have monitoring stations due to a lack of coverage. Fig. 3 shows the distribution of these monitoring stations in Amman, Zarqa, and Irbid. Furthermore, ensuring the completeness and accuracy of the recorded data is crucial, as any gaps or errors can impact the analysis and decision-making processes.

This study also explores the influences of meteorological parameters, such as temperature, humidity, and wind speed, on the dispersion of air pollutants, particularly PM_{10}. Additionally, this research emphasizes the critical environmental and health issues associated with air pollution.

This investigation analyzes the daily, monthly, and yearly records of air pollutant concentrations in Amman and Zarqa,

Table 3: Air pollution stations in Jordan.

Station Name	Station Name	Location	Type of Station	Pollutants
KHG	King Hussein Gardens	Amman	Industrial	NO_2, SO_2, O_3, PM_{10}, MET
GAM	Greater Amman Municipality	Amman	Urban	NO_2, SO_2, O_3, PM_{10}, CO
TAB	Bus Station Tabarbour	Amman	Urban	CO, PM_{10}, NO_2
MAH	Marka/Mahata	Amman	Traffic	NO_2, SO_2, PM_{10}
UNI	University Street/Swelieh	Amman	Traffic	NO_2, PM_{10}
KAC	King Abdullah City	Irbid	Industrial	NO_2, SO_2, PM_{10}
YAR	Yarmouk	Amman	Urban	NO_2, SO_2, PM_{10}
HAJ	Wadi Hajjar Health Center	Zarqa	Traffic	NO_2, SO_2, CO, PM_{10}, MET
MAS	Massane	Zarqa	Industrial	NO_2, SO_2, PM_{10}
HH	Hashemite Hall	Zarqa	Urban	NO_2, SO_2, PM_{10}
HSC	Al Hassan Sport City	Irbid	Traffic	NO_2, CO, PM_{10}
BAR	Al Barah Street	Irbid	Background	NO_2, SO_2, O_3, PM_{10}, MET

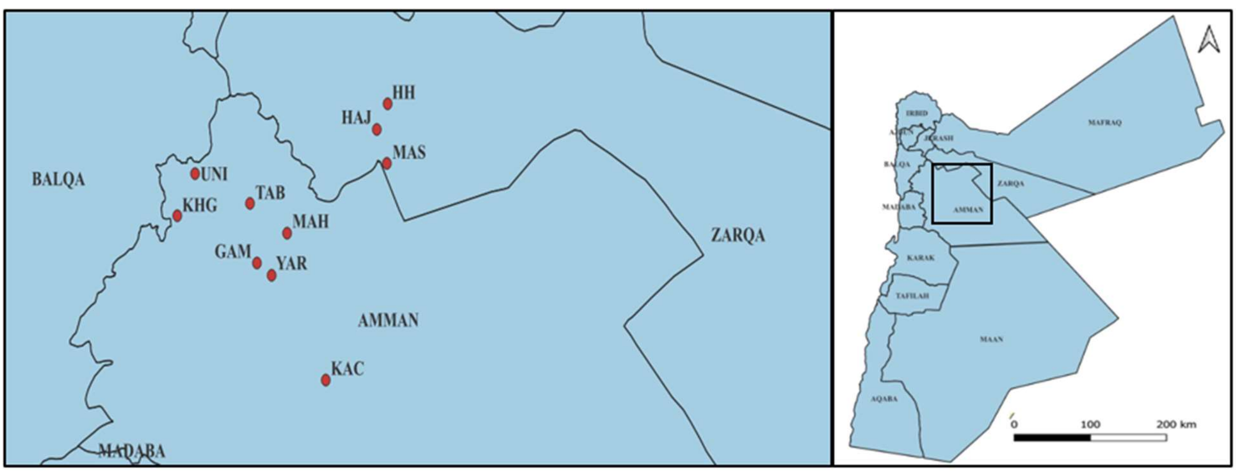

Fig. 3: Distribution of the selected monitoring stations in Amman, Zarqa, and Irbid.

a city with a significant industrial sector representing 55% of the country's industrial facilities. The considered air pollution data was obtained from the Ministry of Environment. The records include measurements of SO_2, NO_2, CO, and PM_{10}. Six monitoring stations in Amman and three stations in Zarqa were considered. Additionally, three stations in Irbid, an area hosting Syrian refugees, were considered.

RESULTS AND DISCUSSION

COVID-19 Impacts and Pollutants' Reduction Trends

COVID-19 has significantly reduced certain pollutants, as many factories, companies, and transportation methods came to a halt between March 2020 and August 2020. Figs. 4 to 13 illustrate the yearly and monthly pollutant concentration trends during this period.

The average yearly concentrations of air pollutants were evaluated before and after COVID-19, as shown in Fig. 4. The concentration of H_2S decreased sharply in 2020 in Amman to 70% due to the reduction in the water consumption rate by factories and companies during the pandemic and the subsequent increase in 2021 (though it remained below the expected value due to improvements in some facilities like filter installation). Regarding Zarqa, upgrading the largest wastewater treatment plant-As Samara-located northeast of Zarqa, and improving some oxidizers and biological filters reduced the amount of H_2S after 2018. The concentration reduction of 36% in Zarqa in 2020 was noticeable but less than in Amman since 55% of different types of industries are there. The average daily standard Jordanian limit for H_2S concentration is 10 ppb (the yearly standard limit was unavailable). Fig. 5 shows the monthly concentration of H_2S during COVID-19 (March 2020 to August 2020).

The reduction of H_2S concentration in treatment plants has led to a gradual decrease in SO_2 levels in Amman and Zarqa during the COVID-19 period to 58% at Amman and 62% at Zarqa, as shown in Figs. 6 and 7. The high concentration of SO_2 in 2015 was due to the high sulfur

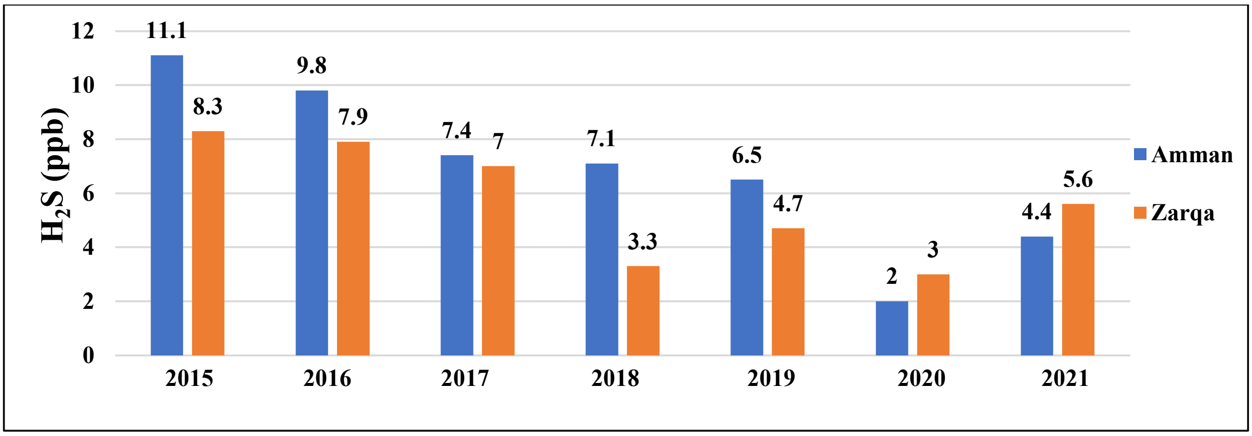

Fig. 4: Average yearly air concentration of H_2S (ppb) from 2015–2021 in Amman and Zarqa.

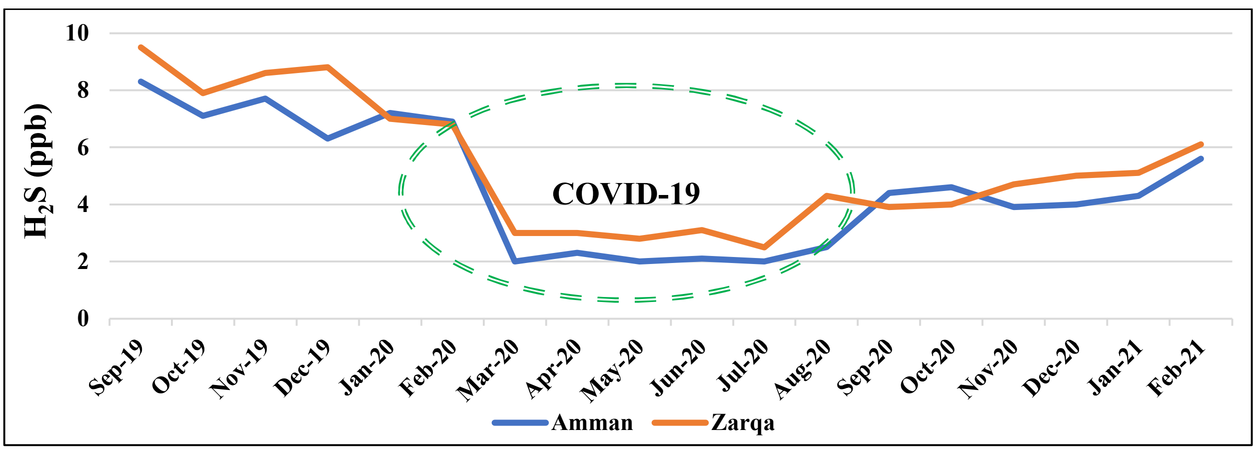

Fig. 5: Monthly air concentration of H_2S (ppb) in Amman and Zarqa.

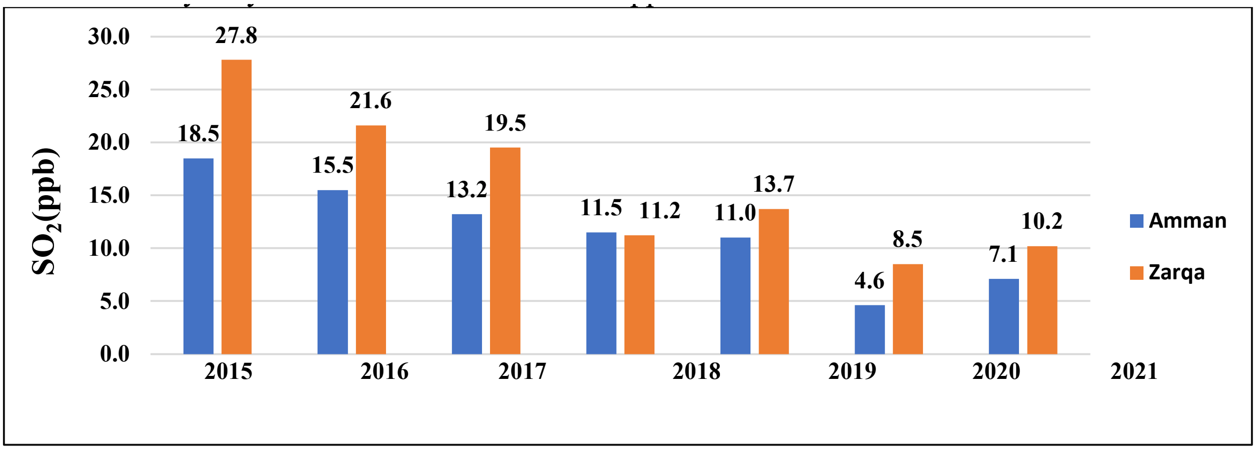

Fig. 6: Average yearly air concentration of SO_2 (ppb) from 2015–2021 in Amman and Zarqa.

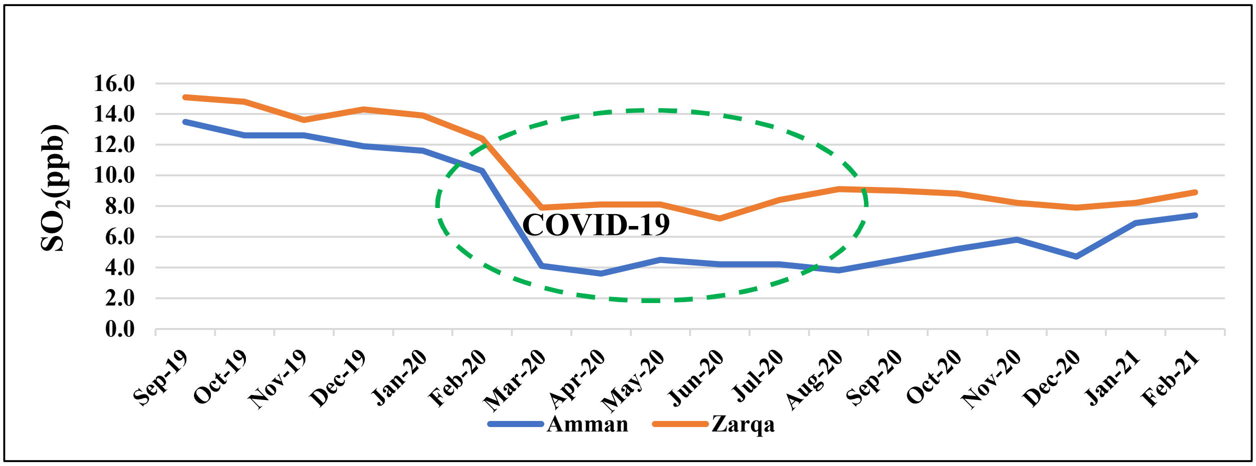

Fig. 7: Monthly air concentration of SO_2 (ppb) in Amman and Zarqa.

production in petroleum refinery plants operating without desulfurization units. Shatnawi & Abu-Qdais (2021) showed that the concentrations of air pollutants during the pandemic decreased compared to before the pandemic period (Shatnawi & Abu-Qdais 2021). Their results were based on an analysis using the ANN model of the expected air pollutants based on Scenario II before and after the pandemic. Decreases in NO_2, SO_2, and PM_{10} concentrations were 72%, 52%, and 29%, respectively. Notably, the Jordanian yearly standard limit for SO_2 is 40 ppb.

Figs. 8 and 9 show that Amman had significantly higher concentrations of NO_2 resulting from fertilizer, agriculture, and green land activities, which decreased sharply after the pandemic to 87% in Amman and 72% in Zarqa. The main reason that the public facility and garden directorates developed an integrated green infrastructure strategy and increased the number of parks and gardens by over 143, according to the Amman Green City Action Plan, which was enacted from 2019 to 2021. In Zarqa, which is considered an industrial region, the level of NO_2 emissions is lower than in Amman; nevertheless, the concentration of NO_2 decreased during COVID-19. Dabbour et al. (2021) estimated a 25.5% reduction in NO_2 concentrations in Amman by 2020. The average daily Jordanian limit for NO_2 concentration is 80 ppb, while the yearly standard limit is currently unavailable (Dabbour et al. 2021).

CO emissions in Jordan are caused by various sources, including transportation, industry, and wastewater treatment plants. The pandemic resulted in a significant decrease in CO concentrations from March 2020 30% in Amman and 19% in Zarqa, as shown in Figs. 10 and 11. However, the concentration of CO was higher in Amman than in Zarqa, which has a high population growth rate due to the use of different transportation methods, which are the main source of CO. The high concentration of CO in Zarqa in 2021 was due to recitation and construction works on Army

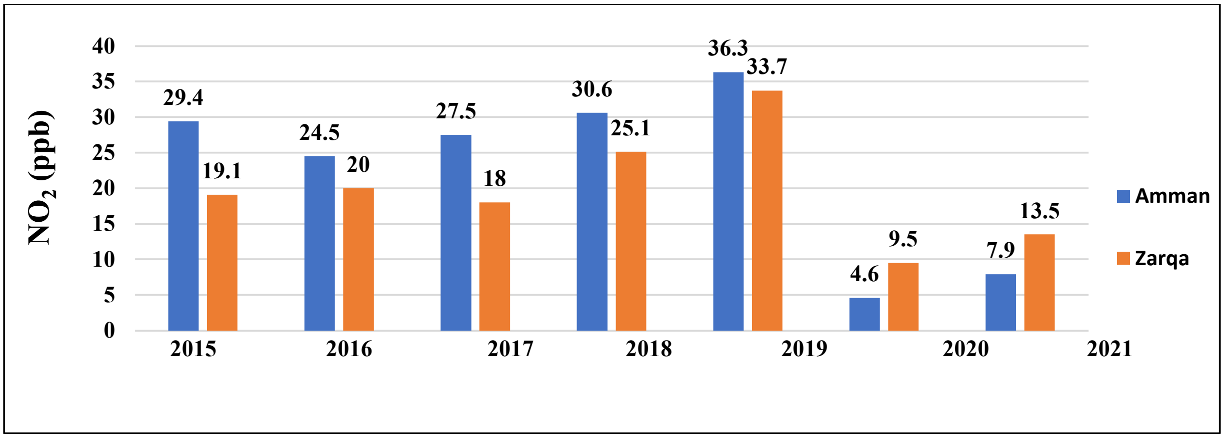

Fig. 8: Average yearly air concentration of NO_2 (ppb) from 2015-2021 in Amman and Zarqa.

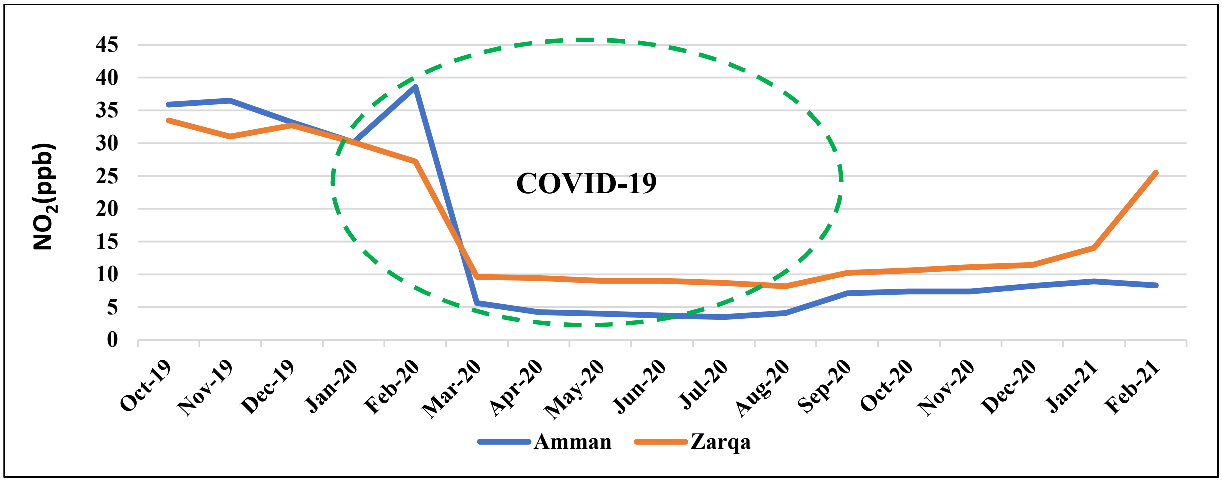

Fig. 9: Monthly air concentration of NO_2 (ppb) in Amman and Zarqa.

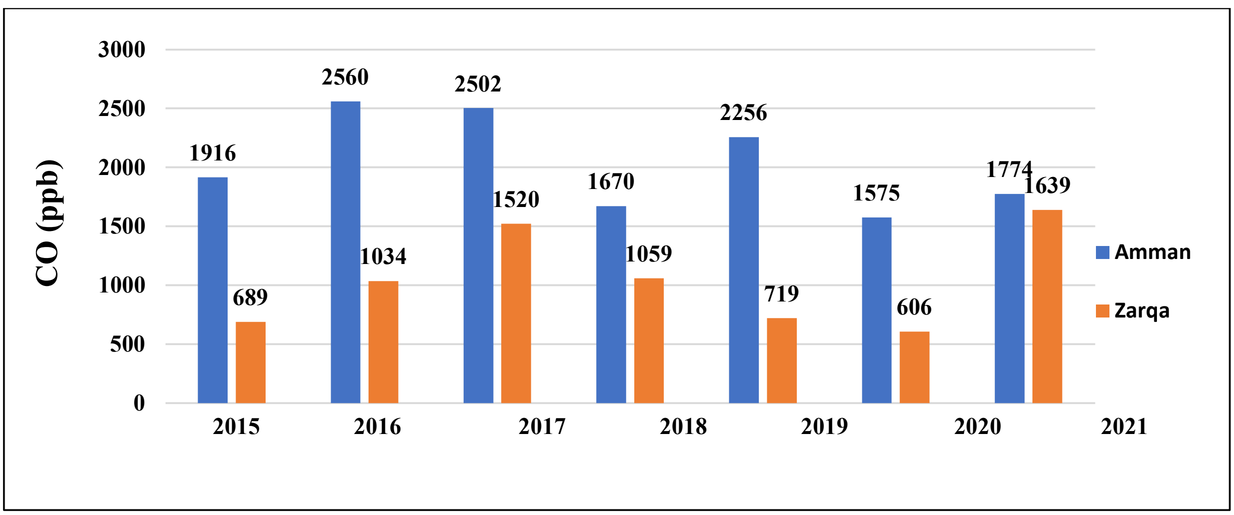

Fig. 10: Average yearly air concentration of CO (ppb) from 2015–2021 in Amman and Zarqa.

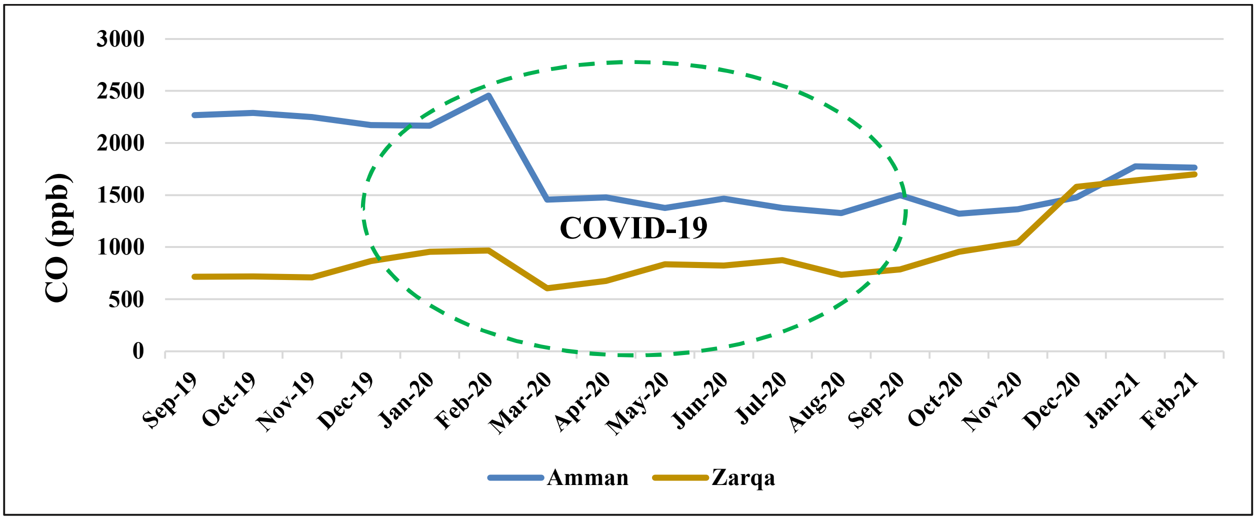

Fig. 11: Monthly air concentration of CO (ppb) in Amman and Zarqa.

Street in Zarqa, 16.8 km from Amman. Shotar et al. (2021) found a 70.4% increase in the death rate associated with CO concentrations in Jordan from 2015 to 2018, followed by a sharp decrease to 20.1% in 2020 (Shotar et al. 2021). Currently, there are no Jordanian standard limits for the yearly concentration of CO.

PM_{10} is a pollutant that is difficult to control and is produced from both natural sources, such as dust, and human activities, such as transportation and industrial activity. In 2015, a sandstorm in April produced a high concentration of PM_{10} (reaching up to 1000 ppb). In 2016, a second sandstorm occurred in the southern desert of Jordan; as a result, PM_{10} concentrations in Jordan remained above the national yearly standard limit of 70 µg/L, as shown in Figs. 12 and 13. The reduction of PM_{10} during COVID-19 was 18% in Amman and 49% in Zarqa. According to the Ministry of Environment, the percentage of PM_{10} reached 40% in the Zarqa region in 2021 due to increased quarrying and construction activities, which may have contributed to further increases in PM_{10} concentrations. According to Shatnawi & Abu-Qdais (2021), as mentioned earlier, PM_{10} levels dropped during 2020. Specifically, a decrease of 29% in Amman and 32% in the Zarqa region were observed. PM_{10} experienced a slightly greater decline than other pollutants during COVID-19.

Meteorological Effects Display on Air Pollution in Amman and Zarqa

Recent research has established a clear and direct link

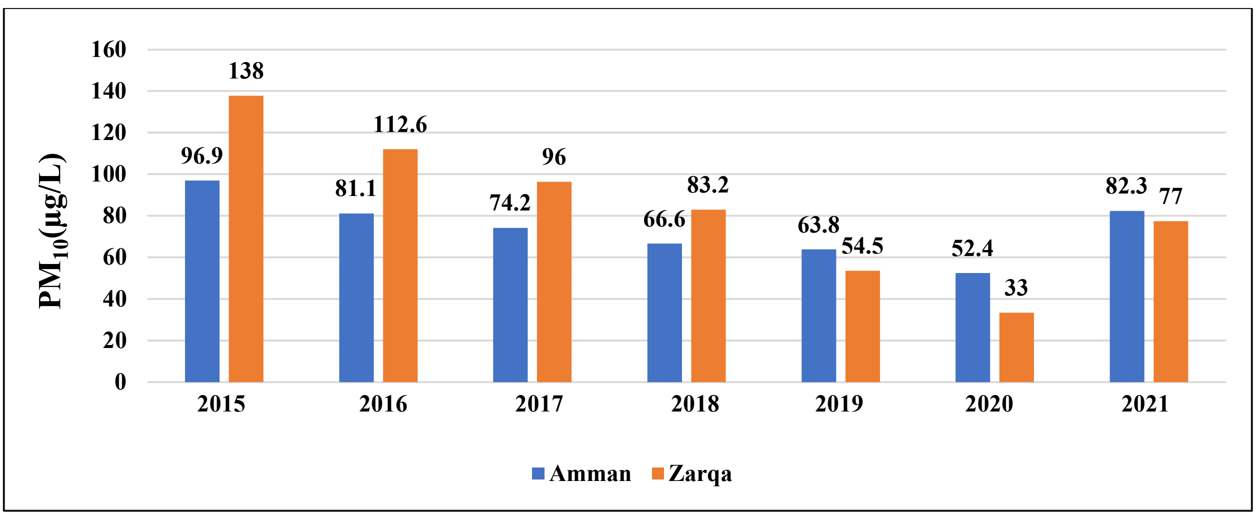

Fig. 12: Average yearly air concentration of PM_{10} (µg/L) from 2015-2021 in Amman and Zarqa.

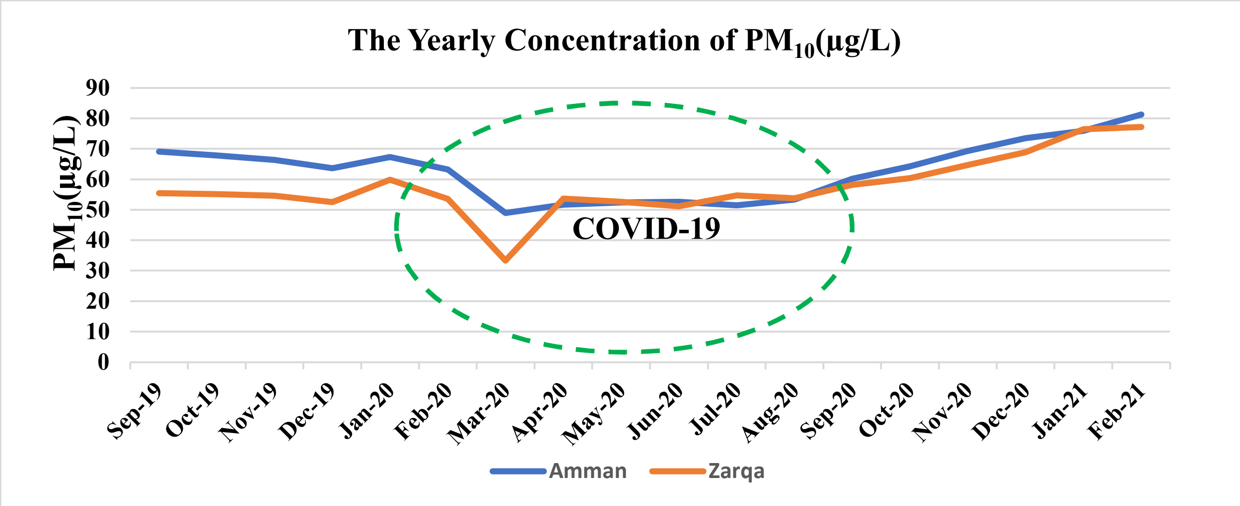

Fig. 13: Monthly air concentration of PM_{10} (µg/L) in Amman and Zarqa.

between climate change-including changes in precipitation, temperature, wind speed, and humidity, and increased air pollution in Jordan. The combination of reduced rainfall, elevated temperatures, high humidity, and strong wind speeds have contributed to heightened levels of air pollution (Al-Smairan & Al-Nhoud 2019). In March 2019, the average yearly maximum temperature and humidity, as depicted in Table 4, was within the typical ranges in both Amman and Zarqa. However, during the COVID-19 pandemic, wind speed was the dominant parameter responsible for reducing the concentration of pollutants, such as CO, SO_2, and NO_2, to about 30% of their usual levels.

Dabbour et al. (2021) examined the impact of meteorological parameters on air pollution dispersion in three zones (Amman, Zarqa, and Irbid). The collected data on annual concentrations of pollutants (CO, SO_2, NO_2, and PM_{10}) and conducted a Sobol sensitivity test. The results showed that in Amman, SO_2 increased significantly with humidity, wind speed, and pressure, while the NO_2 level was directly proportional to temperature. There was no relationship found between meteorological conditions and PM_{10}. Industrial sources of pollution in Amman included the largest cement manufacturer (Lavarge), which produced CO, SO_2, and NO_2, as well as the steel industry (Arab Iron and Steel Industry), which also produced PM_{10} and $PM_{2.5}$. A pottery factory to the north of Amman, near Irbid, also contributed to air pollution, as shown in Table 3.

In Zarqa, the concentrations of CO, SO_2, and NO_2 were directly proportional to the rise in humidity. NO_2 levels also increased with wind speed, while pressure played a significant role in increasing CO concentrations. However, no correlation was observed between PM_{10} concentrations and meteorological conditions. In Irbid, known as the "city of refugees," temperature had the greatest influence on NO_2 levels, high humidity had the most significant impact on SO_2 concentrations, and pressure had the strongest influence on PM_{10} concentrations (Matouq et al. 2013a).

Another important source of air pollution is the industrial sector (e.g., the petroleum refinery, Asmara wastewater purification plant, and Ramallah iron and steel industry). The petroleum refinery in Zarqa produced a sulfur concentration of 300 ppb, which decreased to 50 ppb (which reflects a 95% removal efficiency rate) after a sulfur recovery unit was installed. Wastewater treatment plants significantly impact air pollution; since the 1980s, wastewater has either been discharged into valleys or mixed with fresh water before being reused. The largest wastewater treatment facility in Jordan is located in Asmara, 60 km from Amman, which was established in 2007. It had a maximum capacity of 15,000-20,000 m^3/day, which increased to 267,000 m^3/day in 2008

Table 4: Metrological parameters (temperature, humidity, and wind speed) in Amman and Zarqa during COVID-19.

Year	Region	T (°C)	Humidity (%)	Wind Speed (km/h)	SO_2	NO_2	CO	PM_{10}
2019	Amman	17	64.5	7.5	11	36.3225.6	2,256	63.8
	Zarqa	25	50.1	9.6	13.7	33.762.7	719	54.5
2020	Amman	16	66.3	8.9	4.6	4.6201.8	1,575	52.4
	Zarqa	27	56.2	10	8.5	9.562.9	606	33

and 367,000 m^3/day in 2015 (Bdour & Nidal Hadadin 2005). The amount of H_2S and SO_2 in the final sludge in Asmara was reduced by an upgraded desulfurization facility.

The land area of Jordan experiences an annual rainfall of less than 200 mm, resulting in poor structural stability of soils and a high susceptibility to erosion during shallow rainstorm events (Hammad et al., 2018). According to predictions by Ghanem (2020), droughts and smoke clouds are expected to increase, especially during the summer, while rainfall is anticipated to decrease by 30%. Additionally, temperature has been increasing at a rate of approximately 0.04°C per year (Abdulla 2020, Tabieh et al. 2014). Over the past decade, maximum wind speeds have also increased, reaching 25 km/h. Furthermore, humidity levels have risen to 68% over the past two years, as reported in a 2021 Amman climate weather report.

Several studies in Zarqa have indicated that warming influences rainfall volume reduction. For instance, if the temperature increases annually by 4 °C and rainfall decreases by 10%, it can lead to a 12.4% reduction in cultivated areas (Al Saodi et al. 2023, Tabieh et al. 2014). Meanwhile, in the mid, south, and southeastern regions of Amman; the Zarqa Basin; and Jordan overall, rainfall has decreased by 10-15% over the past two decades. Desert stations have reported even greater reductions in rainfall. Previous studies have confirmed that the evaporation factor for the Zarqa River basin is 90%. However, evaporation has increased due to the shifting of rainfall storms toward the summer season. Consequently, this study suggests that the potential evaporation value has increased from 90% to 91% (Matouq et al. 2013b).

Air Pollution's Impacts on Public Health and the Environment

Effect of air pollution on human health: Khatatbeh et al. (2020) conducted a study in Al-Hashmiya (Zarqa region) and highlighted the negative impact of air pollution on public health, particularly in areas near industrial sources of pollution. They identified that health outcomes, including respiratory issues, skin conditions, and malignancies, are consistent with the known health effects of exposure to air pollutants such as PM_{10} and SO_2. For example, 33.7% of people in this region suffer from chronic diseases, 25.6% have aches or infections, and 19.8% have a family history of cancer (Bdour et al. 2008). The high percentages of chronic diseases, aches and infections, and family histories of cancer among the population living near the oil refinery indicate an urgent need for effective measures to reduce air pollution levels in these areas.

This study was conducted in a specific location and may not represent the entire country. Further studies are necessary to identify areas with the highest levels of air pollution and their impact on public health to inform the development of effective policies and interventions to mitigate these

Table 5: Health effects and sources of air pollutants in Jordan.

Pollutants	Health Effects	Locations	Reference
PM_{10}	Respiratory disorders like bronchitis or asthma damage the immune system. Affects the body's ability to fight infection. High blood pressure, strokes, and lung cancer.	Aljafer Ma'an Karak	(Endale et al. 2024, Rajagopalan et al. 2020, Rozita et al. 2022)
CO, CO_2	Causes asphyxia at high concentrations. Reduces the blood's ability to carry oxygen to cells and organs.	Amman	(WHO, chronic diseases from air pollution report, 2013).
NOx	Asthma symptoms and respiratory infections. Chronic lung disease at high concentrations.	Zarqa	(Muhaidat et al. 2019)
SO_2	Throat and nose irritability. Bronchitis.	Zarqa	(Hadadin & Tarawneh 2007)
O_3	Damages live cells when it reacts with biological membranes. Asthma and reduced lung function.	Amman	(Dabbour 2021)
VOC exposure	Poor coordination and nausea. Irritation of the eyes, nose, and throat. Headaches and neck pain. Damage the kidneys, liver, and nervous system at high concentrations.	Zarqa	(WHO, chronic diseases from air pollution report, 2013 (Rozita et al. 2022))
Nonmethane hydro-carbons (NMHCs)	Chronic obstructive pulmonary disease. Damage to the central nervous system. High cardiorespiratory.	Amman Zarqa	(Herndon et al., 2020; Bhosale et al. 2023)
HAPs (benzene, trichloroethylene, mercury, chromium, and dioxin)	Asthma and lung cancer. Birth defects, reproductive effects, and neurodevelopmental effects.	Zarqa	(International Agency for Research on Cancer, report 2013)

Table 6: Environmental effects associated with air pollutants in Jordan.

Pollutants	Environmental Effects	Locations	Reference
PM_{10}	Affects water's clarity and quality (increased turbidity). Deposition and subsequent uptake by plants. Significantly affects growth and reproduction in some plants. Damage in leaves in some plants.	Irbid	(Shatnawi & Abu-Qdais 2021)
CO, CO_2 (Construction or vehicles)	Global warming. Destroys the Earth's ozone layer.	Amman	(AL-Kurdi & Al Hadidi 2015)
NOx	Damages leaves, slows growth, and lowers agricultural production.		AL-Kurdi & Al Hadidi 2015)
SO_2	Sulfuric acid, which causes acid rain, leads to deforestation. Acidifies waterways to the detriment of aquatic life.	Amman Zarqa Azraq Aljafer	(WHO 2019)
O_3	Decreases the growth and survival of tree seedlings. Decreases agricultural crop and commercial forest yields.	Aqaba	(Gertler et al. 2011)
Volatile organic compound (VOC) exposure	Increases plant diseases, delays seed formation and hinders fertilization. Increases production of low-level ozone as a result of photochemical processes with high temperatures and heat waves.	Amman	(Al Jaber 2016)
Nonmethane-hydrocarbons (NMHC)	Considerably increases the amount of propane and ethane in the air around highways, causing ground-based ozone pollution.	Amman	(Salameh et al. 2015)

effects. Table 5 lists air pollutants' sources and health effects.

Effects of air pollution on the environment: Naber's (2010) environmental analysis related to achieving sustainable development in Jordan indicated that air pollution is the primary cause of environmental degradation in Jordan, with air pollution responsible for the highest annual cost of environmental degradation in terms of gross domestic product, followed by water (0.81%), waste (0.23%), and soil (0.11%). Meanwhile, over the past 10 years, the impact of air pollution on ecosystems has grown significantly, leading to global warming, the loss of vegetation, and stratospheric ozone. Table 6 shows the links between various Jordan air pollutants and their environmental impacts.

CONCLUSIONS

The air pollution in Jordan is a critical problem that has increased over time. This study explains that there was a significant decrease in the annual concentrations of H_2S, SO_2, and NO_2 during the COVID-19 lockdown, with reductions of 70%, 58%, and 87%, respectively in Amman, and 36%, 62%, and 72%, respectively in Zarqa. However, there was only a slight reduction in CO and PM_{10}, with decreases of 39% and 18% in Amman and 19% and 40% in Zarqa, from March 20 to August 20, 2020. This decrease is attributed to the reduction of primary sources of air pollutants, linked to reduced traffic volume and industrial activities during the lockdown. It is also concluded that wind speed was the dominant parameter responsible for reducing the concentration of pollutants like CO, SO_2, and NO_2 to about 30% of their usual levels.

The issue of sandstorms in 75% of Jordan poses a significant challenge in decreasing the levels of PM10 in the atmosphere. As a result, PM_{10} is a significant concern in Jordan and the Middle East because the natural sources of PM_{10}, especially sandstorms in the southern region, are difficult to control and cause health and environmental effects. The Ministry of Environment plans to install advanced instruments in southern areas to better monitor pollution. However, many industries still lack environmental awareness and a sense of responsibility. The Jordan Environmental Monitoring Directorate, established in 2003, oversees air quality through the national ambient air quality monitoring network. However, from 2015 to 2018, air pollutant concentrations (NO_2, CO, SO_2, and O_3) in Amman and Zarqa exceeded the Jordanian standard limit of 1140/2006.

During the COVID-19 pandemic, annual concentrations of air pollutants significantly decreased due to reduced traffic and industrial activities. Sandstorms, affecting 75% of Jordan, present a major challenge in reducing PM10 levels, with significant health and environmental impacts. The Ministry of Environment plans to install advanced monitoring instruments in southern regions, although many industries lack environmental awareness and responsibility. The industrial sector employs filter technologies to reduce emissions, such as bag filters in cement and steel factories, ceramic filters in medical waste incinerators, and particulate matter and chemical filters for manganese production. The high cost of implementing these technologies poses a challenge for the private sector.

The Jordanian government has implemented regulations to address air pollution in residential areas, focusing on preventing tree burning and smoking. New transportation technologies are being adopted to reduce CO_2 and other pollutants from diesel and gasoline vehicles. Green fuels like synthetic natural gas, green methanol, or ammonia, along with increased use of electric cars, are being promoted. The bus rapid transit system, implemented in 2021, has reduced car usage and alleviated congestion in urban areas.

RECOMMENDATIONS

- Encourage and promote the use of public transportation, such as bus rapid transit, as well as environmentally friendly transportation methods like bicycles or walking, to reduce the number of cars on the road and reduce air pollution.
- Enforce regular technical inspections of automobiles to ensure they meet safety and emission standards, either through on-the-spot inspections or regular checks at specialized traffic centers.
- Promote the use of peripheral parking areas near train and bus stations for those who spend extended periods at work or school to reduce traffic in the city center and alleviate pressure on short-term parking areas.
- Improve the efficiency of heating systems by using mechanical means, such as outdoor air intakes connected to the HVAC system, as well as natural ventilation methods, such as openings, joints, and cracks in walls, floors, ceilings, and areas around windows and doors.
- Adopt advanced technologies to measure and monitor air pollutants in the environment, such as high-tech laser particle sensors, beta attenuation, chemiluminescence, and UV fluorescence.
- Implement improved processes for treating waste, such as condensate run-off from autoclaves for medical waste, molten salt oxidation for energy production from solid waste, and composting organic waste for use as fertilizer.
- Encourage a circular economy with a focus on reducing waste and lowering greenhouse gas emissions by eliminating waste and pollution and promoting sustainable practices.

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