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# Spatial and Temporal Variation of Air Quality Index in Amman-Zarqa Urban Area

**A. Al-Kraimeen*, S. Hamasha** and M. Abu-Allaban*†**
*Department of Water Management and Environment, Prince El-Hassan bin Talal Faculty for Natural Resources and Environment, The Hashemite University, Zarqa 13133, Jordan
**Department of Physics, Faculty of Science, The Hashemite University, Zarqa 13133, Jordan
†Corresponding author: M. Abu-Allaban; mlaban@hu.edu.jo

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## ABSTRACT

This paper aimed to investigate the Spatial and Temporal Variation of the air quality index (AQI) in the Amman and Zarqa Metropolitan Areas during the period 2016-2022 following the method adopted by the Environmental Protection Agency of the United States of America (EPA). Air quality data for $PM_{10}$, $PM_{2.5}$, $O_3$, $NO_2$, $SO_2$, and CO recorded at five monitoring stations were downloaded from the official website of the Jordanian Ministry of Environment. Calculated AQI values were generally between the Good class (AQI <50) and the Moderate class (AQI 50-100) at all stations, the AQI calculations for $PM_{10}$ demonstrated a noticeable increase during autumnal months, likely due to natural dust. $PM_{2.5}$ demonstrated seasonal variation, with higher values in winter months where residents burn fossil fuel for heating. Stabel air in winter due to the cooled land surface, and the weak natural air mix and ventilation contribute to the deterioration of air quality. Calculated individual AQI for $SO_2$ and $NO_2$ reveals that all extent of the study area falls in the Good AQI class. Similarly, CO and ozone-based AQI values fluctuate within the "Good" class, with occasional episodes of compromised air quality at specific stations.

## INTRODUCTION

Air pollution refers to the presence of harmful substances in the air, such as particulate matter, gases, and pollutants, which can have adverse health effects (Manisalidis et al. 2020). Common sources include vehicle emissions, industrial activities, and natural processes. Its health impacts vary but can include respiratory and cardiovascular problems, increased risk of lung diseases, and other serious health issues. Long-term exposure to high levels of air pollution is associated with a higher risk of developing chronic conditions and can contribute to premature mortality. The World Health Organization estimated that 2.4 people around the world die every year because they are exposed to poor air quality (Sierra et al. 2012). Additionally, air pollution can harm the environment, affecting ecosystems, water bodies, and climate patterns. It is a significant global concern, and efforts to reduce pollution are crucial for public health and environmental sustainability.

Urban areas are particularly susceptible to deteriorated air quality because of anthropogenic activities that release tons of air contaminants. Air quality at a monitoring station depends on meteorological conditions, atmospheric stability, contaminants transported from remote sources, and local natural and anthropogenic sources in addition to the ability of the atmosphere, either to disperse or absorb these pollutants (Jayamurugan et al. 2013).

Environmental impacts of air pollution include acid rain, smog, odors, and global warming. Acid rain adversely affects soil, aquatic life, forest resources, and other environmental features. Smog restricts visibility due to the spread of airborne particles that cause light scattering (Gold & Samet 2013). Air pollution damages property and materials. Antiques are important cultural and economic commodities that are particularly sensitive to air quality as well as microclimates. Hundreds of ancient monuments around the globe have been destroyed because of acid rain and other chemically active airborne agents (Abu-Allaban & El-Khalili 2014).

Global warming is largely blamed on certain air pollutants (carbon dioxide, methane, nitrous oxides, halogens, and sulfur hexafluoride) and their sources (Orru et al. 2017, Singh et al. 2021, Pinho-Gomes et al. 2023). Air pollution can have a significant impact on metals, dies, and stone materials used in buildings, sculptures, and monuments (Ruffolo et al. 2023). Corrosion is mainly caused by wet or dry deposition of airborne acidic pollutants. It is estimated that the annual cost of corrosion worldwide is over 3% of the world's GDP (Rao et al. 2016). Air pollution may also impair visibility by creating a white or brown haze that affects how far we can see (Majewski et al. 2021). Haze is largely caused by air pollution from human activity including industry, power generation, transportation, and agriculture.

Sources of air pollutants include road traffic, marine vessels, shipping, air traffic, industry, construction, mining, residential heating, wildfires, agricultural activities, dust storms, and volcanic eruptions (Curtis et al. 2006). Common air pollutants in urban areas include tropospheric ozone ($O_3$), sulfur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), carbon monoxide (CO), and airborne particulate matter ($PM_{10}$ and $PM_{2.5}$). Atmospheric abundances of these pollutants are typically higher in urban areas compared to rural areas (UN 2023). Negative impacts of air pollutants become more profound when their concentrations exceed recommended standards (Katsouyanni & Analitis 2009), which identifies limits of air pollutants to reduce exposure risks for people with health problems and sensitive groups (Bachmann 2007).

National ambient air quality standards (NAAQS) are, therefore, legally binding and enforced nationwide. Trained occupation safety and health personnel, site engineers and technicians, environmental inspectors, and researchers are well aware of NAAQS, which is often difficult to convey to the public. Therefore, a simplified air quality indicator, or air quality index (AQI), is used to inform the public about current and forecasted air quality in their domains to take necessary preventive measures. This paper aims to investigate air quality by calculating the Air Quality Index (AQI) as defined by the EPA at the Amman-Zarqa urban area during 2016-2020. This is the most populous metropolitan area in Jordan and most industrial and utility projects are concentrated therein.

## STUDY AREA

The study area is situated at the center of Jordan (Fig. 1) where more than five million persons work and reside (DOS 2023). This region is dominated by rough terrain with elevation ranges between 370 m and 1126 m above the main sea level. It includes two cities: Amman and Zarqa.

Amman is the political and economic capital of Jordan. It enjoys a Mediterranean climate with air temperature rarely exceeding 40ºC on hot summer days and annual precipitation ranges between 150 mm to 580 mm (Dabbour et al. 2021). 80% of industries and vehicles are situated in Amman, where most Jordanians live and work. Local sources of air pollution in Amman include transportation, fugitive dust, industry, brick workshops, rock cutting, and home heating (Alnawaiseh et al. 2015).

Zarqa, to the east of Amman, suffers harsh hot and dry weather conditions with annual precipitation rarely exceeding 150 mm, but because of its proximity to Amman, a good percentage of Zarqa dwellers work in Amman. This leads to heavy trafficking between the two cities. Similar to Amman, the main sources of air pollution sources in Zarqa include motor vehicles, industry, and natural dust from local and regional dust storms (Al-Mashaqbeh et al. 2015), in addition to an oil refinery and a thermal power plant.

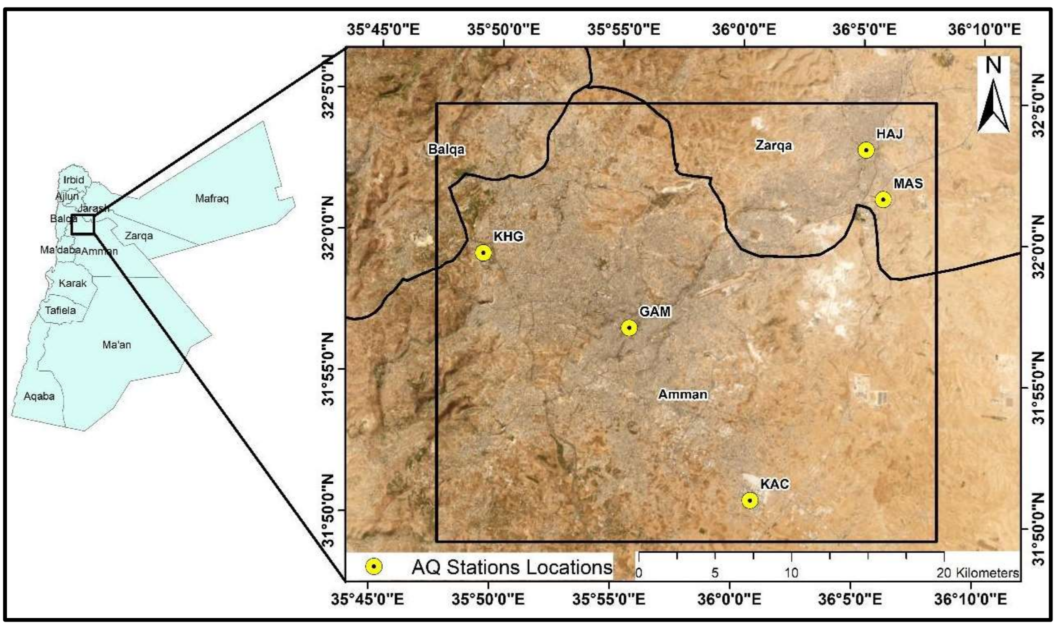


Fig. 1: Location map of the study area with five national air quality monitoring stations.

Natural dust storms, fugitive dust, and frequent stagnation, particularly in autumn and winter, in addition to concentrated anthropogenic activities in the Amman-Zarqa metropolitan area, put air quality under pressure. This situation motivated research groups to investigate and address air quality in this populous area. Saffarini & Odat (2008) examined various time series analyses of the yearly air pollution and reported long-term variations in yearly air pollution at Al-Hashimeya town located at the north-eastern corner of Amman-Zarqa metropolitan area for the years 1992 to 2004 and detected decreasing levels of atmospheric $NO_2$, CO, $H_2S$, NO, and TSP. Al-Mashaqbeh and colleagues reported improved air quality at Al-Hashimeya town after upgrading the Al-Samra wastewater treatment plant, which replaced the outdated sewage facility (Al-Mashaqbeh et al. 2015). Alnawaiseh and colleagues investigated the association between vehicle counts and airborne particulates at four locations in Amman: Downtown, Marka, Shmeisani, and Abu-Nsair. Their findings demonstrated that total elevated concentrations of suspended particulate (TSP) and $PM_{10}$ are associated with large traffic counts and low air temperature (Alnawaiseh et al. 2015). Jaber & Abu-Allaban conducted a study to map the spatial distribution of tropospheric ozone in the northern parts of Jordan, which includes part of the Amman Zarqa metropolitan area, and detected elevated ozone levels on hot days at several parts of the study area due to regional transport of ozone precursors (Jaber & Abu-Allaban 2017). Odat and colleagues conducted a study to assess the influence of Meteorological Parameters on Air Quality at the campus of Hashemite University for two years (1/1/2012 through 30/12/2013) and reported a positive correlation between tropospheric ozone and air temperature, wind speed, and wind direction (Odat et al. 2017).

## MATERIALS AND METHODS

### Data Procurement

Concentrations of airborne $PM_{10}$, $PM_{2.5}$, $O_3$, $NO_2$, $SO_2$, and CO at five monitoring stations were downloaded from the official website of the Jordanian Ministry of Environment (Table 1 & Table 2).

### Data Analysis

After collecting the data, a primary statistical analysis was performed to characterize the data (Table 3)

### Air Quality Index

The AQI is a measure of daily air quality at a particular site used to inform the general public of how clean the air is and stresses the health repercussions that a person may experience in the hours or days following inhaling polluted air. It can be calculated following the method adopted by the U.S. Environmental Protection Agency the following formula (EPA 2018).

Table 1: Air quality stations used in this study and their locations.

| Location | Station Name | Abbreviation | Longitude | Latitude |
|---|---|---|---|---|
| Amman | Greater Amman Municipality | GAM | 35.925921 | 31.945829 |
| | King Abdullah II Industrial City/Sahab | KAC | 36.012713 | 31.846026 |
| | King Hussein Gardens | KHG | 35.823449 | 31.987676 |
| Zarqa | Health Center Wadi Hajar | HAJ | 36.0865 | 32.054607 |
| | Main Slaughterhouse Factories (Masane') Zone | MAS | 36.0992 | 32.025635 |

Table 2: Time periods for the five monitoring stations.

| Parameter | Unit | Data Period | | | | |
|---|---|---|---|---|---|---|
| | | GAM | KAC | KHG | HAJ | MAS |
| $PM_{10}$ (24-hour) | $\mu g.m^{-3}$ | 1/1/2016 to 18/2/2022 | 1/1/2016 to 18/2/2022 | 1/1/2016 to 18/2/2022 | 1/1/2016 to 18/2/2022 | 1/1/2016 to 18/2/2022 |
| $PM_{2.5}$ (24-hour) | $\mu g.m^{-3}$ | 19/2/2022 to 31/12/2022 | 19/2/2022 to 31/12/2022 | 19/2/2022 to 31/12/2022 | 19/2/2022 to 31/12/2022 | 19/2/2022 to 31/12/2022 |
| $O_3$ (8-hour) | Ppm | NA | 1/1/2016 to 31/12/2022 | 1/1/2016 to 31/12/2022 | NA | NA |
| $NO_2$ (1-hour) | Ppb | 1/1/2016 to 31/12/2022 | 1/1/2016 to 31/12/2022 | 1/1/2016 to 31/12/2022 | 1/1/2016 to 31/12/2022 | 1/1/2016 to 31/12/2022 |
| $SO_2$ (1-hour) | Ppb | 1/1/2016 to 31/12/2022 | 1/1/2016 to 31/12/2022 | 1/1/2016 to 31/12/2022 | 1/1/2016 to 31/12/2022 | 1/1/2016 to 31/12/2022 |
| CO (8-hour) | Ppm | 1/1/2016 to 31/12/2022 | NA | NA | 1/1/2016 to 31/12/2022 | NA |

Table 3: Statistical summary of air quality data collected at five monitoring stations in the Amman-Zarqa metropolitan area during the period 2016-2022.

| Parameter | Station | Minimum | Maximum | Average | Standard Deviation |
|---|---|---|---|---|---|
| $NO_2$ (1-hour) ppb | GAM | 0.01 | 267.00 | 28.99 | 15.10 |
| | KAC | 0.49 | 117.00 | 16.60 | 8.78 |
| | KHG | 0.54 | 42.10 | 8.06 | 6.16 |
| | HAJ | 1.80 | 60.70 | 23.19 | 10.60 |
| | MAS | 4.95 | 56.30 | 22.96 | 8.58 |
| $SO_2$ (1-hour) ppb | GAM | 0.15 | 82.00 | 11.99 | 8.61 |
| | KAC | 1.36 | 34.50 | 7.66 | 4.56 |
| | KHG | 0.10 | 204.00 | 4.24 | 4.86 |
| | HAJ | 0.75 | 61.00 | 12.59 | 9.79 |
| | MAS | 1.07 | 41.40 | 6.25 | 3.00 |
| CO (8-hour) ppm | GAM | 0.00 | 6.50 | 2.20 | 1.29 |
| | KAC | NA | NA | NA | NA |
| | KHG | NA | NA | NA | NA |
| | HAJ | 0.00 | 37.55 | 2.15 | 1.65 |
| | MAS | NA | NA | NA | NA |
| $O_3$ (8-hour) ppm | GAM | NA | NA | NA | NA |
| | KAC | 0.00 | 0.05 | 0.01 | 0.01 |
| | KHG | 0.00 | 0.07 | 0.03 | 0.02 |
| | HAJ | NA | NA | NA | NA |
| | MAS | NA | NA | NA | NA |
| $PM_{10}$ (24-hour) $\mu g.m^{-3}$ | GAM | 4.72 | 411.00 | 49.10 | 36.42 |
| | KAC | 4.31 | 306.00 | 46.69 | 31.59 |
| | KHG | 4.08 | 488.00 | 34.39 | 29.20 |
| | HAJ | 7.73 | 419.00 | 58.25 | 37.61 |
| | MAS | 5.08 | 372.00 | 56.52 | 37.98 |
| $PM_{2.5}$ (24-hour) $\mu g.m^{-3}$ | GAM | 7.37 | 498.00 | 29.46 | 32.37 |
| | KAC | 9.22 | 430.00 | 31.70 | 30.88 |
| | KHG | 8.94 | 468.00 | 22.23 | 27.47 |
| | HAJ | 15.30 | 486.00 | 40.38 | 31.97 |
| | MAS | 10.80 | 464.00 | 38.45 | 32.79 |

$$I_p = \frac{I_{Hi}-I_{Low}}{BP_{Hi}-BP_{Low}} \times (c_{P-BP_L}) + I_{Low} \qquad \ldots(1)$$

Where:

$I_p$ is the AQI value for pollutant p, Cp is the concentration of pollutant p, $BP_{hi}$ is the concentration breakpoint that is greater than or equal to Cp, $BP_{low}$ is the concentration breakpoint that is less than or equal to Cp, $I_{hi}$ is the AQI value corresponding to $BP_{hi}$, and $I_{low}$ is the AQI value corresponding to $BP_{low}$.

The values of AQI classes and breakpoints for each parameter are found in EPA (2018). After calculating the AQI values for each parameter, the attained values are converted into six colors (codes) to inform the general public in an easy, simple, and understandable way (Table 4).

## RESULTS AND DISCUSSION

### Temporal Variation of $PM_{10}$ and $PM_{2.5}$

$PM_{10}$ and $PM_{2.5}$ can have significant health effects, but

Table 4: Classification of AQI values based on EPA standards (EPA 2018).

| AQI Value | Color | Description |
|---|---|---|
| 0-50 | Green | Good |
| 51-100 | Yellow | Moderate |
| 101-150 | Orange | Unhealthy for sensitive group |
| 151-200 | Red | Unhealthy |
| 201-300 | Purple | Very Unhealthy |
| 301-500 | Maroon | Hazardous |

$PM_{2.5}$ is generally considered to be more harmful to human health due to its smaller particle size. $PM_{2.5}$ particles can penetrate deeper into the respiratory system and even enter the bloodstream, reaching the lungs' alveoli and causing more severe health effects, and ability to enter the bloodstream, $PM_{2.5}$ particles have been linked to a higher risk of cardiovascular diseases, including heart attacks and strokes. That said, both $PM_{2.5}$ and $PM_{10}$ can cause harm to health, and exposure to elevated levels of either type should be minimized. Regulatory measures and air quality standards are often in place to monitor and control levels of both $PM_{2.5}$ and $PM_{10}$ to protect public health.

AQI values calculated for $PM_{10}$ varied between 15 and 85 (Fig. 2). Most AQI values revealed good air quality (AQI <50), with few exceptions where the AQI exceeded 50 but remained below 100, indicating good to moderate air quality at the five stations based on $PM_{10}$ concentrations. Natural dust leads to elevated $PM_{10}$ in autumn and spring leading to higher AQI values at the five monitoring stations. The two stations located at Zarqa City (Health Center at Wadi Hajar and Main Slaughterhouse) experienced the highest $PM_{10}$ concentrations while King Hussein Gardens at Amman enjoyed the lowest $PM_{10}$ levels during the monitoring period. Zarqa is located in a hot and dry area where air temperature frequently approaches 40°C in summer months while receiving low precipitation leading to loose and dry soil particles that can be easily picked up by wind as fugitive dust. Jordan is frequently impacted by dust storms originating in North Africa or the Arabian Peninsula which leads to elevated dust levels at southern and eastern barren territories that lack adequate vegetation to suppress dust emission. Emissions from local sources, including vehicles, light industries, and home heating, also contribute to $PM_{10}$ and $PM_{2.5}$.

The $PM_{2.5}$ data were only available for the period March 2022 to December 2022. Monitoring stations at all stations recorded high $PM_{2.5}$ concentrations in April and December. High $PM_{2.5}$ are attributed to emissions from natural and anthropogenic sources activities including wildfires,

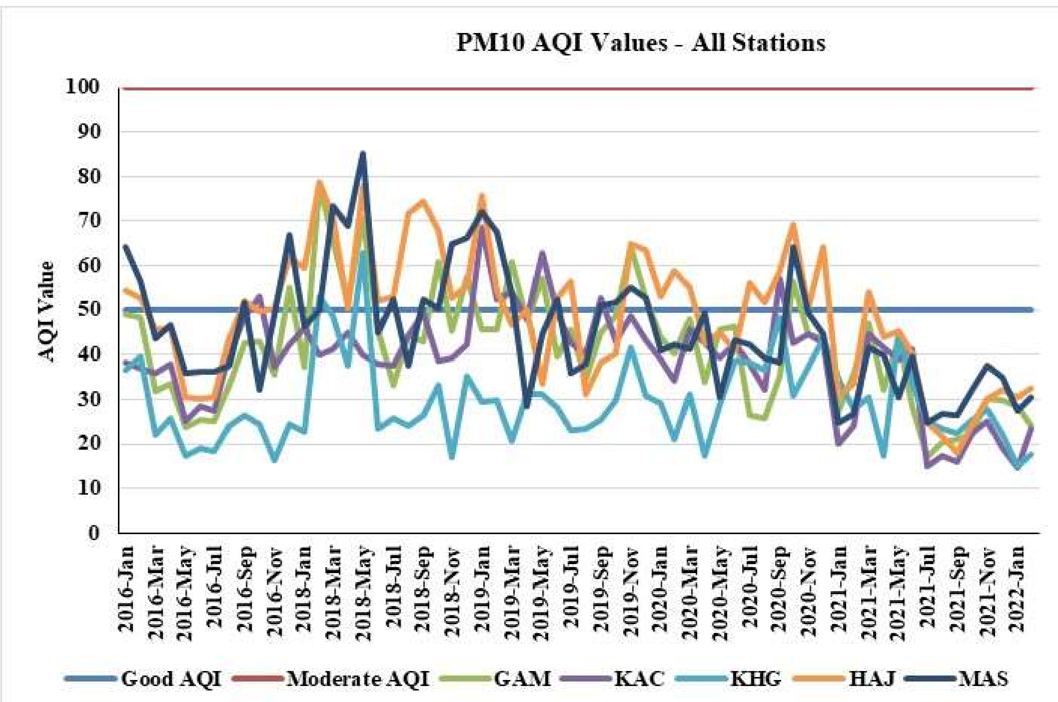


Fig. 2: Mean monthly AQI values for $PM_{10}$ at five air quality monitoring stations in the Amman-Zarqa metropolitan area during the period 2016-2022.

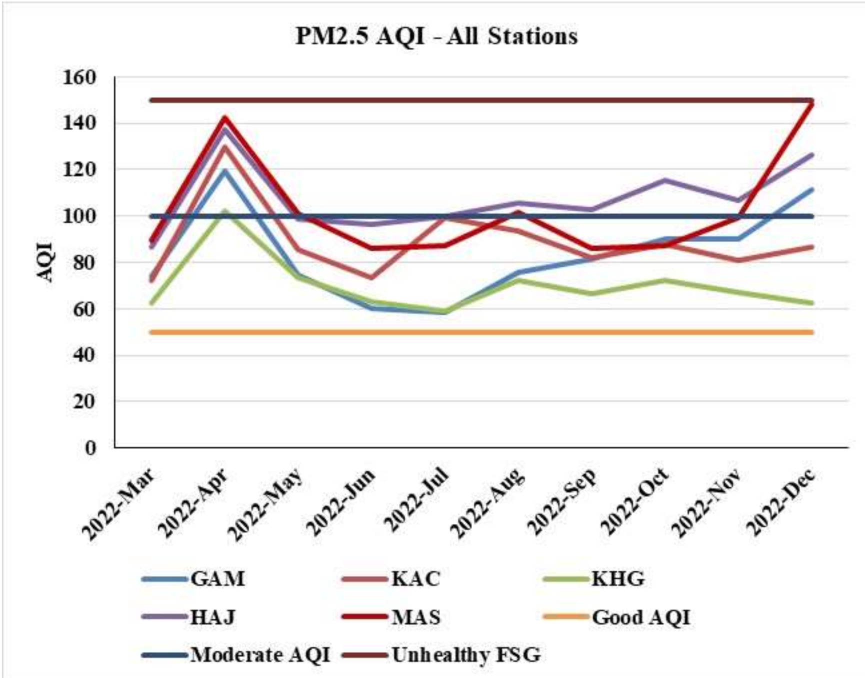


Fig. 3: Mean monthly AQI values for $PM_{2.5}$ at five air quality monitoring stations in the Amman-Zarqa metropolitan area in 2022.

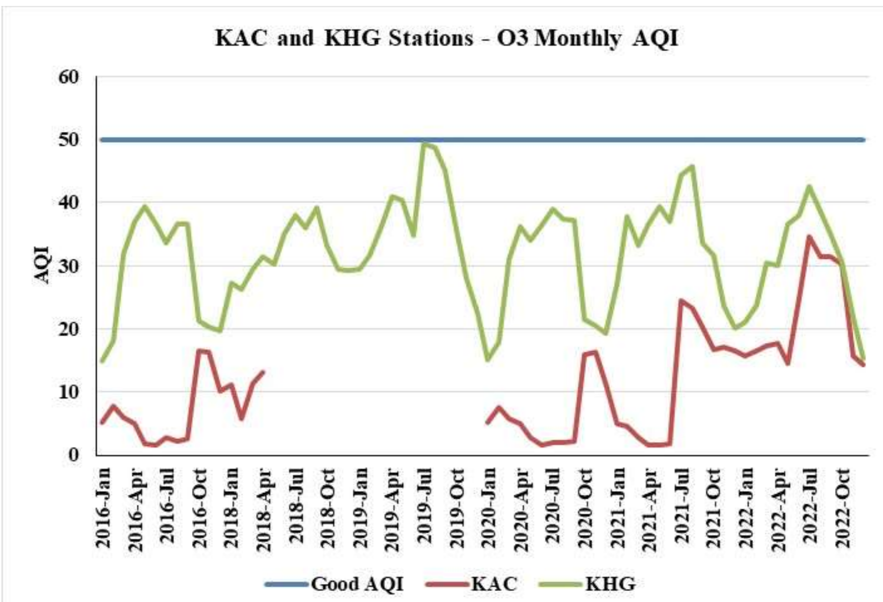


Fig. 4: Mean monthly AQI values for tropospheric ozone at KAC and KHG monitoring stations during the period 2016-2022.

transportation, and burning of fossil fuel for home heating or power generation.

The temporal variation of AQI based on $PM_{2.5}$ fluctuates between good (code green) and unhealthy (code red) air quality (Fig. 3). Highest values were recorded at the Factories Zone in Zarqa during April and December. Cold Earth surface in winter and long nights in spring and autumn promote thermal inversion that halts the mixing of air and constrains dispersing contaminants leading to elevated levels of air pollutants including $PM_{2.5}$.

### Temporal Variation of Tropospheric Ozone

Readings of tropospheric ozone were available for two monitoring stations only. Therefore, AQI values based on Ozone readings were calculated for King Abdullah II Industrial City (KAC) and King Hussein Gardens (KHG) monitoring stations and found to be below 50 (Fig. 4) indicating good air quality in terms of with respect to tropospheric ozone (code green). Ozone is a secondary photosynthetic gas produced when nitrogen oxides and hydrocarbons transported from regional sources undergo chemical reactions in the air. This implies that ozone created due to activities performed at these stations won't be readily detected at nearby monitoring stations.

### Temporal Variations of Carbon Monoxide

The monthly air quality index (AQI) based on CO readings collected at the monitoring stations located at the main building of Greater Amman Municipality (GAM) and the Health Center of Wadi Hajar (HAJ) were below 50 (code green) indicating good air quality at both stations (Fig. 5). However, there are notable differences between GAM and HAJ regarding the magnitude and consistency of AQI values. In GAM, the monthly AQI values for CO consistently remained within the good air quality range, ranging from 20.85 to 36.11. This indicates that GAM generally exhibited stable and satisfactory air quality conditions for CO throughout the year. The highest recorded AQI value in GAM was 41.79 in February 2020, which still falls within the moderate air quality range. Despite this temporary increase, GAM's air quality for CO remained relatively consistent, indicating effective control measures and minimal fluctuations in CO emissions.

HAJ experienced a wider range of AQI values compared to GAM. The monthly AQI values for CO in HAJ ranged from 12.75 to 66.47, demonstrating greater variability in air quality levels. In January 2018, HAJ recorded a significantly high AQI value of 63.77, indicating moderate air quality. This suggests that HAJ experienced occasional episodes of compromised air quality for CO, potentially due to local emission sources or meteorological factors.

When comparing GAM and HAJ, it is evident that GAM exhibited slightly more consistent air quality for CO throughout the year. This could be attributed to several factors, including variations in local emission sources, meteorological conditions, and geographic features. GAM's relative stability in air quality may be attributed to effective air pollution control measures, including regulations on vehicle emissions and industrial activities.

In contrast, HAJ's wider range of AQI values indicates greater fluctuations in air quality, which various factors

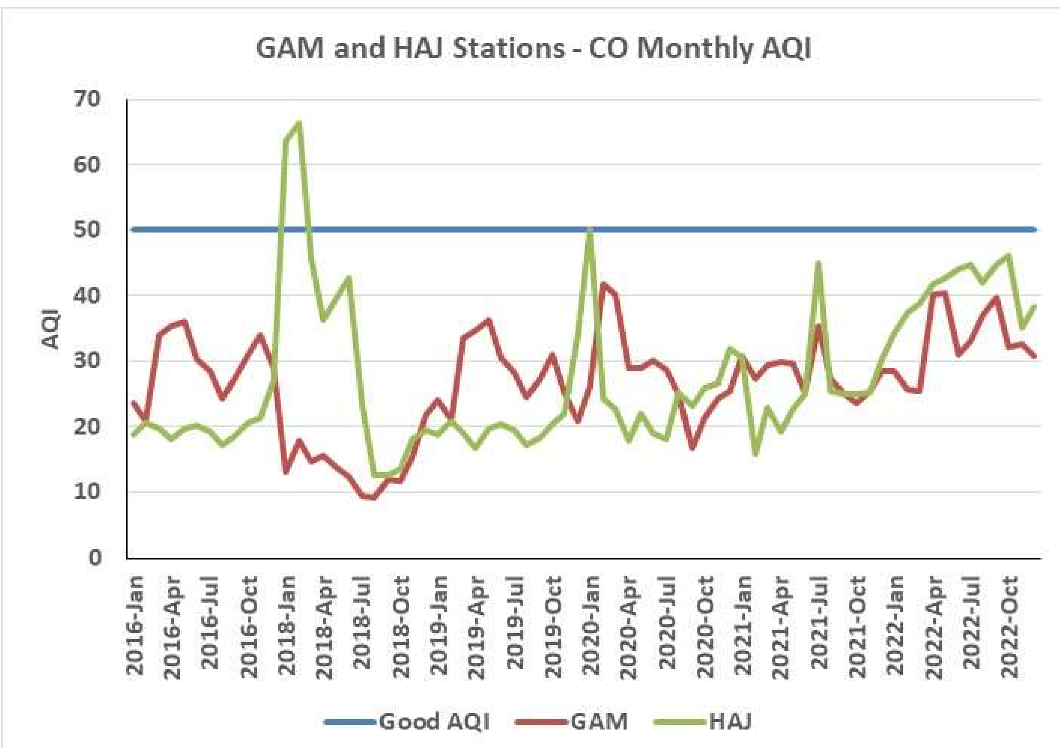


Fig. 5: Mean monthly AQI values for CO readings collected at GAM and HAJ monitoring stations during the period 2016-2022.

could influence. Further analysis is required to identify specific sources contributing to higher AQI values in HAJ. Nonetheless, periodic monitoring, analysis, and implementation of appropriate air quality management measures are crucial for both GAM and HAJ to ensure continuous improvement and maintenance of air quality, particularly for CO.

**Temporal Variations of Sulfur Dioxide**

The monthly air quality index (AQI) results for sulfur dioxide ($SO_2$) in the locations of GAM, KAC, KHG, HAJ, and MAS provide valuable insights into the variations in air quality levels throughout the year, comparing them to the good air quality threshold of 50. The data reveals distinct patterns and differences among these locations, indicating variances in $SO_2$ emissions and air quality management practices.

GAM consistently demonstrated monthly AQI values for $SO_2$ below the good air quality threshold of 50, ranging from 3.19 to 29.37. These values consistently indicated good air quality, suggesting the effectiveness of measures implemented in controlling $SO_2$ emissions in GAM throughout the year (Fig. 6).

Similarly, in the station KAC, the AQI values for $SO_2$ varied between 3.19 and 25.94. These values consistently remained below the AQI threshold of 50, indicating that the air quality in KAC was predominantly in the "Good" category throughout the observed months. The low maximum AQI value of 25.94 further demonstrates the area's relatively low levels of $SO_2$ pollution.

In the case of KHG, the monthly AQI values ranged from 2.19 to 9.92. These values signify that the air quality in KHG consistently stayed within the "Good" category, indicating minimal impact from $SO_2$ pollution. The highest AQI value of 9.92 further reinforces the station's good air conditions for $SO_2$.

In contrast, the station HAJ exhibited higher fluctuations in AQI values, ranging from 2.54 to 60.85. Although most recorded months experienced "Good" air quality for $SO_2$, the maximum AQI value of 60.85 indicates an instance where the air quality temporarily exceeded the acceptable threshold. This suggests the possibility of occasional higher concentrations of $SO_2$ in the atmosphere, potentially due to localized emission sources or meteorological factors.

Lastly, the station MAS demonstrated consistent "Good" air quality for $SO_2$, with AQI values ranging from 3.14 to 20.68. The relatively low maximum AQI value of 20.68 indicates that the air quality in MAS remained well below the acceptable threshold, implying favorable air quality conditions for the residents.

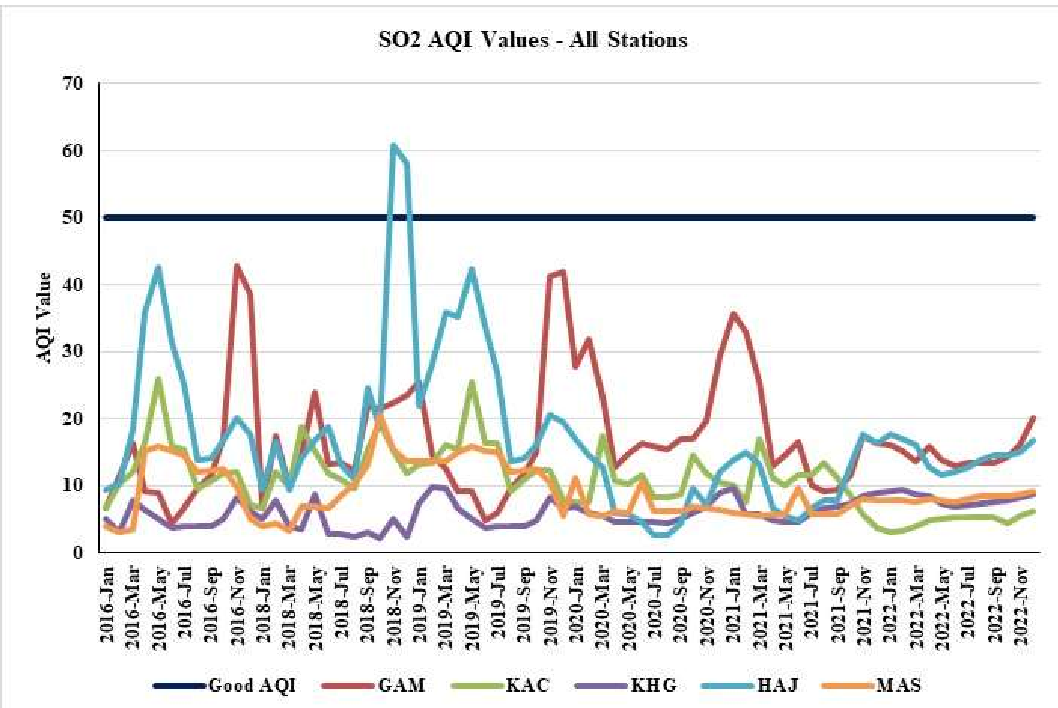


Fig. 6: Mean monthly AQI values for $SO_2$ at five air quality monitoring stations in the Amman-Zarqa metropolitan area during the period 2016-2022.

### Temporal Variations of Nitrogen Dioxide

In GAM, the monthly average AQI values for $NO_2$ generally remain below the threshold of "good" air quality AQI of 50 throughout the year. However, slight fluctuations can be observed. During the winter months (December to February), the AQI values range from 22.31 to 36.52, indicating a relatively better air quality compared to other seasons. The summer months (June to August) exhibit slightly comparable AQI values, ranging from 26.38 to 26.99. Overall, GAM maintains good air quality with only minor fluctuations (Fig. 7).

KAC also demonstrates relatively good air quality throughout the year, with the monthly average AQI values for $NO_2$ mostly staying below the "good" level of 50. KAC experienced higher AQI values during the winter months (December to February), ranging from 14.25 to 20.81. The summer months (June to August) show slightly lower AQI values, ranging from 11.81 to 17.74. KAC generally maintains good air quality, although there are slight seasonal variations.

At KHG, the monthly average AQI values for $NO_2$ consistently remain below the threshold of "good" air quality level of 50 throughout the year. The winter months (December to February) exhibit slightly higher AQI values, ranging from 13.39 to 19.78, while the summer months (June to August) show lower AQI values, ranging from 3.14 to 5.82. KHG consistently maintains good air quality, with only minimal variations observed.

HAJ demonstrates relatively good air quality, with the monthly average AQI values for $NO_2$ mostly remaining below 50. Similar to the other locations, HAJ experienced higher AQI values during the winter months (December to February), ranging from 17.13 to 18.86. The summer months (June to August) display slightly lower AQI values, ranging from 12.38 to 15.44. HAJ generally maintains good air quality, with seasonal variations within a relatively narrow range.

MAS also enjoyed good air quality, with the monthly average AQI values for $NO_2$ remaining below the "good" level of 50 throughout the year. Similar to the other locations, MAS experienced higher AQI values during the winter months (December to February), ranging from 12.92 to 30.43. The summer months (June to August) exhibit slightly lower AQI values, ranging from 13.62 to 17.26. MAS maintains good air quality with seasonal variations within an acceptable range.

When comparing the locations, it is evident that all five locations generally maintain good air quality with monthly

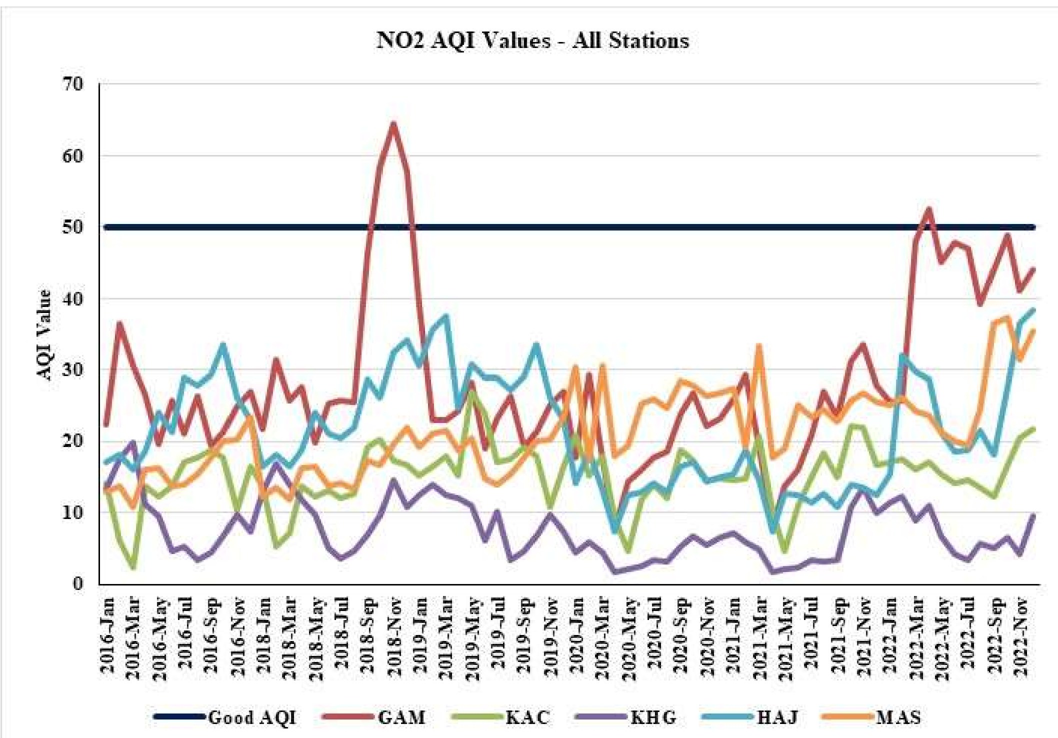


Fig. 7: Mean monthly AQI values for $NO_2$ at five air quality monitoring stations in the Amman-Zarqa metropolitan area during the period 2016-2022.

average AQI values for $NO_2$ below 50. However, slight differences can be observed. For example, KHG consistently exhibits the lowest AQI values among the locations, indicating consistently good air quality. On the other hand, MAS occasionally shows higher AQI values, particularly during the winter months. KAC and HAJ exhibit relatively similar patterns, while GAM consistently maintains good air quality with minimal fluctuations.

The observed seasonal variations in the AQI values can be attributed to several factors. Higher AQI values may occur during the winter months due to increased emissions from heating sources, limited atmospheric dispersion, and potential temperature inversions. Burning fossil fuels in residential and commercial heating systems can release pollutants such as nitrogen dioxide, leading to higher winter AQI values. Limited atmospheric dispersion during this season hinders the dilution and dispersal of pollutants, contributing to higher AQI values. Temperature inversions, where a layer of warm air traps cooler air near the ground, can further exacerbate the accumulation of pollutants.

Conversely, the lower AQI values observed during summer months can be attributed to reduced emissions from heating sources, enhanced atmospheric mixing, and favorable meteorological conditions. Reduced heating-related emissions during summer contribute to lower levels of $NO_2$ in the atmosphere. Enhanced atmospheric mixing, driven by convective processes and increased wind speeds, aids in the dispersion and dilution of pollutants, leading to lower summer AQI values. Furthermore, higher temperatures and increased solar radiation can facilitate the breakdown of pollutants through chemical reactions, further improving air quality.

In conclusion, the monthly average AQI values for $NO_2$ indicate that the five locations generally maintain good air quality. Seasonal variations are observed, with higher AQI values during winter and lower values during summer. These variations can be attributed to increased emissions from heating sources, limited atmospheric dispersion, temperature inversions during winter, reduced emissions, enhanced atmospheric mixing, and favorable meteorological conditions during summer. Understanding these variations and their causes is crucial for implementing effective air quality management strategies in each location.

## CONCLUSIONS

Air pollution is an alarming threat to humanity and ecosystems on Earth with far-reaching consequences impacting climate change, public health, and mortality rates. Immense efforts have been undertaken globally to control emissions of air contaminants, particularly in densely populated urban centers where human activities emit an excessive influx of air pollutants.

This research aimed to calculate the quality index of air pollutants including ground-level ozone, carbon monoxide, sulfur dioxide, particulate matter, and nitrogen dioxide in the mostly populated area in Jordan which spans over Amman-Zarqa metropolitans during the period 2016-2022. A total of five air quality monitoring stations, three located in Amman and two in Zarqa, were selected for this study. Daily air quality data was downloaded from the official website of the Jordanian Ministry of Environment website. The Air Quality Index (AQI) was calculated using the esteemed U.S. Environmental Protection Agency (EPA) method, providing a comprehensive assessment of air quality in the study region. The AQI values were further classified into distinct categories, signifying the varying degrees of air quality, ranging from “Good” to “Hazardous.”

Regarding $PM_{10}$, variations in the Air Quality Index (AQI) were observed for each station, with fluctuations occurring predominantly in the “Good” AQI class (0-50), except for several days where it reached the “Moderate” AQI classification (51-100). For $PM_{2.5}$, available data showed AQI values fluctuating between “Moderate” and “Unhealthy for Sensitive Groups” (FSG). Ozone-based AQI values varied within the “Good” class for KAC and KHG stations, while AQI values for CO predominantly remained in the “Good” range at GAM, while HAJ experienced occasional episodes of compromised air quality for CO. Spatially, the GIS interpolation results illustrated areas with higher AQI values, particularly around HAJ and MAS stations, indicating potential hotspots for pollution.

Furthermore, $SO_2$ AQI values were predominantly “Good” for all stations, with GAM, KAC, KHG, and MAS consistently maintaining good air quality throughout the study period. HAJ, however, exhibited higher fluctuations in AQI values, occasionally exceeding the “Good” threshold. When assessing $NO_2$, all five locations demonstrated good air quality, with monthly average AQI values consistently below 50. Seasonal variations were observed, with higher AQI values during winter attributed to increased emissions from heating sources and limited atmospheric dispersion, while lower values during summer were attributed to reduced emissions and enhanced atmospheric mixing.

Based on the study findings, it is suggested that:

1. Develop and enforce strict legislation: Governments should develop and implement strong and stringent legislation to control air pollution. Such legislation should include strict emission standards for industries and transportation and specific laws to prevent waste burning and air pollution from other sources.

2. Encouraging the transition to clean energy sources: The use of renewable and clean energy sources such as solar, wind, and safe nuclear energy should be promoted. Governments should provide encouragement, financial support, and appropriate legislation for companies and individuals to invest in these clean resources.
3. Improving the quality of transportation: Public transportation should be strengthened and improved, and the use of clean transportation such as electric vehicles should be encouraged. This can be achieved by providing adequate infrastructure and encouraging investment in environmental technology for transportation.
4. Awareness and education: Awareness and education should be strengthened about the impact of air pollution on public health and the environment. This can be achieved through information campaigns and the provision of information and educational resources to the public. Efforts should be directed to educate young people and enhance their awareness of the importance of protecting the environment.
5. International cooperation: International cooperation and exchange of knowledge and experience in the field of air quality protection should be strengthened. This can be achieved by forming international and regional organizations that share data and technology and develop joint strategies to improve air quality.
6. Research and development: Research and development in technology to reduce pollution and improve air quality should be supported. This can be done by allocating more funding to scientific research and encouraging cooperation between universities, research institutions and industry.
7. Monitoring and Control: Effective systems for monitoring and controlling air quality must be developed at the global level. Data and information should be exchanged between countries and international organizations to assess the transboundary impact of air pollution and take corrective action based on the assessments.

## LIMITATIONS OF THE STUDY

The air quality index was introduced to inform the public about environmental conditions, which is especially useful for people suffering from illnesses aggravated or caused by air pollution. However, it does have limitations, including a general inability to inform the public regarding health risks occurring at concentrations below regulatory standards and an inability to account for the health effects of exposure to multiple pollutants.

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## ORCID DETAILS OF THE AUTHORS

M. Abu-Allaban: https://orcid.org/0000-0003-3067-6231