ESJ Natural/Life/Medical Sciences Peer-reviewed

Recent Trends in Air Pollution in the Most Important City of The Romanian Black Sea Coast

Miruna-Amalia Nica, MSc
Valentina-Mariana Mănoiu, Associate Professor
Faculty of Geography, University of Bucharest, Romania

Doi:10.19044/esj.2024.v20n27p1

Submitted: 23 August 2024
Accepted: 13 September 2024
Published: 30 September 2024

Cite As:
Nica, M-A. & Mănoiu, V-M. (2024). *Recent Trends in Air Pollution in the Most Important City of The Romanian Black Sea Coast*. European Scientific Journal, ESJ, 20 (27), 1. https://doi.org/10.19044/esj.2024.v20n27p1

Abstract

Air pollution is one of the greatest environmental issues of contemporary society, affecting virtually all major cities worldwide, including those in Romania. Consequently, evaluating the dynamics of pollution conditions in urban environments is essential for designing control measures and adaptation strategies to this environmental disruption. This paper aims to analyze the recent dynamics of pollution and air quality in Constanta, the largest city on the Romanian coastline and one of the most important cities along the entire Black Sea coast. The investigations were based on the official concentrations of major atmospheric pollutants recorded at air quality monitoring stations located within or near Constanta. The dynamics of pollutant concentrations were explored at annual and seasonal levels, and the results showed a mixed picture of changes in the atmospheric pollutant concentrations, in recent years. Essentially, the findings highlighted both increases and decreases in air pollution conditions, emphasizing the need for constant air quality monitoring and controlling throughout Constanta city.

Keywords: Constanta, air pollution, air quality, port city, chemical pollutants

Introduction

Environmental pollution remains one of the most important global threats to the environment and humanity, being a major cause of human morbidity and mortality (Ukaogo et al, 2020). This environmental disturbance

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

involves the introduction of substances or energies into the natural environment that cause significant harm to human health, ecosystem balance, and the quality of natural resources (Nica et al, 2024).

Environmental pollution is an emerging environmental problem in many regions of the world, which triggers many ecological and socio-economic problems (Gaur et al, 2024). This phenomenon is driven by anthropogenic activities such as industrialization, urbanization, and intensive agriculture, which can trigger a significant degradation of air, water, and soil environmental components, leading to biodiversity loss or climate change (Farhan et al, 2022).

Air pollution consists of the presence of substances or particles in the air at concentrations high enough to cause adverse effects on human health, ecosystems, and climate (Rentschler and Lenova, 2023). It may contain gases such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), and particulate matter ($PM_{2.5}$, PM_{10}), as well as tropospheric ozone (O_3), which is a secondary pollutant formed through chemical reactions between primary pollutants in the presence of sunlight (Sicard et al, 2023).

Air quality is determined by emissions into the air from natural and anthropogenic sources, such as industry, road transport, agriculture, and other human activities (Vohra et al, 2021). These sources contribute to the release of primary pollutants, which can be directly harmful or react with each other to form secondary pollutants, thus exacerbating their impact on human health and the environment. Meteorological factors, such as temperature, humidity, wind speed, and direction, are also crucial in pollution dynamics, influencing their dispersion and concentration in the atmosphere (Zhu et al, 2021).

Air pollution can pose a major health problem, especially due to the risks associated with simultaneous exposure to various atmospheric pollutants (Chen et al, 2024). The interaction between pollutants such as particulate matter (PM), nitrogen oxides (NOx), sulfur dioxide (SO_2), and ground-level ozone (O_3) can exacerbate respiratory and cardiovascular conditions, leading to a higher incidence of chronic diseases (Contini and Costabile, 2024).

Air pollution and other pollution sources represent a significant environmental issue also in Romania, which ranks 13th on the list of the most polluted countries in Europe, according to the 2021 Global Air Quality Report (Mahler et al, 2023). Thus, large cities such as Bucharest, Cluj-Napoca, Timisoara, Iasi and Constanta exhibit deteriorated air quality due to emissions from transportation, industrial activities, fossil fuel-based heating and other pollution sources.

Constanta city, the largest and most important port city situated on the Romanian Black Sea coast and the largest city port along the entire Black Sea coast (Partene et al, 2023), faces significant issues related to atmospheric and

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

environmental pollution (Rata and Rusu, 2019). Port activities, including handling and transporting goods, generate significant emissions of gases and particles into the atmosphere (Song et al, 2022). Additionally, the intense vehicular traffic, both maritime and road, contributes to increased pollutant concentrations. The local industry, along with refineries and other production units, represents a major source of pollutant emissions.

Moreover, the city's diverse industrial profile, which includes the largest refinery in the country, Petromidia Refinery, as well as the Palas Thermal Power Plant and other production units, constitutes a significant source of pollutant emissions (Tiscovschi, 2005). The city (with the surrounding areas) is also a major tourist pole in the country, which further complicates the atmospheric pollution, through the generally high traffic conditions (Anton, 2021).

In these circumstances of socio-economic relevance, the assessment of air quality across Constanta city is crucial. Therefore, this study aims to examine the recent dynamics of atmospheric pollution in the Constanta city area, based on some air quality data which are freely available and highly relevant for the analysis of air pollution. Exploring changes in air pollution and providing up-to-date air quality information can be useful for the key policies that address the urban pollution issue in southeastern Romania.

Data and methodology

Study area

The study area is located in the southeastern part of Romania (Fig. 1a), in Dobrogea, Constanta County (Fig. 1b), and is situated on the western shore of the Black Sea, being a coastal city (Fig. 1c). The county seat, with the same name, is one of the oldest settlements in the country, with origins dating back to the 7th century BC (Cracu et al, 2024). Constanta is close to the localities of Agigea, Navodari, Techirghiol, Cumpana, Valu lui Traian, and Murfatlar, with direct access to the Black Sea to the east. This location provides a significant advantage in terms of economic and tourist development, playing an important role in maritime transport networks and regional commercial activities.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

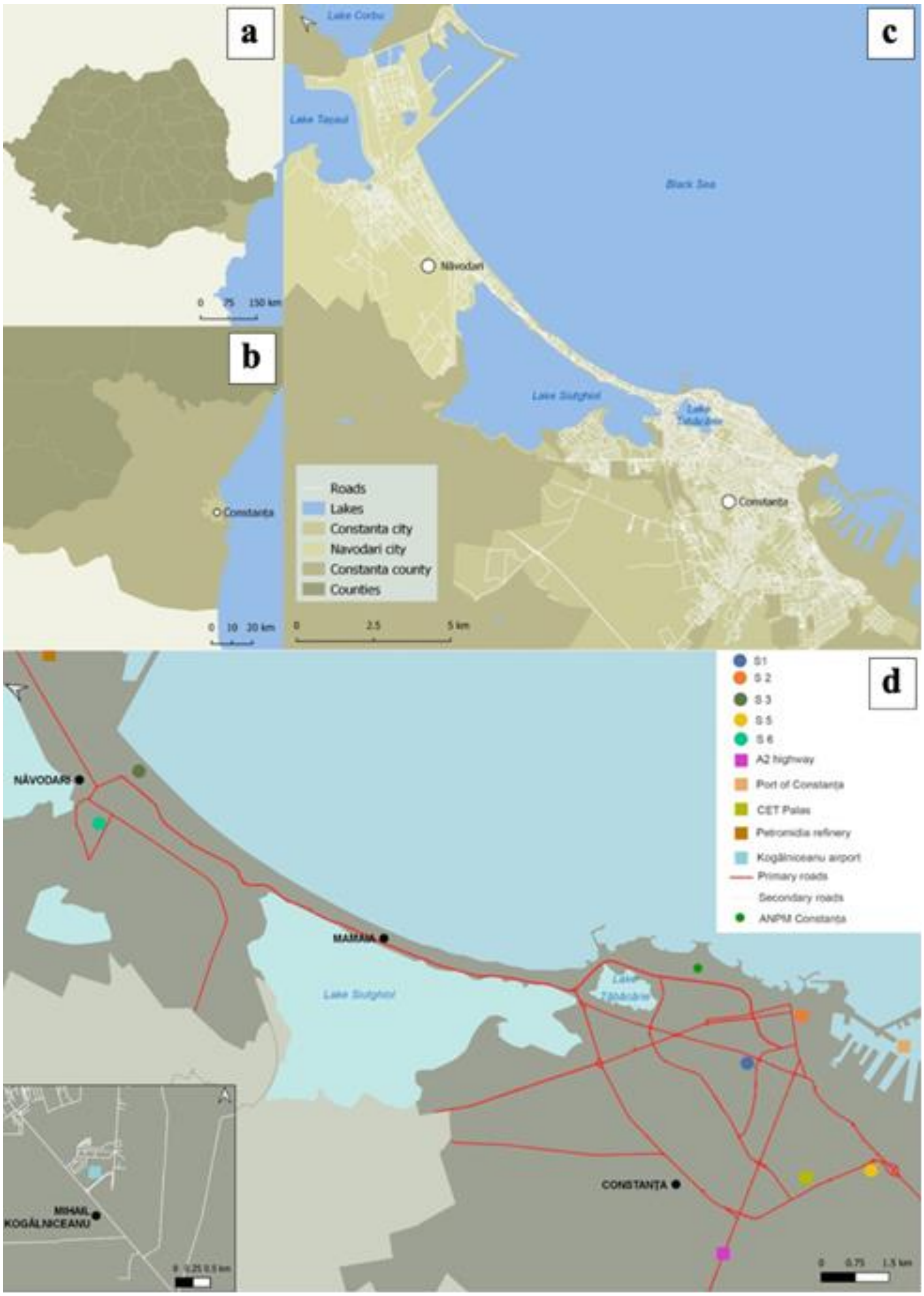

Figure 1. The study area and geographic distribution of Constanta Environmental Protection Agency, air quality monitoring stations and major pollution sources

Constanta is among the top five largest cities in Romania (Population HUB, 2024). For 2024, the estimated population is approximately 249,423

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

inhabitants, according to the World Population Review (WPR, 2024). When considering the peri-urban area, which includes nearby localities like Navodari, the population increases, emphasizing the city's significance. Constanta also experiences a substantial influx of tourists annually, further adding to its demographic importance during peak seasons.

In recent years, Constanta has recorded an average of over 1 million tourists per year, with peaks during the summer season (June-August). For example, in the summer of 2023, more than 1.5 million tourists were registered in Constanta County, according to the National Institute of Statistics (NIS, 2024), most of whom were attracted by the beaches in Mamaia and the events organized in the city. These factors, combined with its multi-industrial profile and extensive spatial expansion, make the city and its surrounding area particularly relevant for studies on atmospheric pollution due to the various emission sources present.

Data

This study examines the dynamics of atmospheric pollution in the municipality of Constanta, based on data collected from the environmental reports of the Agency for Environmental Protection (AEP) Constanta, an institution subordinated to the National Administration for Environmental Protection. The data used in this study refer to the monthly average concentrations of the following atmospheric pollutants: carbon monoxide (CO), nitrogen monoxide (NO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), benzene (C_6H_6), ozone (O_3) and particulate matter with a diameter smaller than 10 micrometers but larger than 2.5 micrometers (PM_{10}) (AEPC, 2024).

The data are recorded by the five air quality monitoring stations located along the urban and peri-urban areas of the city (Fig. 1d). The analysis period covers the years 2017-2022, which is limited to just 6 years due to the fact that AEP Constanta began building an online database, in the form of environmental reports, only from 2016. This period is not included in the current study due to the large amount of missing data. It should also be noted that 2 out of the 5 stations do not monitor all the pollutants mentioned earlier. Thus, station S1 does not monitor O_3, while station S5 does not monitor C_6H_6.

Therefore, all the data used in this study were collected from the air quality monitoring network consisting of five automatic stations (Fig. 1d): a traffic-type station (station S1, located near the Cultural Center in Constanta) – which evaluates the impact of emissions from linear pollution sources; an urban background station (station S2, located in the park near the Constanta City Hall) – which measures the average pollution level in a well-defined urban area; a suburban background station (station S3, located near the Victoria Camp in Navodari) – with a role similar to that of the urban background station, measuring the impact of suburban activities; and two

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

industrial stations (station S5, on Prelungirea Liliacului Street in Constanta, and station S6, near Lazar Edeleanu High School in Navodari) – both analyzing the impact of industrial activities on air quality.

All these five monitoring stations are managed by AEP Constanta (Fig. 1d), which continuously records pollutant concentrations. The automatically collected data are compiled into monthly reports by the same institution, which are then made available to the public for various purposes, including research.

Methods

The methodology adopted in this study was based on the graphic analysis of atmospheric pollutant concentrations, which enabled the identification of trends and concentration fluctuations, as well as on the comparative analysis of the differences and similarities between the collected datasets. The entire processing of the collected data was carried out using Excel software, in five main working steps, each with a specific role in extracting relevant information about pollution dynamics and atmospheric quality.

The first step (1) involved calculating the average concentrations of monitored atmospheric pollutants, on annual and seasonal timescales, for each of the five air quality monitoring stations. This mathematical averaging process included collecting and processing the monthly data provided by the air quality monitoring stations. Raw data were processed in Excel, where arithmetic means were applied to each dataset annually and for each season (spring – with the period of March- May, summer – June-August, autumn – September-November, winter – December-February). Seasonal averaging is crucial for identifying the variability of pollution and air quality in relation to seasonal climate changes and different pollution sources that may be active at certain times of the year.

The second step (2) involved the graphical processing of the averaged data, generating basic charts that illustrate the dynamics of atmospheric pollutant concentrations over the 6 years, for each station and timescale (annual and seasonal). In the third step (3), linear trends were plotted for each air quality monitoring station, annually and seasonally.

In these two working steps, each station was analyzed separately to highlight whether there are increasing, decreasing, or stable trends in pollutant concentrations at each monitoring point. This individual analysis is crucial for understanding how pollution and air quality differ across various areas of the city and for identifying local pollution sources.

After these individual processings, the calculation of a mean concentration for all 5 monitoring stations was performed, in the fourth working phase (4). Finally, in the last working step (5), the equation of the

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

average linear trend was extracted, based on the mean concentrations calculated in the previous phase.

Although the concentrations averaged and plotted as mean trends may obscure the local variations, these procedures can still be useful for the overall dynamics of air pollution. Consequently, calculating the mean concentrations and extracting the mean trend slopes were considered useful steps for a general assessment of pollution changes, in Constanta and in the surrounding areas.

Results

The graphical results of this study highlight the mean concentrations (on the left) and their trends / mean trend (on the right) of atmospheric pollutants, both on annual and seasonal timescales (Figs. 2–6). This organization of the findings was considered useful because it allowed a detailed assessment of the annual and seasonal variability of pollutants, providing a clear picture of their dynamics during different times of the year.

On the annual time scale (Fig. 2), carbon monoxide (CO) exhibits an interesting dynamic over the period 2017-2022, with two notable peaks in 2020 and 2022. Station S1 recorded the highest average concentration in 2021 – 0.45 mg/m^3. These two increases might seem counterintuitive given the mobility restrictions and reduction in road traffic during the early COVID-19 pandemic. However, a possible explanation could be changes in vehicle usage patterns and heating sources. The annual average trend, at 0.0111 mg/m^3 / yr, shows a slight increase from year to year.

Nitrogen monoxide (NO) showed a surprising trend, marking an average annual increase of 0.3463 µg/m^3. This pollutant, predominantly associated with road traffic emissions and industrial activities, reached a notable peak in 2020, especially at station S1 – 37.20 µg/m^3. Although a decrease might have been expected due to the pandemic, the explanation likely lies in the persistence of industrial emissions and increased traffic in central areas, similar to the area where station S1 is located, which might have been intensified by goods transport, possibly increased in central areas for supply purposes. Thus, in 2020, this station recorded a concentration of 37.20 µg/m^3, exceeding the annual critical level of 30 µg/m^3 set for vegetation protection, but remaining below the 40 µg/m^3 threshold considered safe for human health. Nitrogen dioxide (NO_2), a key pollutant associated with severe respiratory problems, recorded a peak concentration of 54.05 µg/m^3 in 2020 at station S1 (Fig. 2), due to the high traffic density in central Constanta. This value exceeds the maximum allowable limit of 40 µg/m^3 set for human health protection. Additionally, station S1 also recorded values exceeding the critical threshold for vegetation protection in the years 2017, 2018, and 2022. However, the annual average trend shows a decreasing trend of 0.6685 µg/m^3 per year.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

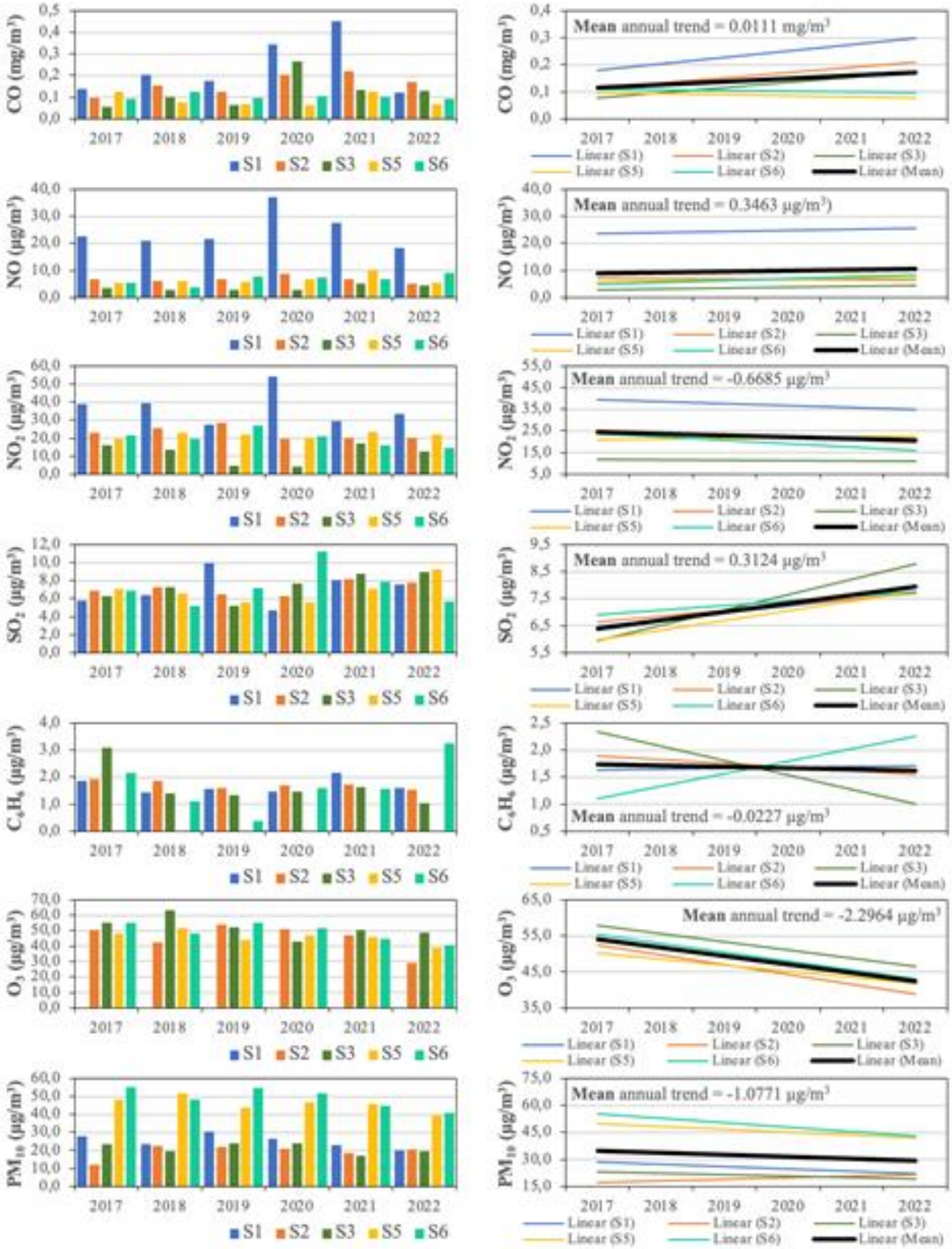

Figure 2. Annual mean concentrations of the main air pollutants and their trends during 2017–2022, at 5 air quality monitoring stations (S) located in the Constanta city area. Note: some data are missing in the case of C_6H_6 (S5) and tropospheric O_3 (S1), for which no air quality data were freely available in the official inventories; the mean linear trend was processed based on the averaged values of all 5 air quality monitoring stations, and the mean annual trend value was extracted from the mean linear trend equation

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Regarding sulfur dioxide (SO_2), exhibited a slight increasing trend (03124 µg/m³ /yr), although with minor fluctuations in concentrations between stations. The moderate increase observed in 2022 may be associated with the intensification of industrial activities in Constanta and Navodari following the resumption of economic activities post-pandemic. It is also noteworthy that the industrial station located in Navodari (station S6) recorded the highest annual average concentration of 11.28 µg/m³, which was observed in 2020. This elevated value can be explained by the station's proximity to the Petromidia Refinery, the largest and most significant oil processing facility in Romania. Emissions from the refinery, including sulfur dioxide from fossil fuel combustion and specific industrial processes, significantly contributed to the concentrations recorded by this station.

Benzene (C_6H_6), a volatile organic compound and a known carcinogen, monitored by 4 out of the 5 stations, exhibited marked fluctuations, particularly at stations S3 and S6 in the first and last years of the analysis, respectively, both of which are located near the Petromidia Refinery. However, the average trend indicates a slight annual decrease of 0.0227 µg/m³. Tropospheric ozone (O_3), a dangerous pollutant at ground level in the troposphere, revealed an interesting dynamic in recent years. Analyzed at 4 out of the 5 air quality monitoring stations, this gas showed an annual concentration regime with values that do not exhibit significant fluctuations and an average annual trend that is decreasing by 2.2964 µg/m³ /yr. This suggests an improvement in air quality, potentially due to a reduction in its precursors, nitrogen oxides (NO and NO_2), as well as changes in meteorological conditions and pollutant dispersion.

Suspended particulate matter PM_{10}, known for its harmful effects on respiratory health, has shown a moderate decrease over the analyzed period, with an average annual trend of 1.0771 µg/m³ per year. It is noteworthy that, despite the slight decrease in PM_{10} concentrations, the industrial stations (S5 and S6) in Constanta and Navodari showed relatively high values compared to the other three stations, reflecting the impact of activities carried out by the Petromidia Refinery and Palas Thermal Power Plant, as well as heavy traffic.

The seasonal picture of pollutant dynamics is, as expected, more complex. Fig. 3 illustrates the concentrations of pollutants during the winter season from 2017 to 2022. During winter, air quality in Constanta and Navodari is influenced by a range of factors interacting complexly, from intensified heating activities to the strategic placement of monitoring stations.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

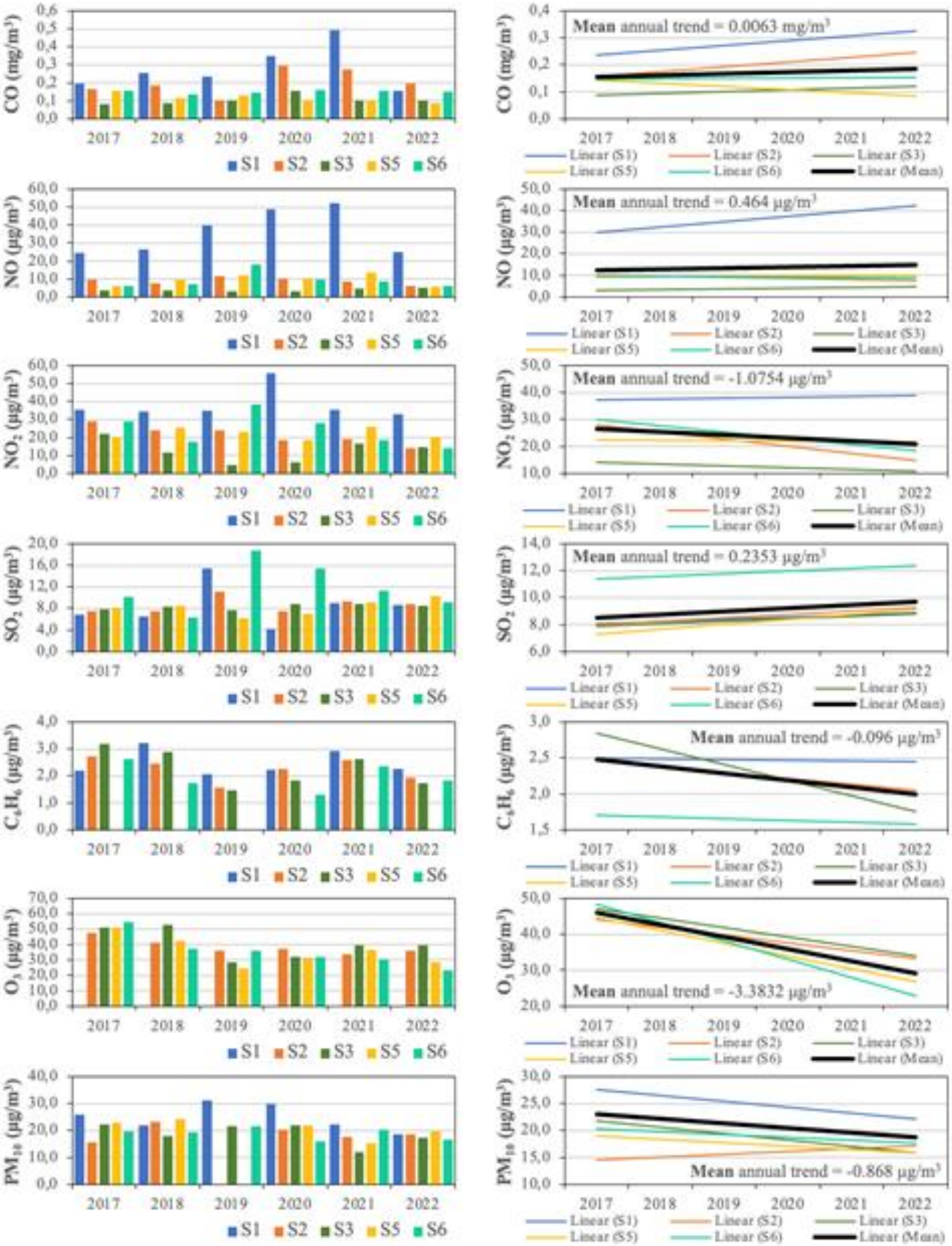

Figure 3. Seasonal (winter) mean concentrations of the main air pollutants and their trends during 2017–2022, at 5 air quality monitoring stations (S) located in the Constanta city area. Note: some data are missing in the case of C_6H_6 (S5) and tropospheric O_3 (S1), for which no air quality data were freely available in the official inventories; the mean linear trend was processed based on the averaged values of all 5 air quality monitoring stations, and the mean annual trend value was extracted from the mean linear trend equation

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

The concentrations of CO during winter have followed a generally stationary trend, with a seasonal average trend of 0.0063 mg/m³ /yr. Notably, the graph showing the seasonal regime of pollutant concentrations highlights a significant increase in 2021 at the S1 station, a traffic-type station, where values are higher compared to other stations. This can be explained by the intensive use of fossil fuel-based heating, combined with increased road traffic during the cold period, especially in the city center considering the location of the monitoring station. Additionally, pandemic restrictions, although they reduced general traffic, shifted activity from public transport to private transport, amplifying CO emissions in dense urban areas.

Regarding NO, there is an average seasonal increase of 0.464 µg/m³, with a notable increase at station S1 in 2021. In 2019 and 2022, average concentrations exceeded the critical threshold of 30 µg/m³ established for vegetation protection. Moreover, in 2020 and 2021, values were above the maximum allowable limit of 40 µg/m³ set for human health protection. The upward seasonal trend reflects the impact of emissions from vehicles and, particularly, the intensive use of fossil fuel-based heating sources, while specific winter meteorological conditions limit dispersion and lead to the accumulation of pollutants in the air.

The seasonal regime of NO_2 indicates a constant increase from 2017 until 2020, when the highest value is recorded, 55.87 µg/m³ at station S1, exceeding the maximum allowable concentration of 40 µg/m³ for human health protection. This suggests that during the cold season, traffic density and industrial activity significantly contribute to pollution, especially in central areas. Furthermore, the traffic-type station S1 recorded values exceeding the maximum allowable level of 30 µg/m³ for vegetation protection each year. In addition to these exceedances at station S1, station S6 also recorded an exceedance of the maximum allowable threshold for vegetation protection in 2019. Since 2021, values have started to gradually decrease, with the average trend showing a decrease of 1.0754 µg/m³ /yr.

SO_2 exhibits an average increasing trend of 0.2353 µg/m³ per year, with higher concentrations during winter closely linked to industrial activities and residential heating. Consequently, the industrial-type station S6, for instance, captures direct SO_2, emissions from industrial burning processes and the use of fossil fuels for heating, intensifying concentrations in the winter season.

C_6H_6 shows fluctuations in average concentrations, but the average trend indicates a slight decrease of 0.096 µg/m³ /yr. Winter values of O_3 remain low due to unfavorable climatic conditions for its formation—low temperatures and limited sunlight. Thus, this pollutant shows a descending seasonal average trend, decreasing by 3.3832 µg/m³ each year.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

The average trend of PM_{10} has moderately decreased during winter, with an average trend of 0.868 µg/m /yr and the average concentration regime of PM_{10} does not exhibit significant fluctuations. Thus, despite seasonal changes, PM_{10} concentrations remain relatively stable.

During spring (Fig. 4), some important nuances in pollutant concentrations are also highlighted, influenced by both local factors and the specific climatic dynamics of this season. CO shows a slight increase in the average trend compared to the trend observed during winter, an evolution that may seem paradoxical given the typical expectations for spring when the need for heating decreases. However, this increase can be attributed to intensified road traffic in urban areas, such as near station S1, which recorded a notable peak in 2021 (0.41 mg/m³). During this period, the seasonal transition is marked by increased population mobility and economic activities, generating emissions that may not be efficiently dispersed due to thermal inversions typical of spring.

Spring favors the dispersion of pollutants due to higher temperatures and air circulation, so the average trend of NO concentrations showed a smaller increase compared to that recorded during winter. Nevertheless, traffic in the central area of Constanta, as well as economic activities, cause station S1 to record the most significant fluctuations in concentrations, with some instances exceeding the maximum concentration limit of 30 µg/m³ for vegetation protection.

Spring brings a seasonal decrease in emissions from heating sources, but road traffic remains a major source of NO_2, especially in densely populated urban areas such as those monitored by station S1. At this station, constant exceedances have been recorded each year analyzed, with values exceeding the critical level of 40 µg/m³ for human health protection in 2017, 2018, and 2020. Additionally, a similar concentration was observed in 2019 at station S2. However, specific spring weather conditions, such as stronger winds, can contribute to the dispersion of this pollutant, which partially explains the decreasing trend of 0.7583 µg/m³ per year.

SO_2, known for its impact on acid rain formation, has shown a moderate increase of 0.3958 µg/m³ /yr (Fig. 4). This is more evident in the industrial area monitored by station S6, located near the Petromidia Refinery. In spring, increased industrial activities, combined with specific weather conditions such as marine breezes, contribute to the accumulation of this pollutant in the air. This is particularly relevant for areas where industrial activity is predominant, as milder temperatures can reduce the effectiveness of emission dispersion.

ISSN: 1857-7881 (Print) e - ISSN 1857-7431

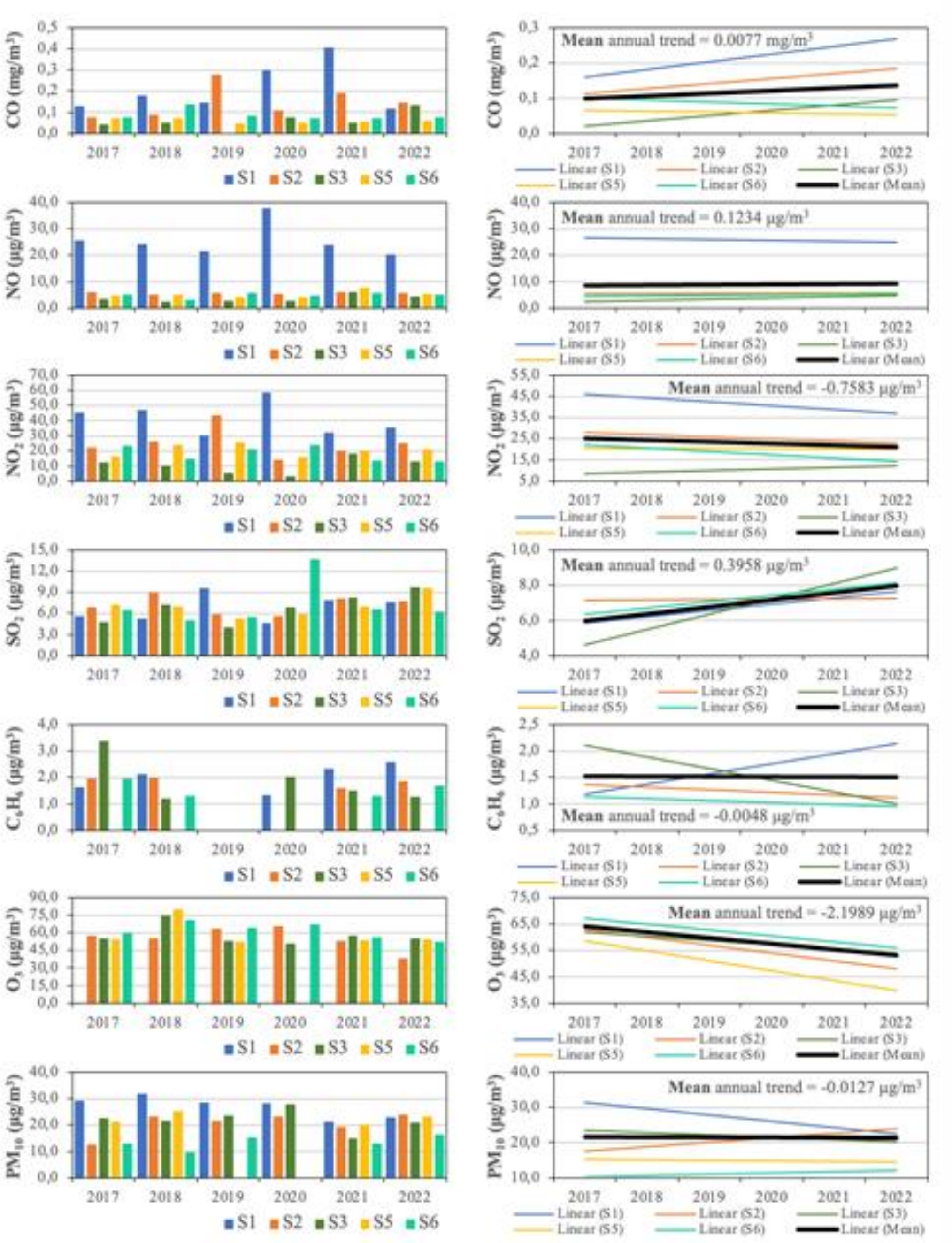

Figure 4. Seasonal (spring) mean concentrations of the main air pollutants and their trends during 2017–2022, at 5 air quality monitoring stations (S) located in the Constanta city area. Note: some data are missing in the case of C_6H_6 (S5) and tropospheric O_3 (S1), for which no air quality data were freely available in the official inventories; the mean linear trend was processed based on the averaged values of all 5 air quality monitoring stations, and the mean annual trend value was extracted from the mean linear trend equation

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Fluctuations in C_6H_6 concentrations observed, especially at station S3, indicate the direct influence of nearby industrial sources. In spring, the resumption of industrial activities and increased traffic contribute to higher levels of C_6H_6, which are significantly captured at these stations, reflecting both local and regional pollution.

The decreasing average trend of O_3 by 2.1989 µg/m³ /yr suggests a slight improvement in air quality, which may be due to both the decrease in its precursors, nitrogen oxides (NO_x), and seasonal meteorological changes that favor pollutant dispersion. In spring, the intensity of solar radiation combined with higher humidity can influence the formation of ground-level ozone.

PM_{10} shows a relatively stationary average trend compared to the trend recorded during winter. This can be explained by the increase in industrial and construction activities in spring, contributing to temporary increases in concentrations. Meteorological conditions such as spring rains can help reduce particulate matter, but these reductions are temporary and depend on the frequency and intensity of precipitation.

The summer season (Fig. 5) records pollutant concentrations that are generally lower than those in winter but higher than in spring, primarily due to increased traffic and tourist activities. CO concentrations during the summer remain relatively low compared to winter but are closer to those recorded in spring. The average trend for the period 2017-2022 indicates an approximately stationary trend, with a value of 0.0076 mg/m³ /yr. During summer, the rise in road traffic typical of the tourist season should increase concentration levels. However, natural dispersion due to marine breezes and higher temperatures reduces CO concentrations compared to the colder months. Stations in Constanta have reported higher values, especially at station S1, a traffic station, reflecting the significant influence of vehicles.

NO shows a significant peak at station S1 in 2020, exceeding the maximum allowable limit of 30 µg/m³ for the protection of vegetation, reflecting the increase in road traffic during the tourist season. The average trend is rising by 0.504 µg/m³ per year, indicating a consistent impact from anthropogenic activities, particularly in the context of the growing seasonal population.

During the summer, NO_2 values are lower than those in winter but similar to those in spring, reflecting a slight decrease in residential heating activities and an increase in road traffic. Traffic and urban stations reported higher concentrations, with exceedances of the maximum allowable limits. For example, at station S1 in 2017, 2018, 2022, and at station S2 in 2019 and 2020, NO_2 concentrations exceeded the maximum limit of 30 µg/m³ for vegetation protection. Notably, 2020 recorded the highest NO_2 concentration during the entire study period (2017-2022), surpassing the maximum allowable threshold of 40 µg/m³ for human health protection. However, the

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

average trend indicates a decrease of 0.4439 µg/m³ per year (Fig. 5), suggesting a progressive reduction in NO_2 pollution in the area.

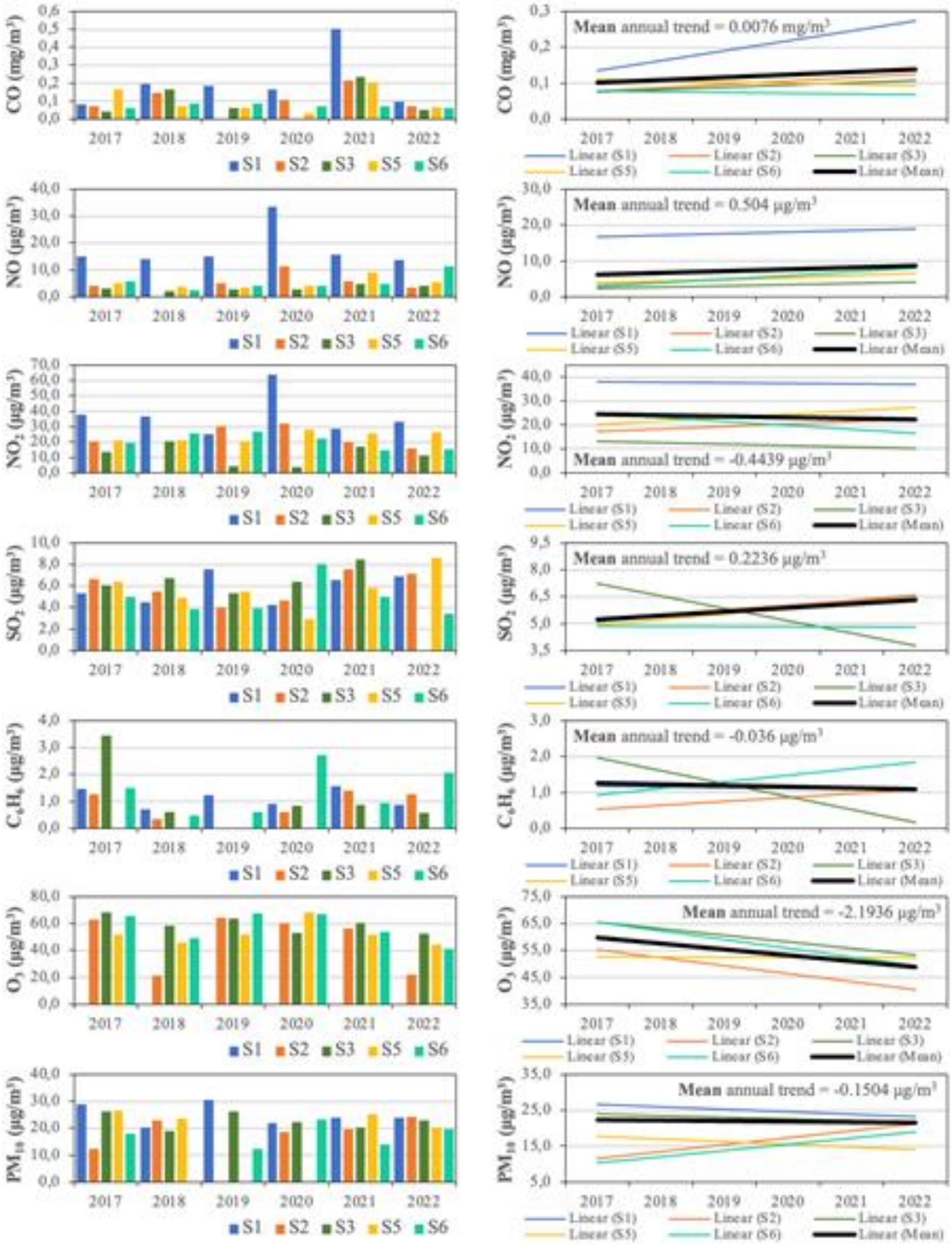

Figure 5. Seasonal (summer) mean concentrations of the main air pollutants and their trends during 2017–2022, at 5 air quality monitoring stations (S) located in the Constanta city area. Note: some data are missing in the case of C_6H_6 (S5) and tropospheric O_3 (S1), for which no air quality data were freely available in the official inventories; the mean linear trend was processed based on the averaged values of all 5 air quality monitoring stations, and the mean annual trend value was extracted from the mean linear trend equation

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

SO_2 maintains moderate values, but a slight increase is observed in 2022 at stations S3 and S6, located near industrial zones. Industrial activity and increased maritime traffic during the summer may explain these increases. High summer temperatures can limit pollutant dispersion, creating conditions for SO_2 accumulation in the air.

C_6H_6 concentrations are higher at stations located in Navodari (S3 and S6) during the summer due to emissions from the refinery area and increased volatilization at high temperatures. Nevertheless, the average trend is decreasing by 0.036 µg/m³ /yr.

O_3 records the highest values in the summer season due to intensified photochemical reactions at high temperatures. The annual trend indicates a decrease of 2.1936 µg/m³, suggesting a reduction in ozone precursors, such as NO_2, but it remains a significant pollutant during the summer.

PM_{10} shows the highest concentrations at the traffic station S1, likely due to the intense traffic during the summer season. The average trend shows a decrease of 0.1504 µg/m³ per year, but the summer season continues to be marked by significant particulate pollution. Nonetheless, meteorological conditions, such as sea breezes, can favor the dispersion of these particles.

Autumn (Fig. 6) typically brings more humid weather and lower temperatures, which can influence pollutant dispersion. It is also a transitional season for industrial and tourist activities.

Regarding CO, the graphs indicate higher variability at the traffic station S1 and the suburban station S3 in Navodari, but with generally lower values compared to other seasons. Reduced traffic activity outside the tourist season and cooler temperatures contribute to decreased CO emissions. The average trend shows a slight increase of 0.0115 mg/m³ /yr, which can be associated with increased use of fossil fuels as the transition to the colder season occurs.

NO shows a slight decrease compared to the values recorded in the summer. This reduction can be explained by the drop in temperatures and tourist traffic, leading to a reduction in direct vehicle emissions. Additionally, the onset of the cold season favors better dispersion of pollutants due to more stable atmospheric conditions and more frequent winds. The average trend, however, indicates a slight increase of 0.0179 µg/m³ per year.

NO_2 concentrations follow a similar trend to NO, showing a decrease compared to the summer. This is due to both the reduction in traffic and more favorable dispersion conditions, including lower temperatures and increased frequency of precipitation. Overall, NO_2 concentrations remain low, but station S1 still shows exceedances of the maximum permissible limit for vegetation protection in 2017, 2018, and 2020. The average trend indicates a decrease of 1.0255 µg/m³ per year (Fig. 6).

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

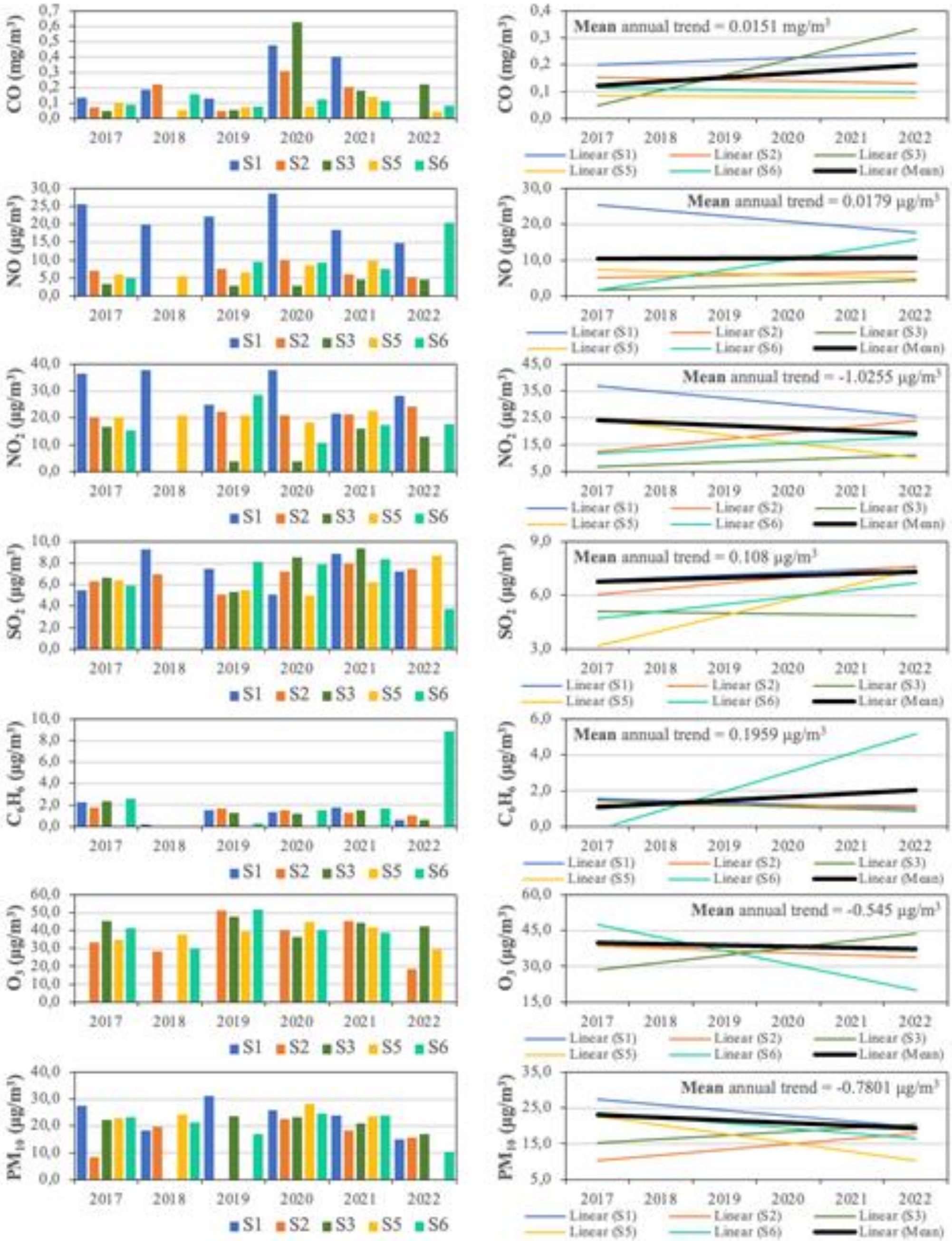

Figure 6. Seasonal (autumn) mean concentrations of the main air pollutants and their trends during 2017–2022, at 5 air quality monitoring stations (S) located in the Constanta city area. Note: some data are missing in the case of C_6H_6 (S5) and tropospheric O_3 (S1), for which no air quality data were freely available in the official inventories; the mean linear trend was processed based on the averaged values of all 5 air quality monitoring stations, and the mean annual trend value was extracted from the mean linear trend equation

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

SO_2 shows slight increases compared to summer. Industrial sources, such as the Palas Thermal Power Plant and the Petromidia refinery, continue to influence the values of this pollutant at the beginning of the heating season, but the gradual cooling of the weather and more frequent winds help disperse emissions.

C_6H_6 exhibits little variation during autumn, remaining at similar levels, except for the autumn of 2022, which recorded a peak likely due to intensified industrial activities near station S6. Additionally, C_6H_6 shows a slightly upward trend, increasing by 0.1959 µg/m³ /yr.

O_3 decreases significantly compared to summer, as light intensity and temperature drop, thereby reducing the photoreactions that form ground-level ozone. This makes autumn a season with a lower risk of O_3 pollution compared to summer, and the average trend shows a slight decrease of 0.545 µg/m³ per year.

A slight increase is also observed in PM_{10} concentrations, with the highest values still recorded at the traffic station S1, reaching a maximum of 30.68 µg/m³. The average trend shows a decrease of 0.1504 µg/m³ /yr.

Discussions

Air pollution and the deterioration of air quality are major issues in modern cities, and Constanta is no exception. Given the specifics of this city, located on the coast and characterized by heavy road traffic, significant industrial activities, and pronounced seasonal tourism, pollution sources can be classified into two main categories: stationary sources and mobile sources. (Panaitescu et al, 2020).

The Palas Thermal Power Plant (Fig. 1d), located in the southwestern part of Constanta, is one of the main stationary sources of pollution in the city. It uses fossil fuels such as coal and oil to generate thermal and electrical energy, and the burning of these fuels releases pollutants into the atmosphere, including nitrogen oxides, sulfur dioxide, and particulate matter, significantly contributing to air pollution.

Additionally, the Petromidia Refinery (Fig. 1d), the largest refinery in Romania, situated in Navodari, northwest of Constanta, represents another major stationary source of pollution. The oil refining activities carried out here produce significant emissions of sulfur dioxide, nitrogen oxides, and volatile organic compounds, and through its distillation processes, dangerous pollutants such as benzene can be released into the air.

Furthermore, Constanta hosts various industries, including metal processing, chemical, and textile factories, which contribute to atmospheric pollution through the emission of sulfur dioxide, nitrogen oxides, volatile organic compounds, and particulate matter. Specific industrial processes, such

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

as metal casting or processing, often generate metallic dust and toxic chemical compounds.

In addition to these, waste treatment facilities in Constanta represent another stationary source of pollution. Methods such as incineration and composting of municipal waste produce emissions of gases, including carbon dioxide and nitrogen oxides, along with particulate matter, which impact the air quality in the area.

Road traffic proves to be the primary mobile source of pollution. Vehicles traveling around the city contribute to the emissions of nitrogen oxides, volatile hydrocarbons, and particulate matter generated through the combustion of fuels in engines. In this study, nitrogen oxides (NO and NO_2) have recorded exceedances of the maximum permissible concentrations. These pollutants are known for their adverse health effects, including irritation of the eyes, nose, and throat, and can exacerbate allergic and asthmatic symptoms (Latza et al., 2009). For example, research has demonstrated that individuals exposed to high levels of atmospheric pollutants face an increased risk of developing bronchial asthma, characterized by inflammation and narrowing of the airways, and COPD, a chronic condition that reduces airflow and causes breathing difficulties (Manoiu et al, 2018). Additionally, nitrogen oxides significantly contribute to the formation of photochemical smog (Colbeck and MacKenzie, 1994), a harmful mixture of atmospheric pollutants, and to acid rain, which can damage aquatic and terrestrial ecosystems, affecting biodiversity and soil health. Moreover, the layout and structure of the city's streets, particularly the major boulevards such as Tomis, Mamaia, Alexandru Lapusneanu, and I.C. Bratianu, significantly influence atmospheric pollution levels, a factor with a direct impact on residents' health and quality of life.

Some large boulevards existing along the city, such as Tomis, Mamaia, Alexandru Lapusneanu, and I.C. Bratianu are the main thoroughfares of the city, playing a crucial role in managing traffic flow. These streets are heavily trafficked, serving as key routes for both locals and tourists. For instance, Boulevard Mamaia, which runs parallel to the coastline, experiences high traffic volumes, especially during the tourist season, leading to significant emissions of pollutants such as carbon dioxide, nitrogen oxides, and particulate matter. Similarly, Boulevard I.C. Bratianu, acting as a major entry point into the city from the A2 Motorway, handles a large volume of traffic, thus contributing to elevated pollutant concentrations in the air.

The layout and orientation of the streets in Constanta significantly affect how air circulates and, consequently, the distribution of atmospheric pollutants. For example, Boulevard Mamaia benefits from maritime air currents, which can aid in dispersing pollutants. In contrast, on Boulevards Tomis and Lapusneanu, where buildings are tall and closely spaced, air

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

circulation is obstructed, creating urban microclimates. In these areas, pollutants can accumulate, increasing the risk of exposure to poor air quality.

Maritime transportation is another significant mobile source of pollution. The largest port on the Black Sea, Port of Constanta (Fig. 1d), hosts a variety of vessels that use diesel engines and other types of propulsion, emitting various hazardous pollutants.

In the end, the results of this study should be interpreted with caution, considering that this analysis was based on a relatively short data series, covering only the period from 2017 to 2022. This limitation is due to the availability of pollution data, which is only freely accessible for this period. While the available data provides an initial insight into trends in pollutant concentrations, the relatively short time frame may not be sufficient to clearly detect and characterize all long-term patterns.

Given this limitation, our study did not use some more appropriate methods for quantifying the magnitude and statistical significance of pollution trends, such as the Mann-Kendall test (Mann, 1945; Kendall, 1975) and *Sen's slope* estimator (Sen, 1968; Gilbert, 1987; Salmi et al., 2002), which require longer environmental data series. Therefore, future research is recommended to use more extensive data series over longer periods, which would allow the application of more robust statistical methods, such as the Mann-Kendall test and *Sen's Slope* procedure. The integration of more extended datasets would contribute to a more robust assessment of trends and help achieve more solid conclusions regarding the medium and long-term dynamics of air pollution.

Conclusions

Based on the statistical data investigated, it seems that the Constanta city area has not experienced a clear intensification of pollution conditions in recent years. The annual and seasonal analysis of major air pollutants reveals significant variations, potentially driven by climatic factors and local emission sources, suggesting that air quality issues are largely seasonal and localized. It is important to note that, in terms of mean concentrations, most pollutants concentrations were observed below the maximum permissible limits, indicating relatively acceptable air quality, even in the context of seasonal variations. However, the only exceptions were observed for nitrogen oxides (NO and NO_2), where exceedances of the maximum allowed concentrations were noted.

On the annual timescale, Constanta exhibits significant variations in air quality, influenced by potential factors such as industrial activity, road traffic, weather conditions, and the intensity of tourism activities. During the whole year, the concentrations of atmospheric pollutants show significant fluctuations, while the average annual trends highlight predominantly decreases, which may indicate an improvement in air quality. However,

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

nitrogen oxides register persistent excesses of the maximum allowed concentrations, indicating a consistent level of pollution that is not limited to a certain season, but is maintained throughout the year.

The seasonal analysis of air pollutants in the studied area reveals distinct results, with each season contributing uniquely to the overall pollution profile. Winter is marked by high levels of SO_2, CO, NO_x, and PM_{10}, most likely due to increased heating and industrial activities, combined with temperature inversions that potentially hinder pollutant dispersion. Spring brings a gradual reduction in CO and SO_2, likely owing to decreased heating demands, along with a slight increase in O_3 as solar radiation intensifies. Summer sees the highest O_3 levels, most probably as a result of strong photoreactions. However, improved dispersion conditions during summer potentially reduce other pollutants like CO, SO_2, and PM_{10}. In autumn, industrial activities and heating likely lead to moderate increases in CO and SO_2, while O_3 levels decrease as solar radiation weakens, indicating a probable balance between the seasonal drivers of air quality. Average trends show both increases and decreases in pollutant concentrations.

All this picture of anthropogenic gas concentrations revealed that Constanta city area did not recorded severe trends of pollution intensification in recent years, but rather experienced some important annual and seasonal fluctuations in air quality. However, the positive trends of atmospheric pollutants, detected in many cases in this research, require adaptive monitoring and management strategies to prevent negative impacts on public health and the environment.

Conflict of Interest: The authors reported no conflict of interest.

Data Availability: All data are included in the content of the paper.

Funding Statement: The authors did not obtain any funding for this research.

References:

1. AEPC. (2024). Monthly average concentrations of CO, NO, NO_2, SO_2, C_6H_6, O_3 and PM_{10}, *Agency for Environmental Protection Constanta*, retrieved August 11, 2024, from http://www.anpm.ro/web/apm-constanta/rapoarte-lunare1.
2. Anton C. (2021). Disadvantages of Developing Mass Tourism in Constanta (Romania), Journal of Tourism & Hospitality, S5: 001, DOI: 10.35248/2167-0269.21.
3. Chen Z.-Y., Petetin H., Méndez Turrubiates R.F., Achebak H., Garcia-Pando C.P., Ballester J. (2024). Population exposure to multiple air

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

pollutants and its compound episodes in Europe, *Nat Commun* 15, 2094, https://doi.org/10.1038/s41467-024-46103-3.

4. Colbeck I., MacKenzie A. R. (1994). Air pollution by photochemical oxidants, Netherlands.
5. Contini D., Costabile F. (2024). Air Pollution, Health Effects Indicators, the Exposome, and One Health, *Atmosphere* 15, no. 5: 618, https://doi.org/10.3390/atmos15050618.
6. Cracu G.-M., Schvab A., Prefac Z., Popescu M., Sîrodoev I. (2024). A GIS-based assessment of pedestrian accessibility to urban parks in the city of Constanța, Romania, *Applied Geography*, Volume 165, 103229, https://doi.org/10.1016/j.apgeog.2024.103229.
7. Farhan A., Imtiaz A., Shazia K, Saira A. (2022). The environmental impact of industrialization and foreign direct investment: empirical evidence from Asia-Pacific region. *Environmental Science and Pollution Research*, 29. 1-15. 10.1007/s11356-021-17560-w., DOI: 10.1007/s11356-021-17560-w.
8. Gaur N., Sharma S., Yadav N. (2024). Chapter 2 - Environmental pollution, Editor(s): Vinod Kumar Garg, Anoop Yadav, Chandra Mohan, Sushma Yadav, Neeraj Kumari, In Advances in Green and Sustainable Chemistry, Green Chemistry Approaches to Environmental Sustainability, Elsevier, Pages 23-41, https://doi.org/10.1016/B978-0-443-18959-3.00010-0.
9. Gilbert R. O. (1987). Statistical methods for environmental pollution monitoring, Van Nostrand Reinhold, New York.
10. Kendall M. G. (1975). Rank Correlation Methods, fourth ed. Charles Griffin, London.
11. Latza U., Gerdes S., Baur X. (2009). Effects of nitrogen dioxide on human health: Systematic review of experimental and epidemiological studies conducted between 2002 and 2006, *International Journal of Hygiene and Environmental Health*, Volume 212, Issue 3, Pages 271-287, https://doi.org/10.1016/j.ijheh.2008.06.003.
12. Mahler B., Băiceanu D., Panciu T. C., Florea R. M., Iorga A. L., Gnat M., German C. F., Pârvu S., Paraschiv D., Manea D., Mihai M., Ibraim E., Timar B., Mihălțan F. D. (2023). Air Pollutants and Their Impact on Chronic Diseases—A Retrospective Study in Bucharest, Romania, *Atmosphere* 14, no. 5: 867, https://doi.org/10.3390/atmos14050867.
13. Mann H. B. (1945). Non-parametric tests against trend, *Econometrica* 13, 245–259.
14. Manoiu V.-M., Tiscovschi A.A., Craciun A.-I. (2018). A Deep Dive into the Chronic Air Pollution Reality in Baia Mare. Part III: Air Pollution Effects on the Local Population between 1980 and 2006,

INTCESS 2018- 5th International Conference on Education and Social Sciences, February 5-7, 2018, Istanbul, Turkey, ISBN: 978-605-82433-2-3, ISI Conference Abstracts and Proceedings: http://www.ocerint.org/intcess18_e-publication/papers/167.pdf.

15. Nica M.-A., Costache M.-S., Marin M.-I., Mănoiu V.-M, (2024). A Review of Water Pollution in Israel and Palestine, *European Scientific Journal*, *ESJ*, *20*(18), 285. https://doi.org/10.19044/esj.2024.v20n18p285.
16. NIS. (2024). Statistical data regarding tourism in 2023, *National Institute of Statistics*, retrieved August 18, 2024, from https://constanta.insse.ro/wp-content/uploads/2024/04/comunicatDJSCT_nr4_2024_TurismAn2023.pdf.
17. Panaitescu M., Panaitescu F.-V., Panait C., Bardasu O., Merla V.-A. (2020). Assessment and risk prevention of air pollution in urban sites, E3S Web of Conferences, 180. 04014, DOI: 10.1051/e3sconf/202018004014.
18. Partene G-C., Simion D., Ionescu S., Nicolae F., Cotorcea A. (2023). Analysis of maritime container traffic in the ports of the Black Sea basin, *International Conference of Management and Industrial Engineering*, 11, 139–146. https://doi.org/10.56177/11icmie2023.20.
19. Population HUB. (2024). List of cities in Romania 2024, retrieved August 18, 2024, from https://population-hub.com/en/ro/list-of-cities-in-romania-by-population.html.
20. Rata V., Rusu L. (2019). Air pollutant products resulting from port activity of ships in Constanta harbour, 10.5593/sgem2019/4.1/S19.104, DOI: 10.5593/sgem2019/4.1/S19.104.
21. Rentschler J., Leonova N. (2023). Global air pollution exposure and poverty, *Naure Communications* 14, 4432, https://doi.org/10.1038/s41467-023-39797-4.
22. Salmi T., Maatta A., Anttila P., Ruoho-Airola T., Amnell T. (2002). Detecting trends of annual values of atmospheric pollutants by the Mann–Kendall Test and Sen's Slope Estimates – The Excel Template Application Makesens, Finnish Meteorological Institute, Helsinki, Finland.
23. Sen P. K. (1968). Estimates of the regression coefficient based on Kendall's Tau, *Journal of the American Statistical Association* 63, 1379–1389.
24. Sicard P., Agathokleous E., Anenberg S.C., Alessandra De Marco, Paoletti E., Calatayud V. (2023). Trends in urban air pollution over the last two decades: A global perspective, *Science of The Total*

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Environment, Volume 858, Part 2, https://doi.org/10.1016/j.scitotenv.2022.160064.
25. Song S.-K., Shon Z.-H., Moon S.-H., Lee T.-H., Kim H.-S., Kang S.-H., Park G.-H., Yoo E.-C. (2022). Impact of international Maritime Organization 2020 sulfur content regulations on port air quality at international hub port, *Journal of Cleaner Production*, Volume 347, 131298, https://doi.org/10.1016/j.jclepro.2022.131298.
26. Tiscovschi A.A. (2005). Climate and air pollution in Southern Dobrogea (in Romanian), *Univeristy Publishing House,* Bucharest, Romania.
27. Ukaogo P.O., Ewuzie U., Onwuka C.V. (2020). 21 - Environmental pollution: causes, effects, and the remedies, Editor(s): Pankaj Chowdhary, Abhay Raj, Digvijay Verma, Yusuf Akhter, Microorganisms for Sustainable Environment and Health, Elsevier, Pages 419-429, https://doi.org/10.1016/B978-0-12-819001-2.00021-8.
28. Vohra A., Vodonos A., Schwartz J., Marais E.A., Sulprizio M.P., Mickley L.J. (2021). Global mortality from outdoor fine particle pollution generated by fossil fuel combustion: Results from GEOS-Chem, *Environmental Research*, Volume 195, 110754, https://doi.org/10.1016/j.envres.2021.110754.
29. WPR. (2024). Demographic statistical data of Romanian cities, retrieved August 18, 2024, from https://worldpopulationreview.com/cities/romania/constanta.
30. Zhu Z., Qiao Y., Liu Q., Lin C., Dang E., Fu W., Wang G., Dong J. (2021). The impact of meteorological conditions on Air Quality Index under different urbanization gradients: a case from Taipei. *Environ Dev Sustain* 23, 3994–4010, https://doi.org/10.1007/s10668-020-00753-7.