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Spatio-Temporal Analysis of NO_2 and CO Production with Sentinel 5P Tropomy Time Series Images : The Case of Torbalı and Kemalpaşa Districts of Izmir Province in Türkiye

Münevver Gizem Gümüş*

*Geomatics Engineering, Nigde Omer Halisdemir University/Engineering Faculty, Nigde, Türkiye

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ABSTRACT

Air pollution is an environmental problem that seriously impacts human health and ecosystems and is associated with anthropogenic sources such as industry, traffic, and fossil fuel use. Nitrogen dioxide (NO_2) and carbon monoxide (CO) are the main air pollutants that cause respiratory diseases and contribute to climate change. This study combines Sentinel-5P TROPOMI satellite data with terrestrial air quality monitoring data provided by the National Air Quality Monitoring Network (UHKIA) of the Turkish Ministry of Environment, Urbanization, and Climate Change to perform a spatial and temporal analysis of NO_2 and CO emissions in the Kemalpaşa and Torbalı districts of Izmir, Türkiye. For the 17 months between January 2022 and July 2023, analysis using the Google Earth Engine (GEE) platform revealed that emission concentrations increase in winter months due to industrial activities and domestic heating and decrease in summer months due to reduced traffic density and meteorological conditions. It was observed that CO emissions spread over a wider area, while NO_2 emissions are concentrated in industrial and traffic-oriented regions. Accuracy analyses between satellite and UHKIA data showed a general agreement, but small deviations were recorded due to atmospheric effects and resolution differences. These analyses emphasized the importance of the integrated use of satellite and ground data in air pollution monitoring. The results provide a valuable scientific basis for local governments and policymakers for air quality management and strategic decision-making, especially in the Kemalpaşa and Torbalı districts.

Keywords: Air Quality, CO, Google Earth Engine, NO_2, Remote Sensing, Sentinel 5P

Introduction

Air pollution stands out as one of the biggest environmental problems in both developed and developing countries, with serious negative impacts on human health, ecosystems, and overall environmental quality [1-2]. The World Health Organization (WHO) emphasizes that air pollution causes health problems such as respiratory diseases and cardiovascular diseases, leading to millions of premature deaths every year [3]. NO_2 and CO are major air pollutants from anthropogenic processes such as motor vehicles, energy production, and industrial activities. NO_2 causes acute respiratory problems in the short term, while in the long term, it creates environmental and climatic impacts by contributing to secondary processes such as ozone formation and acid rain. CO is a gas produced by the incomplete combustion of carbon-based fuels and can have toxic effects on human health, particularly on the central nervous system. Therefore, regular monitoring of both NO_2 and CO emissions is a critical requirement for improving air quality and protecting public health.

In recent years, advances in remote sensing technologies have enabled spatial and temporal monitoring of air pollutants over large areas. Satellite-based observing systems such as Sentinel-5P TROPOMI provide an important complementary resource to ground-based monitoring stations by providing high-resolution data of NO_2, CO, and other pollutants in the atmosphere [4]. Such data are used as a powerful tool for temporal and spatial analysis of air pollution, especially when integrated with cloud-based big data platforms such as GEE.

Studies on air pollution and monitoring of NO_2 and CO emissions reveal the importance of this issue at the global and regional level. Martin et al. [5] examined the global distribution of NO_2 in the atmosphere and assessed the effects of industrial activities and meteorological conditions. Beirle et al. [6] analysed the temporal variations of NO_2 emissions in Europe with TROPOMI data and showed how concentrated emissions in industrial areas are transported and distributed by atmospheric processes. Fioletov et al. [7] analysed the seasonal NO_2 distributions in urban, industrial, and rural areas at the global level using TROPOMI satellite data and enabled the identification of emission sources with these data. Liu et al. [8] improved the accuracy of atmospheric measurements and created high-resolution emission maps using an improved TROPOMI tropospheric NO_2 product over Europe. Martínez-Alonso et al. [9] compared CO measurements using TROPOMI satellite data with MOPITT and ATom data and assessed the accuracy of satellite-based CO observations. Lama et al. [10] quantitatively assessed combustion efficiency in megacities using NO_2/CO ratios from TROPOMI and showed that this ratio is a useful indicator for monitoring the efficiency of combustion processes. In Türkiye, Çiçek et al. [11] statistically analysed air pollution in Ankara and revealed the effects of industrial and meteorological factors on this pollution. Sünsüli and Kalkan [12] examined NO_2 pollution using Sentinel-5P satellite imagery and emphasized that this method is a powerful tool for monitoring air quality. However, existing studies generally focus either only on satellite data or only on data obtained from ground stations, and studies using both data sources together are limited.

Türkiye meets most of its energy needs from fossil fuels and obtained 84% of its energy from fossil fuels in 2021. This high use of fossil fuels has a negative impact on air quality, especially in industrial areas. According to Greenpeace Akdeniz [13], the top three districts in Izmir with the most polluted air are Torbalı, Kemalpaşa, and Alsancak. This shows that air pollution has reached serious levels in these districts. In this context, the main objective of this study is to conduct a spatial and temporal analysis of emissions in the Kemalpaşa and Torbalı districts of Izmir province by comparing NO_2 and CO data obtained from the Sentinel-5P TROPOMI satellite with UHKIA data of the Turkish Ministry of Environment, Urbanization, and Climate Change. These analyses, which will be carried out using the Google Earth Engine platform, aim to reveal the effects of industrial and traffic density on air quality in detail. This study aims to provide a scientific basis for local governments and policymakers in air pollution management and strategic decision-making processes.

Methods and Material

This section describes the methods of the study in detail. The flow diagram is presented in Figure 1 and covers the general methodology of the study. The study area, the data used, the use of the GEE platform, and the accuracy assessment steps are discussed in subheadings.

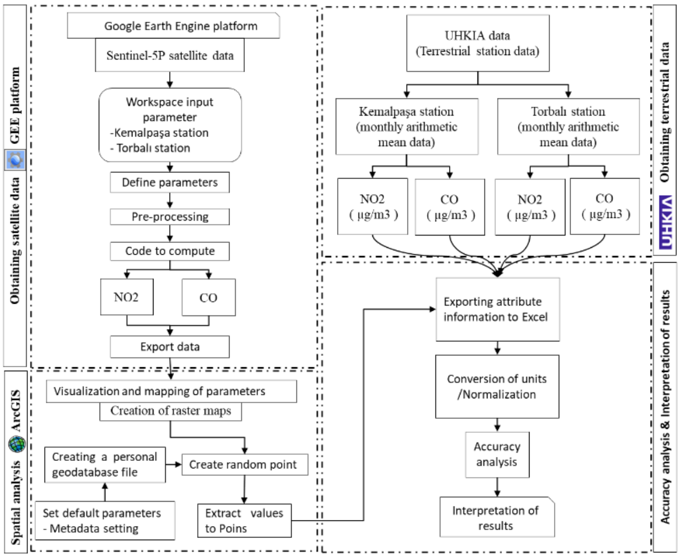

Figure 1. Workflow Chart of the Study Process

A. Defining the Study Area

This study was conducted in the Kemalpaşa and Torbalı districts of the Izmir province, located in the Aegean Region of Türkiye. Izmir is one of the three largest cities in Türkiye and stands out with its economic and demographic importance. Izmir is one of Türkiye's busiest provinces in terms of industry, agriculture, and tourism, and it also draws attention with its population growth and urbanization rate. According to the Turkish Statistical Institute (TUIK) [14], Izmir's population was recorded as 4,479,525 by the end of 2023. This population is expected to increase at an annual rate of approximately 1.5%. Kemalpaşa and Torbalı districts have an important position as the industrial and logistics centers of Izmir. Kemalpaşa stands out especially with its organized industrial zones and factories, while the Torbalı district stands out with its large agricultural lands as well as its industrial and trade activities. These districts are among the most polluted regions of Izmir due to air pollution problems caused by heavy traffic and industrial activities. According to the Greenpeace Akdeniz [13] report, Torbalı and Kemalpaşa districts were identified as the most polluted regions of Izmir in 2023. Figure 2 shows the geographical boundaries of the study area and the locations of the air quality measurement stations in these regions in detail. These regions are critical for air pollution monitoring and provide a convenient sample to understand the impacts of industrial, agricultural, and transportation activities on terrestrial air quality.

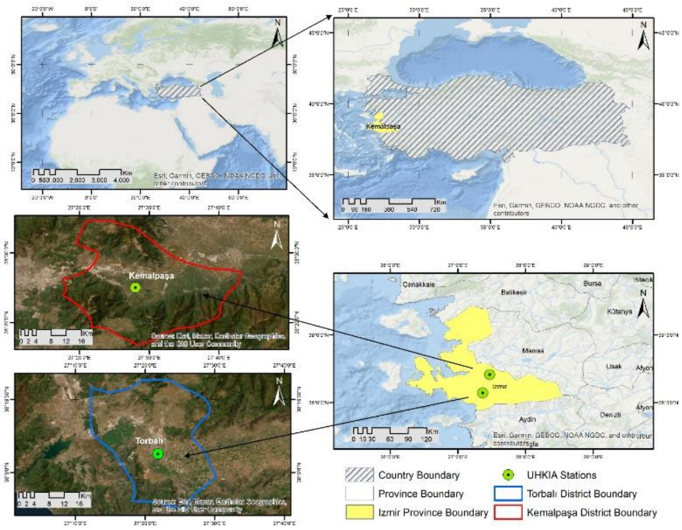

Figure 2. Geographical extent of the study

B. Satellite Data

In this study, satellite data from the Sentinel-5P TROPOMI (TROPOspheric Monitoring Instrument) sensor were used. Sentinel-5P was developed by the European Space Agency (ESA) to measure the concentrations of gases in the atmosphere at high resolution. The satellite is equipped with remote sensing technologies to measure air pollution components in the atmosphere and is capable of monitoring large areas globally.

Sentinel-5P can monitor the distribution of trace gases such as NO_2, CO, O_3, formaldehyde, SO_2, CH_4, and aerosols with its TROPOMI spectrometer sensor. The satellite has pixel dimensions of 3.5x7 km² resolution and can provide continuous data with a daily revisit time [15]. These features enable air pollution analysis at large spatial scales. Sentinel-5P plays an important role in detecting the concentration of air pollutants, especially in urban and industrial areas. The TROPOMI sensor measures gas concentrations in the atmosphere with high precision using optical and infrared wavelengths. Every day, the satellite scans the Earth's surface and analyses atmospheric constituents using methods that minimize cloud effects. The acquired data is processed in three different formats: real-time (NRTI), offline (OFFL), and reprocessed (RPRO). Real-time data is available approximately three hours after it is received by the satellite, while offline and reprocessed data are available within a few days.

In this study, Sentinel-5P data were processed and analysed using the GEE platform for a total of 17 months between January 2022 and July 2023. Parameters in the scope of the study include NO_2 and CO concentrations, and the data are presented in units of mol/m².

TABLE I TECHNICAL SPECIFICATIONS OF SENTINEL-5P

Feature	**Description**
Satellite Name	Sentinel-5P
Sensor	TROPOMI (TROPOspheric Monitoring Instrument)
Launch Date	October 13, 2017
Spatial Resolution	3.5 x 7 km²
Daily Revisit Time	1 day
Wavelength Range	UV, Visible, NIR, and SWIR (280 nm – 2,400 nm)
Target Parameters	NO_2, CO, O_3, CH_4, SO_2, formaldehyde, aerosols
Data Types	Near Real-Time (NRTI), Offline (OFFL), Reprocessed (RPRO)
Data Unit	mol/m²
Data Platforms	Google Earth Engine (GEE) ve Copernicus Open Access Hub
Orbital Altitude	824 km
Orbit Type	Polar, Sun-Synchronous

Table 1 summarizes the technical features of Sentinel-5P and its advantages in air pollution analysis. These features were comprehensively evaluated to improve the methodological accuracy of the study.

C. Ground Station Data

The terrestrial air quality data used in this study were obtained from the UHKIA operated by the Continuous Monitoring Center (SIM) under the Ministry of Environment, Urbanization, and Climate Change of Türkiye [16]. UHKIA provides daily and hourly data on various air pollution parameters through monitoring stations established across Türkiye. All data can be accessed free of charge from the ministry's website.

The stations used in the study are terrestrial air quality monitoring stations located in the Kemalpaşa and Torbalı districts of Izmir. Measurements of NO_2 and CO concentrations were taken from these stations in line with the main objective of the study. The data were collected hourly from the stations and presented as monthly arithmetic averages. NO_2 and CO concentrations are reported in units of micrograms per cubic meter (μg/m³). The relevant datasets contain the following summary information: minimum value (Min. Value) and date of measurement (Min. Date), maximum value (Max. Value) and date of measurement (Max. Date), mean value (Mean Value), total number of data (Number of Data), and standard deviation (Std. Deviation). These data cover a total period of 17 months, from January 2022 to July 2023. The data of both stations were normalized in GEE for comparative analysis with satellite data. By providing high-precision measurements at the local scale, the NWHIA system enabled the integrated evaluation of satellite-based wide-area analyses and terrestrial monitoring data.

These ground data from the UHKIA were used as a reference data source to analyse the spatial and temporal distribution of air pollution in detail and to perform accuracy analyses with Sentinel-5P TROPOMI satellite data.2.3.

D. Google Earth Engine (GEE) Platform

GEE is a cloud-based big data platform widely used in environmental data processing and analysis. This platform enables users to process large volumes of satellite data and perform complex geospatial analysis. GEE provides advanced algorithms and coding tools to analyze environmental data quickly and efficiently. In this study, Sentinel-5P TROPOMI data were processed and analyzed using the GEE platform [17].

The study area covering the Kemalpaşa and Torbalı districts of Izmir province was defined through GEE, and data for the 17 months between January 2022 and July 2023 were used. Sentinel-5P data focused on NO_2 and CO concentrations obtained with the TROPOMI sensor. During the data analysis, the data were first filtered for a specific period, and spatial boundaries specific to the study area were determined. Cloud removal and atmospheric correction were performed to improve the accuracy of TROPOMI data. These steps made the satellite data suitable for the analysis process.

Temporal analyses of the satellite data were performed by calculating monthly average NO_2 and CO concentrations on the GEE platform. During the spatial analyses, the data were processed in raster format, and the distribution of emission levels in the region was visualized in detail. The obtained results were used to assess the impacts of industrial and traffic activities on air quality in the Kemalpaşa and Torbalı districts.

Thanks to GEE's powerful data processing capacity and the ready-to-use algorithms available to users, the analysis processes were carried out quickly and efficiently. The atmospheric correction tools provided by the platform increased the accuracy of the data and ensured the reliability of satellite-based analyses. At the end of the study, the processed data were exported in raster format, and spatial maps were created using ArcGIS, a GIS-based software (Figures 3-4). These maps visualized the spatial distribution of NO_2 and CO emissions in the Kemalpaşa and Torbalı districts and contributed significantly to the identification of air pollution sources. This analysis infrastructure provided by the GEE platform has been used as a critical tool in understanding the spatial and temporal dynamics of environmental problems.

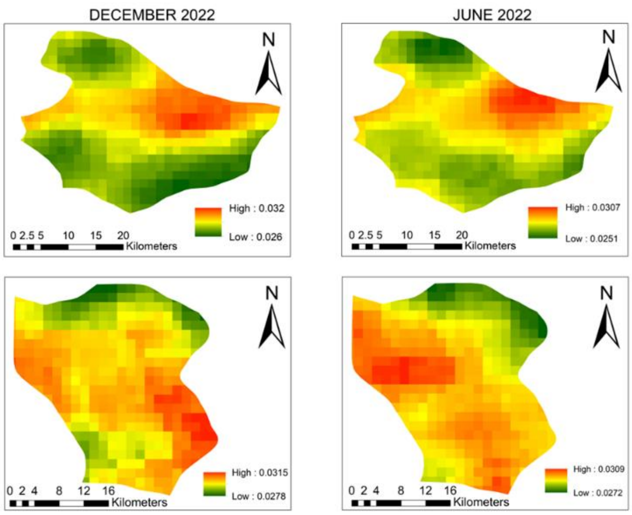

Figure 3. CO maps obtained with Sentinel 5P (June and December 2022)

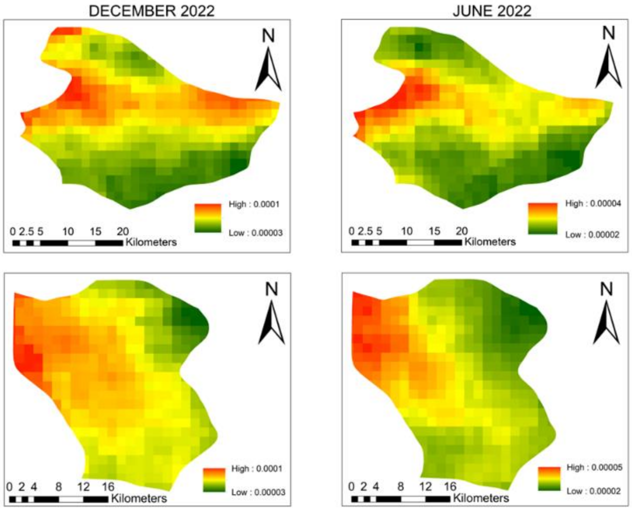

Figure 4. NO_2 maps obtained with Sentinel 5P (June and December 2022)

E. Min-Max Normalization

In this study, min-max normalization was performed to evaluate the agreement between Sentinel-5P TROPOMI satellite data and measurement data obtained from ground-based air quality monitoring stations. Min-max normalization is considered a critical step to increase the reliability of satellite data, to better understand terrestrial air quality conditions, and to demonstrate the contributions of the combination of satellite and ground data. The units of CO and NO_2 data provided by Sentinel-5P TROPOMI are in mol/m², while the measurement data for the same gases obtained from ground-based air quality monitoring stations are in µg/m³. Since these two different units are not suitable for direct comparison, the data were de-unitized to make them analysable. The unitization process enabled the data sets to be harmonized with each other by the proportioning method.

The min-max normalization method was applied to the de-unitized data to make the analysis visually and statistically more understandable [18]. Min-max normalization ensured that all data were scaled between 0 and 1 by using the smallest (Xmin) and largest (Xmax) values in the data set [19]. This process allowed comparisons to be made between data at different scales during data analysis. The normalization formula is presented in Equation 1. The margins must be set as follows:

$$X' = \frac{X - Xmin}{Xmax - Xmin} \qquad (1)$$

Here it is:

- X': Normalized value
- X: original data value
- Xmin: Minimum value in the dataset
- Xmax: Maximum value in the dataset.

Results and Discussion

In this study, the concentrations of NO_2 and CO gases in the Kemalpaşa and Torbalı districts of the Izmir province were analyzed using both Sentinel-5P satellite data and data obtained from ground stations. Satellite data were obtained from the Google Earth Engine (GEE) platform, and ground station data were obtained from the National Air Quality Monitoring Network of the Turkish Ministry of Environment, Urbanization, and Climate Change. Since the data are in different units (mol/m² and µg/m³), the data were unitized and scaled between 0 and 1 using the min-max normalization method for comparison.

Satellite data were identified on the GEE platform, cropped for the study area, and cloud effects were removed with atmospheric correction algorithms. NO_2 and CO data obtained from ground stations were organized in Excel format, and monthly arithmetic averages were calculated and made suitable for analysis. Temporal and spatial analyses were performed by normalizing satellite and ground data. In the analyses performed on both data sets, changes in concentrations were evaluated and interpreted. All changes are presented in Table 2-5, and all graphs are presented in Figure 5-8.

It was observed that NO_2 concentrations increased, especially in winter months (December, January, and February), and decreased significantly in summer months (June and July). These increases and decreases were associated with meteorological conditions as well as human activities such as industrial activities, domestic heating, and traffic intensity. Especially in winter months, the increase in industrial activities and intensification of domestic heating caused an increase in NO_2 concentrations. In the summer months, on the other hand, it was determined that the concentrations decreased due to the decrease in traffic density with the increase in air temperatures and the effect of meteorological conditions.

Similarly, CO gas concentrations increased in winter and showed a downward trend in spring and summer. High CO concentrations in winter were associated with increased domestic heating activities and industrial emissions. The decreases in spring and summer were explained by the increase in air temperatures and the decrease in domestic heating. In the fall period, CO concentrations were observed to increase again.

A general agreement was observed between satellite and ground data, but some minor differences were noted. Differences in spatial resolution compared to the point measurements of ground stations were found due to the large areas represented by satellite data. In addition, atmospheric effects and cloud cover limited the sensitivity of satellite data in some periods. The limited coverage of the ground stations was also a factor to be taken into account when making comparisons.

In general, these findings revealed that NO_2 and CO in the Kemalpaşa and Torbalı districts reach high concentrations in winter months and decline to low levels in summer months. The combined use of satellite and ground-based data provided a more comprehensive understanding of the temporal and spatial dynamics of air pollution and emphasized the complementary nature of both data sources. This study demonstrated the importance of using satellite and ground data together in air quality management and planning.

TABLE III NO_2 DATA OBTAINED FROM GROUND-BASED DATA AND MIN-MAX NORMALIZATION VALUES

	İzmir - Torbalı		İzmir-Kemalpaşa	
	NO_2 µg/m³	NO_2 (Min-Max)	NO_2 µg/m³	NO_2(Min-Max)
Date	**monthly arithmetic mean data**			
Jan 2022	39.63	0.52	40.83	0.41
Feb 2022	46.99	0.70	45.60	0.49
Mar 2022	39.48	0.51	37.88	0.36
Apr 2022	36.00	0.47	35.28	0.32
May 2022	27.77	0.27	18.56	0.05
Jun 2022	28.87	0.30	27.85	0.20
Jul 2022	16.23	0.02	17.16	0.03
Aug 2022	15.25	0.00	16.16	0.01
Sep 2022	21.32	0.12	23.20	0.12
Oct 2022	28.59	0.27	21.98	0.10
Nov 2022	46.84	0.69	41.36	0.42
Dec 2022	62.23	1.00	53.26	0.61
Jan 2023	57.17	0.91	77.09	1.00
Feb 2023	43.92	0.60	64.01	0.79
Mar 2023	40.43	0.61	53.37	0.61
Apr 2023	-	-	47.76	0.52
May 2023	40.90	0.51	38.55	0.37

	İzmir - Torbalı		İzmir-Kemalpaşa	
	NO_2 µg/m³	NO_2 (Min-Max)	NO_2 µg/m³	NO_2(Min-Max)
Date	**monthly arithmetic mean data**			
Jun 2023	47.96	0.73	47.94	0.53
Jul 2023	41.01	0.56	15.61	0.00

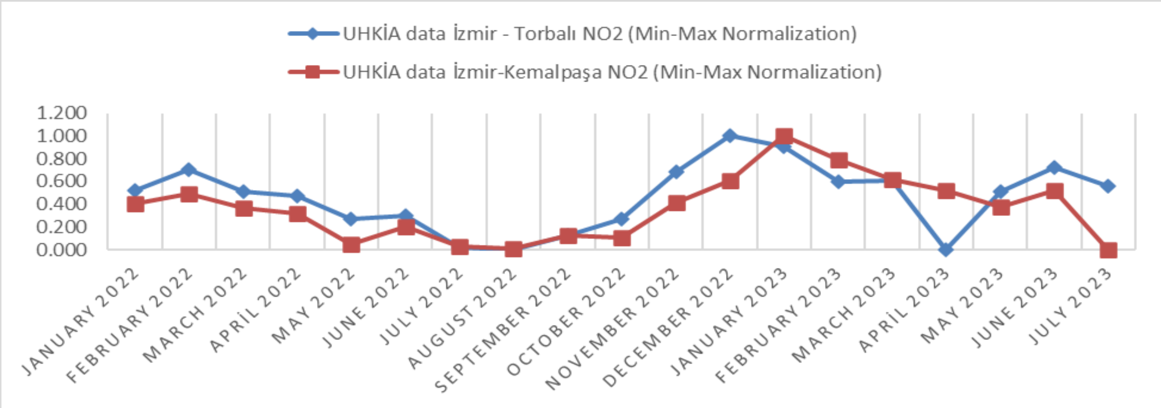

Figure 5. Min-Max normalization values of NO_2 parameter obtained with terrestrial data

TABLE IIIII CO DATA OBTAINED WITH TERRESTRIAL DATA AND MIN-MAX NORMALIZATION VALUES

	İzmir - Torbalı		İzmir-Kemalpaşa	
	CO µg/m³	CO (Min-Max)	CO µg/m³	CO (Min-Max)
Date	**monthly arithmetic mean data**			
Jan 2022	725.43	0.10	1092.41	0.37
Feb 2022	765.91	0.13	1476.34	0.63
Mar 2022	858.00	0.20	1089.61	0.37
Apr 2022	801.83	0.16	895.16	0.24
May 2022	705.47	0.09	907.17	0.25
Jun 2022	711.38	0.09	911.18	0.25
Jul 2022	592.78	0.00	544.32	0.00
Aug 2022	639.25	0.03	689.67	0.10
Sep 2022	724.80	0.10	974.91	0.29
Oct 2022	887.33	0.22	1079.57	0.36
Nov 2022	1245.92	0.52	1647.01	0.75
Dec 2022	1903.48	1.00	2013.00	1.00
Jan 2023	1824.54	0.94	1844.01	0.88
Feb 2023	1639.77	0.80	1575.77	0.70
Mar 2023	1516.70	0.70	1556.23	0.69
Apr 2023	1430.46	0.64	1646.89	0.75
May 2023	1475.76	0.67	1775.55	0.84
Jun 2023	1404.41	0.63	1829.49	0.88
Jul 2023	1489.20	0.68	-	-

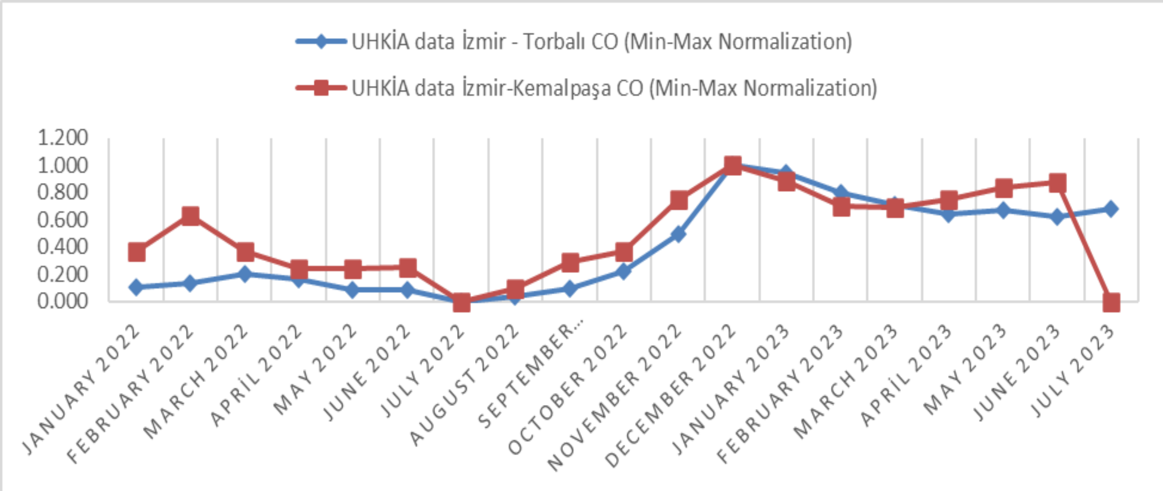

Figure 6. Min-Max normalization values of CO parameter obtained with terrestrial data

TABLE IVV NO_2 DATA OBTAINED WITH SATELLITE DATA AND MIN-MAX NORMALIZATION VALUES

	İzmir - Torbalı		**İzmir-Kemalpaşa**	
	NO_2 µg/m²	**NO_2 (Min-Max)**	**NO_2 µg/m²**	**NO_2 (Min-Max)**
Date	**monthly arithmetic mean data**			
Jan 2022	0.000051	0.203	0.000055	0.479
Feb 2022	0.000064	0.424	0.000080	1.000
Mar 2022	0.000052	0.220	0.000052	0.417
Apr 2022	0.000063	0.407	0.000051	0.396
May 2022	0.000052	0.220	0.000066	0.708
Jun 2022	0.000039	0.000	0.000034	0.042
Jul 2022	0.000042	0.051	0.000032	0.000
Aug 2022	0.000049	0.169	0.000045	0.271
Sep 2022	0.000056	0.288	0.000060	0.583
Oct 2022	0.000062	0.390	0.000045	0.271
Nov 2022	0.000098	1.000	0.000071	0.813
Dec 2022	0.000080	0.695	0.000071	0.813
Jan 2023	0.000098	1.000	0.000078	0.958
Feb 2023	0.000068	0.492	0.000060	0.583
Mar 2023	0.000070	0.525	0.000052	0.417
Apr 2023	0.000041	0.034	0.000049	0.354
May 2023	0.000051	0.203	0.000033	0.021
Jun 2023	0.000046	0.119	0.000037	0.104
Jul 2023	0.000043	0.068	0.000036	0.083

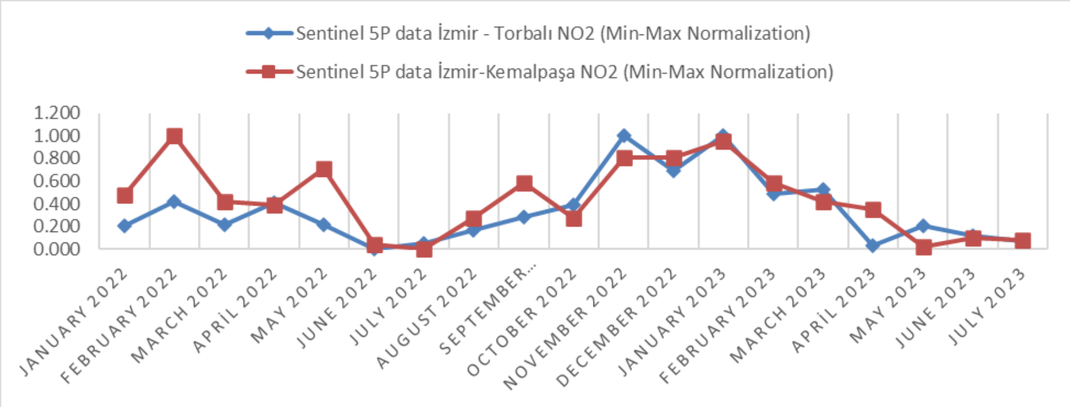

Figure 7. Min-Max normalization values of NO2 parameter obtained from satellite data

TABLE V CO DATA OBTAINED WITH SATELLITE DATA AND MIN-MAX NORMALIZATION VALUES

	İzmir - Torbalı		İzmir-Kemalpaşa	
	CO μg/m²	CO (Min-Max)	CO μg/m²	CO (Min-Max)
Date	monthly arithmetic mean data			
Jan 2022	0.03496	0.85	0.032766	0.69
Feb 2022	0.03295	0.58	0.034906	0.95
Mar 2022	0.03611	1.00	0.035319	1.00
Apr 2022	0.03342	0.65	0.033993	0.84
May 2022	0.03246	0.52	0.033099	0.73
Jun 2022	0.02973	0.16	0.028602	0.19
Jul 2022	0.03088	0.31	0.029448	0.29
Aug 2022	0.03342	0.65	0.030181	0.38
Sep 2022	0.02882	0.04	0.028140	0.13
Oct 2022	0.02852	0.00	0.027037	0.00
Nov 2022	0.02876	0.03	0.028266	0.15
Dec 2022	0.03034	0.24	0.029904	0.35
Jan 2023	0.03236	0.51	0.031060	0.49
Feb 2023	0.03385	0.70	0.033681	0.80
Mar 2023	0.03419	0.75	0.032811	0.70
Apr 2023	0.03308	0.60	0.032457	0.65
May 2023	0.03354	0.66	0.032244	0.63
Jun 2023	0.03372	0.69	0.032986	0.72
Jul 2023	0.03497	0.85	0.033527	0.78

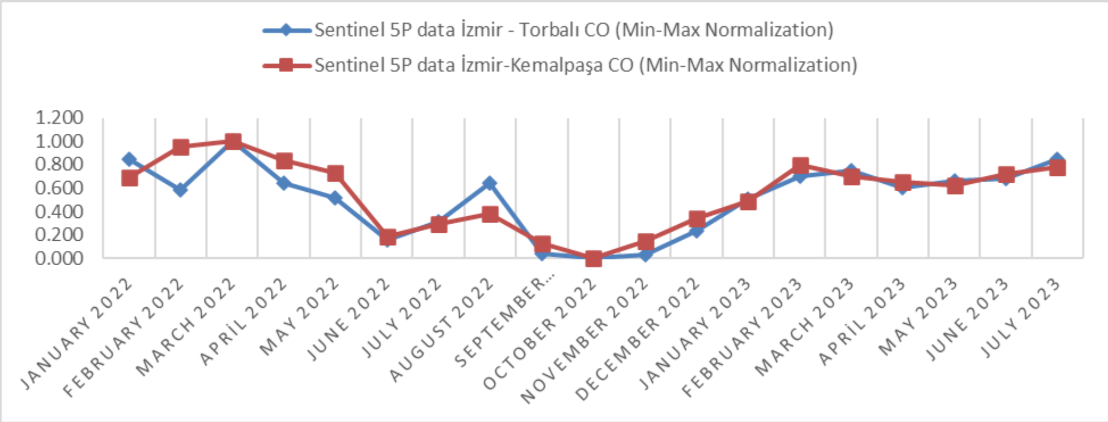

Figure 8. Min-Max normalization values of CO parameter obtained with satellite data

Conclusion

In this study, the spatial and temporal dynamics of NO_2 and CO emissions in the Torbalı and Kemalpaşa districts were analysed in detail. The findings revealed that industrial activities and traffic density have a significant impact on air pollution in both districts. In winter months, a significant increase in air pollution levels was observed due to the increase in industrial production and emissions from domestic heating. In the summer months, concentrations were found to decrease due to the decrease in traffic density and changes in meteorological conditions. Differences in NO_2 and CO levels were observed between the Torbalı and Kemalpaşa districts, especially due to the density of industrial zones and traffic load. Organized industrial zones in the Kemalpaşa district stood out as the areas with the highest air pollution concentrations. When satellite data and ground station measurements were compared, a general agreement between the two data sources was observed. Sentinel-5P TROPOMI satellite data can reveal the regional and global distribution of NO_2 and CO concentrations in the atmosphere by covering large spatial areas. In contrast, ground-based stations provide more detailed and point data at the local scale, measuring the concentration of atmospheric pollutants more precisely. The combined use of these two data sources allows for more comprehensive and reliable results in spatial and temporal analyses. The fact that the emission densities obtained from satellite data and the results of ground measurements show similar trends in regions where industrial and traffic density is effective is an important indicator of this compatibility. According to the data obtained after normalization, while the NO_2 concentration in Torbalı in December 2022 was determined as 1.000 in normalized units, this value decreased to 0.023 in July 2022 during the summer months. In Kemalpaşa, NO_2 concentration took the normalized values of 1.000 and 0.03 in the same periods, respectively. Similarly, in terms of CO concentrations, while the normalized value was 1.000 in December 2022 in Torbalı, it decreased to 0.000 in July 2022 during the summer months. For the same periods for Kemalpaşa, CO concentrations are at normalized values of 1.000 and 0.000, respectively. These results reveal that emissions from industrial and domestic heating reach high levels in winter months, while these effects decrease in summer months. Moreover, the agreement between satellite and ground-based data contributed to the spatial and temporal verification of these trends. However, small discrepancies between satellite data and ground station measurements were detected in some periods. The main reasons for these discrepancies are that the spatial resolution of Sentinel-5P TROPOMI (3.5 x 7 km²) is lower than the point measurement accuracy of ground stations and atmospheric effects such as cloud cover limit the accuracy of satellite data.

It is concluded that the combined use of satellite and ground data provides a significant advantage in understanding the spatial and temporal dynamics of air pollution. The large-scale spatial coverage of satellite data, combined with the detailed and terrestrial measurement precision of ground stations, provides a more robust and reliable approach to air quality monitoring and management. This integration allows both the identification of general trends in broad areas and the identification of specific problems at the local level.

To reduce air pollution, the use of clean production technologies and filtration systems should be expanded to reduce industrial emissions. To reduce traffic congestion, it is important to improve public transport infrastructure, encourage the use of electric vehicles, and reorganize transportation policies. Furthermore, the establishment of a new air quality monitoring system that integrates satellite and ground-based data can provide more effective air quality management at regional and local levels. To mitigate the impacts on public health, it is recommended to organize awareness campaigns on air pollution and strengthen cooperation between local authorities and industrial organizations. However, interdisciplinary research should be encouraged to better understand the relationship between air pollution and meteorological factors and to investigate the factors affecting air quality in more depth. This study provides a scientific basis for local governments and policymakers in air pollution management and strategic planning processes in the Torbalı and Kemalpaşa districts.

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