SPATIAL AND TEMPORAL ANALYSIS OF POLLUTANT GASES IN WESTERN BLACK SEA OF TURKIYE

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KEY WORDS: Air quality, Sentinel-5P satellite, Google Earth Engine, Pollutant gases, Carbon monoxide, Nitrogen dioxide, Aerosol index.

ABSTRACT:

Environmental pollution, particularly air pollution, is one of the foremost problems we face today. Air pollution has become a global issue that affects not only regional areas but also the entire planet. The increase in the amount and concentration of pollutants or harmful substances in the atmosphere, such as various gases, particulate matter, and water vapor, causes air pollution. The rise in these substances can be due to human activities or natural environmental factors. It is crucial to examine air quality to reduce the harm inflicted on living and non-living entities. In this study, the spatial and temporal analysis of air pollutants (CO, NO2, UV_AER) in the Western Black Sea region was conducted using the Sentinel-5 TROPOMI satellite sent to monitor climate change and air quality. The Google Earth Engine platform was used to obtain the data. Monthly pollution maps were created for the year 2022, and the primary sources of pollutants were analysed. As a result, it was observed that pollutants changed on a monthly and seasonal basis, and areas with high pollutant concentrations in the region were identified. Mining, industrial activities, transportation networks, and domestic activities were determined to be the primary sources of air pollution in the study area.

1. INTRODUCTION

Air pollution is defined as the presence of foreign substances in the atmosphere, in solid, liquid, or gaseous form, in quantities and concentrations higher than normal levels (Sicard et al., 2023)

Rapid population growth, industrialization, and increased use of fossil fuels are on the rise in developing countries. These regions are experiencing an increase in air pollution, which has become one of the most devastating issues affecting the quality of life.

Air quality, its impacts, and the goals of combating it are recognized in the United Nations Sustainable Development Goals (SDG) 7. The increase in air pollution negatively impacts the quality of life of individuals. The increase in pollutants triggers respiratory illnesses such as asthma, lung cancer, and cardiovascular diseases, leading to health problems and even deaths. Air pollution not only affects health but also has a detrimental impact on the ecosystem of the region. Harmful gases and particles can reduce the diversity of flora and fauna, as well as pollute water sources or wetlands. This situation also leads to a decrease in biological diversity. Furthermore, pollution causes the formation of fog/smoke in the air.
Therefore, it is crucial to examine air quality. Various data sources and methods are available to determine and evaluate air quality in a region (Elangasinghe, Singhal, Dirks, Salmond, & Samarasinghe, 2014; Vlachogianni, Kassomenos, Karppinen, Karakitsios, & Kukkonen, 2011). For example, most countries have pollution monitoring stations. For this purpose, the The Ministry of Environment, Urbanization, and Climate Change of the Republic in Turkey has established national air quality stations. As of 2023, the number of stations in Turkey is 365. Through the air quality measurement devices and sensors at these stations, the levels of particulate matter (PM2.5 and PM10) and various gases (carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone) are recorded (URL,1). Through the data collected from these stations, the state of pollutants can be monitored over time. Pollution monitoring stations are considered one of the most accurate methods for measuring air pollution (Kazemi Garajeh et al., 2023). However, since these stations are typically located in urban centers, the measurements are limited to the areas surrounding the stations.

Recently, thanks to the advancements in satellite technology, there are also the creation of satellites that have been designed and use for this purpose. For instance, on a global scale the Aura and Terra satellite of the National Aeronautics and Space Administration (NASA), and the GOSAT-2 satellites of Japan and China on a regional scale are are some of the satellites used to detect air pollution (Halder et al., 2023). Currently, the NASA Earth Observing System (EOS) satellite and its MODerate Resolution Imaging Spectroradiometer (MODIS) sensor, as well as the Sentinel-5 satellite from the European Space Agency's Copernicus project satellite series, are the preferred choices for air pollution studies (Gharibvand, Jamali, & Amiri, 2023; Nouri, Vahidi, Hatamzadeh, Afshinfar, & Karimi, 2023). These satellite systems can measure the levels of other greenhouse gases such as carbon monoxide, methane, and nitrogen dioxide. Additionally, these satellites can map the distribution of pollutants, monitor regional air quality trends, and identify pollutant sources (Arikan & Yildiz, 2023).

In this study, an examination of temporal and spatial air quality in the Western Black Sea region for the year 2022 was conducted. Data was obtained using the TROPOMI sensor on the Sentinel-5P satellite. The aim of the study is to identify the main causes of pollutants in the region. Over a 12-month period, efforts were made to determine the periods of increase or decrease in pollutants and their contributing factors.

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2. CASE OF STUDY: WESTERN BLACK SEA OF TURKIYE

The region has a coastline on the Black Sea to the north, and the extensions of the North Anatolian Mountains are located to the south (Ercanoglu & Gokceoglu, 2004). The cities in the region include Zonguldak, Bartin, Kastamonu, Sinop, Karabuk, Duzce, and Bolu. It's geographic coordinates are between 40°30 N and 42°00 N, and between 31°00 E and 34°30 E. (Figure 1). The region is famous for its mountainous terrain and forested areas. Important rivers such as the Yesilirmak Kizilirmak, and Coruh pass through this region. Additionally, many natural beauties can be found in the region. Historic and touristic cities like Amasra, Safranbolu, and Inebolu are also located in this region.
The climate of Western Black Sea is generally temperate continental. Winters are cold and snowy, while summers are warm and humid. However, mountainous areas in the region can have a different climate structure.

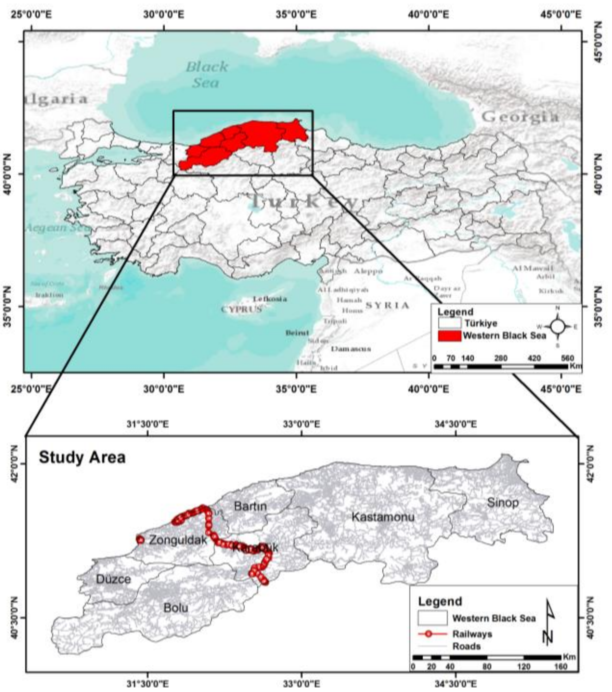

Figure 1. Study area

3. MATERIAL – METOD

In this study, carbon monoxide, nitrogen dioxide, and ultraviolet aerosol index were examined for the entire 12 months in the Western Black Sea region. The workflow diagram of the study is presented in Figure 2 and the information about the satellite used in this study is presented in Table 1.

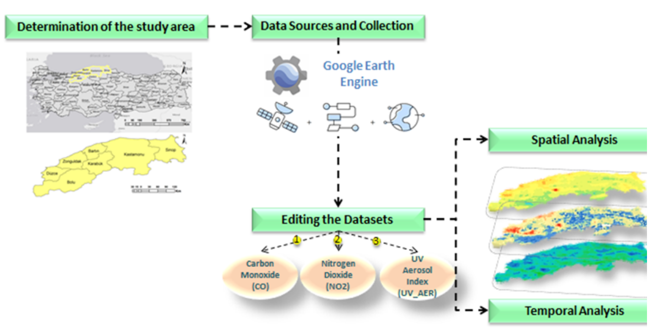

Figure 2. Workflow diagram

The data used in the study was obtained from the TROPOMI sensor, which is part of the Sentinel-5 satellite operated by the European Space Agency. Launched in 2017, the satellite's primary objective is to detect air pollution, monitor climate, and make predictions (Veefkind et al., 2012). It records gases such as ozone, methane, formaldehyde, aerosols, carbon monoxide, nitrogen dioxide, and sulfur dioxide (Safarianzengir, Sobhani, Yazdani, & Kianian, 2020; Zheng, Yang, Wu, & Marinello, 2019). The satellite provides daily data, and pollutant images are obtained in three different ways: real-time imagery, offline imagery, and reprocessed imagery. Offline data is used a few days after the imaging, while real-time data can be used within an average of 2-3 hours (Shikwambana, Mhangara, & Mbatha, 2020). The preferred data type in the study is offline data.

Data retrieval for the study was performed through the Google Earth Engine platform. The GEE platform offers a user-friendly interface and computational capabilities that enable efficient processing and analysis of large datasets(Qu, Chen, Li, Zhi, & Wang, 2021). This web-based application hosts satellite imagery spanning over 40 years. With free access, the application allows online processing of spatial and geographic data (Feizizadeh, Omarzadeh, Kazemi Garajeh, Lakes, & Blaschke, 2023; Halder et al., 2023). Additionally, it enables visualization and exportation of the processed data. The conversion of satellite images from Level 2 to Level 3 was performed using harpconvert in GEE. Subsequently, temporal, and spatial filters were applied for each pollutant.

Different spectral bands reflecting from the satellite sensor were used to determine the air pollution status in the region. The detection process of aerosol index, carbon monoxide, and nitrogen dioxide gases relied on their absorption and reflection properties. CO is a colorless, odorless, and tasteless gas released due to incomplete combustion of carbon(Kazemi Garajeh et al., 2023). To detect this primary air pollutant, near-infrared (NIR) and short-wave infrared (SWIR) spectral bands are used in Sentinel-5. The main spectral bands range from 2.3 microns (NIR) to 4.7 microns (SWIR). Nitrogen dioxide is one of the gases that most significantly affect human health(Kazemi Garajeh et al., 2023). It is released into the atmosphere as a result of human activities, including industrial areas in urban regions, vehicles used for transportation, and heating in residential areas. Visible (VIS) and near-infrared (NIR) spectral bands are utilized to detect this gas. The visible bands within the range of 405-500 nm for blue and 570-675 nm for red (VIS) measure the absorption properties of nitrogen dioxide. The ultraviolet aerosol index, on the other hand, is generated as a result of dust, ash, or biomass burning. Unlike other gases, this index can be produced even in cloudy environments. The unitless index is calculated using the wavelength pairs within the range of 340-380 nm.

Carbon monoxide, nitrogen dioxide, and aerosol index values were obtained from the Sentinel-5 satellite. The general characteristics of these products are presented in the table 1.

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Name of the gas used	Band Name	Resolution	Units	Description
CO (Carbon Monoxide)	CO_ column_ number_ density	1132 meters	mol/m^2	Vertically integrated CO column density.
NO_2 (Nitrogen Dioxide)	NO2_ column_ number_ density		mol/m^2	Total vertical column of NO2
UVAI (Ultraviolet Aerosol Index)	absorbing_ aerosol_ index		None	A measure of the prevalence of aerosols in the atmosphere.

Table 1. The general characteristics of used gases study

4. RESULTS

Pollution maps (CO, NO2, UVAI) were generated using Google Earth Engine (GEE). JavaScript code was written in the web-based application for this purpose. The CO map for the 12 months in the Western Black Sea region is presented in Figure 3, the NO_2 map is presented in Figure 4, and the UVAI map is presented in Figure 4.

In Figure 3, the CO values are represented using a color scheme where red indicates high CO levels, while blue represents low CO levels. It has been determined that the pollution level is particularly high in Karabuk and Zonguldak provinces in the Western Black Sea region. On the other hand, Sinop and Kastamonu provinces have relatively low pollution levels compared to other cities. CO gas is emitted especially when something is burned. The sources of CO in the atmosphere include cars, trucks, and other vehicles or machinery that burn fossil fuels. The iron and steel factories in Karabuk and Zonguldak contribute positively to the industry but also negatively affect the air quality. The month with the highest pollution level has been identified as March. Decreases in CO levels have been observed in June, July, August, and September. When looking at the pollution levels by province, it can be seen that the CO levels in Karabuk province significantly increase in February and November.

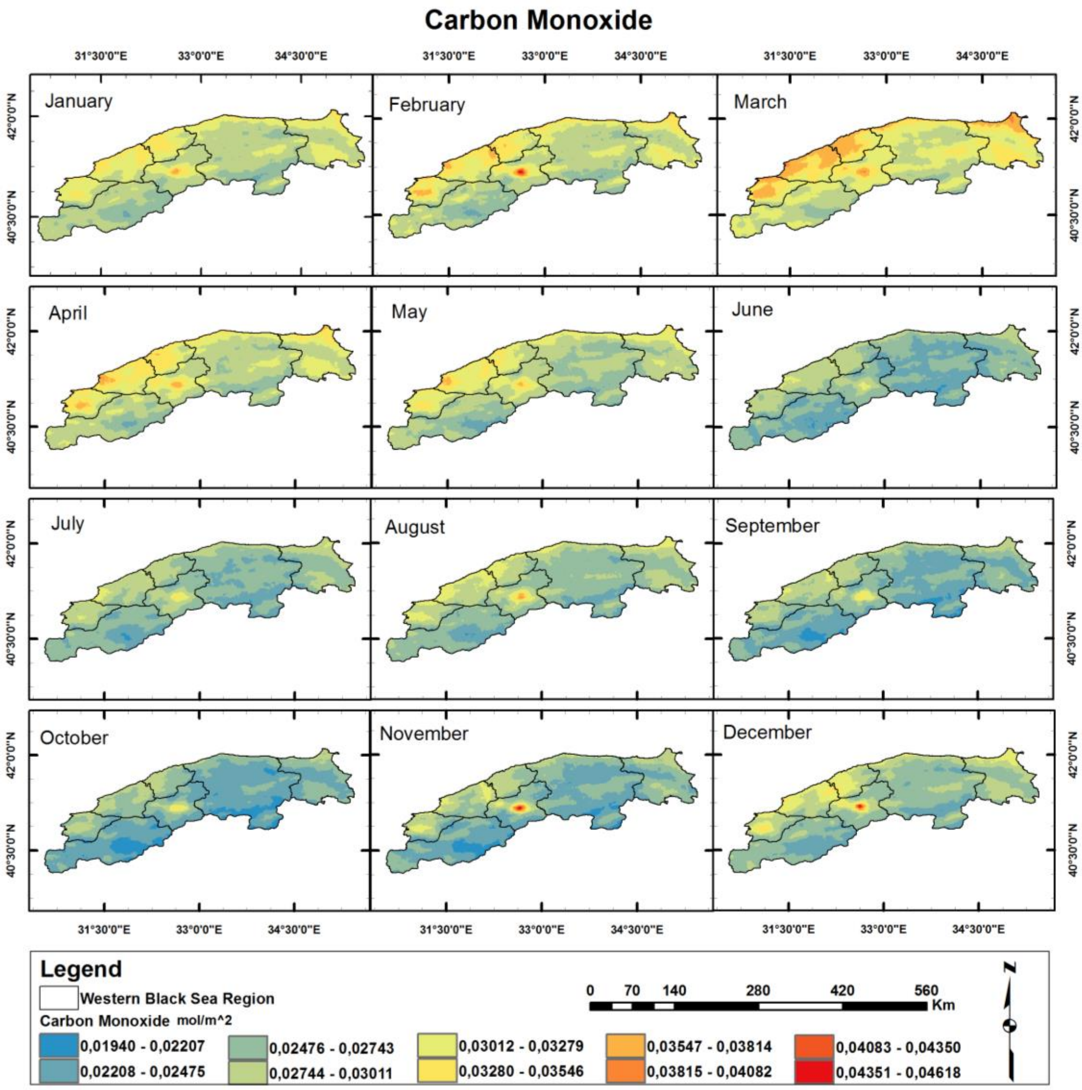

Figure 3. The monthly spatial distribution of CO in January, February, March, April, May, June, July, August, September, October, November, and December for the year 2022

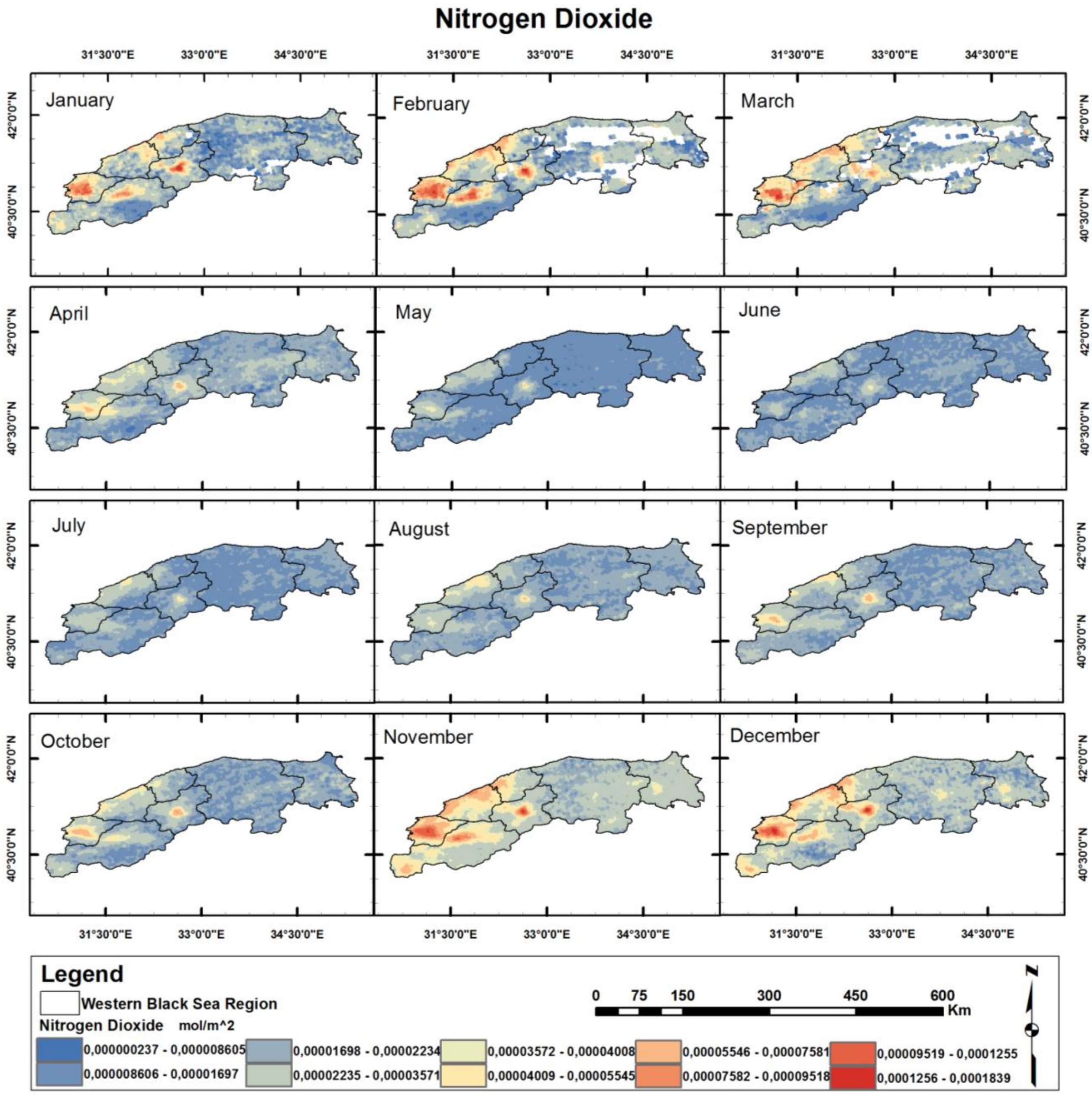

Figure 4. The monthly spatial distribution of NO_2 in January, February, March, April, May, June, July, August, September, October, November, and December for the year 2022.

In Figure 4, the NO_2 values are represented using a color scheme where red indicates high NO_2 levels, while blue represents low NO_2 levels. As seen in Figure 4, the highest NO_2 levels were recorded in December during the year 2022. July was determined to be the month with the lowest NO_2 levels.

In Figure 5, the UVAI values are represented using a color scheme where blue indicates high UVAI levels, while green represents low UVAI levels. As seen in Figure 5, the highest UVAI levels were recorded in April and November during the year 2022. July was determined to be the month with the lowest UVAI levels.

The annual temporal graphs of the pollutant gases are presented in Figure 6. The trend line in the CO graph appears negative, while it is positive for NO2 and UVAI. Throughout the year, the average pollutant levels are 0.0272 mol/m2 for CO, 0.0000237 mol/m2 for NO2, and -0.5567 for UVAI. At the beginning of 2022, the levels of all three pollutants were high, but reductions occurred in the middle of the year. When considering the maps, it can be observed that the pollutant levels are higher during the winter season. The average values for December, January, and February are 0.0295 mol/m2 for CO, 0.0000304 mol/m2 for NO2, and -0.5532 for UVAI. The average values for June, July, and August are 0.02328 mol/m2 for CO, 0.0000187 mol/m2 for NO2, and -0.66815 for UVAI. Therefore, it can be concluded that pollutant levels are higher during the winter season compared to the summer season. This can be attributed to the use of fuels for heating purposes.

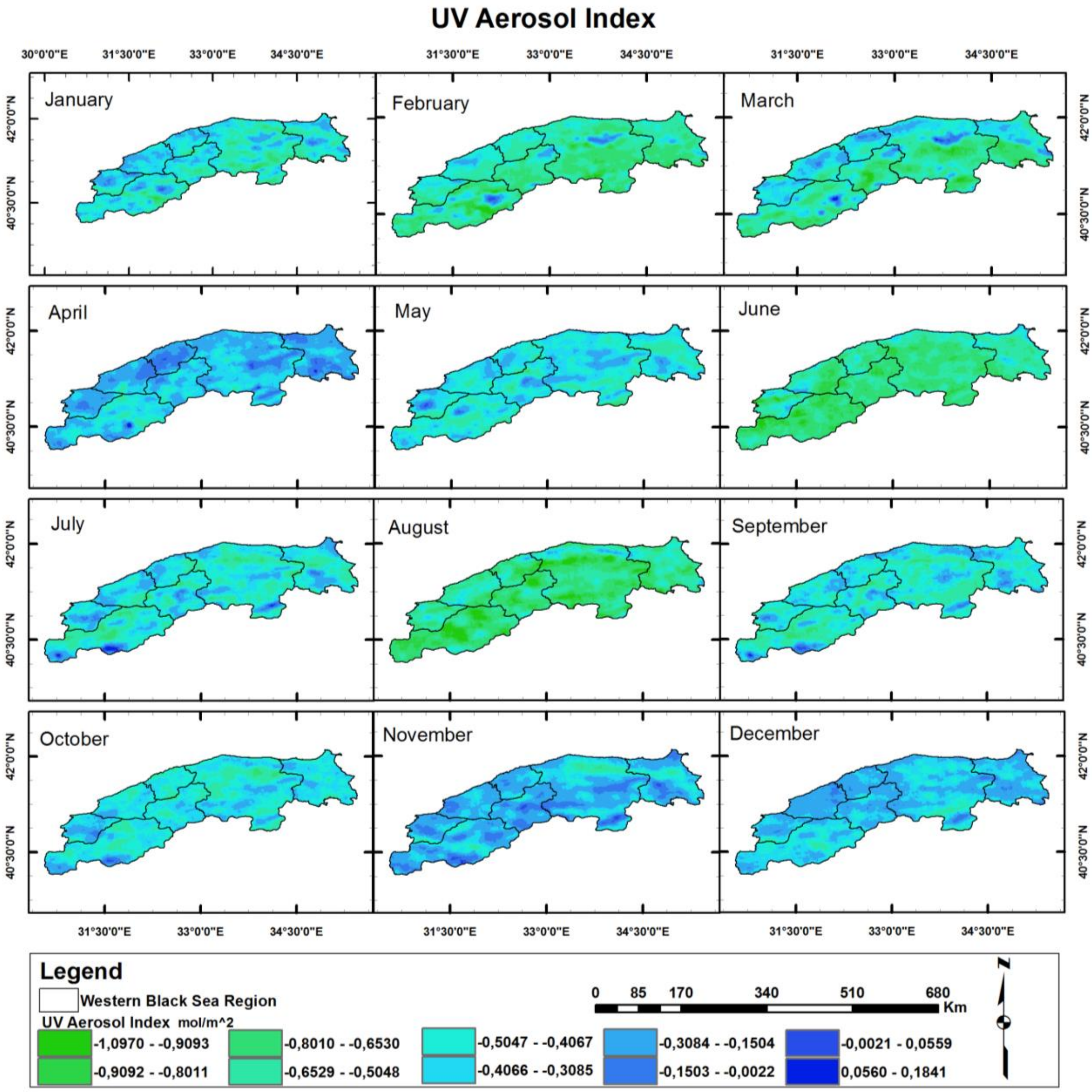

Figure 5. Figure 3. The monthly spatial distribution of UVAI in January, February, March, April, May, June, July, August, September, October, November, and December for the year 2022.

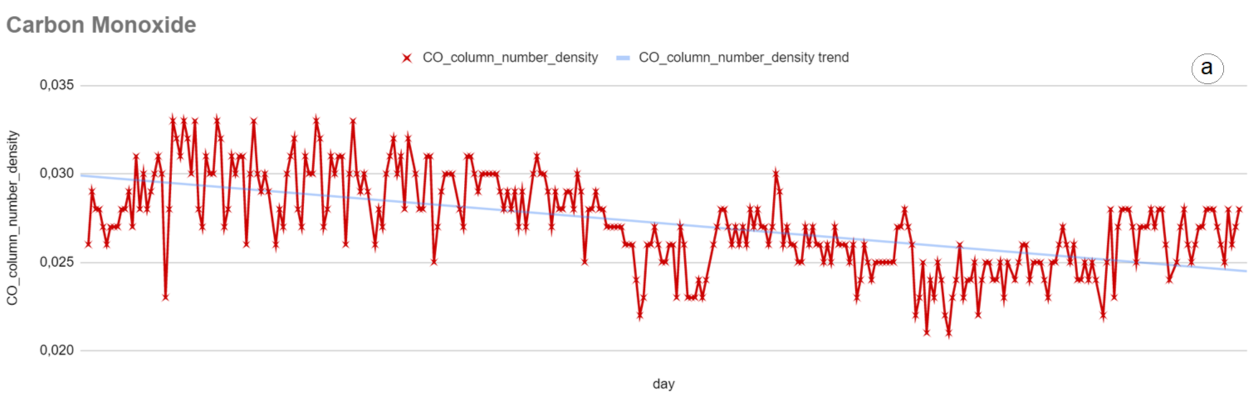

Figure 6. Temporal status of (a) CO, (b) NO2 and (c) UVAI in the Western Black Sea region in 2022

5. DISCUSSION

Air quality is an important issue that needs to be investigated as it affects the climate, environmental structure and human health due to anthropogenic activities.

Based on the trends observed in Figures 3, 4, and 5, it can be concluded that the levels of all three pollutants are low during the summer season and significantly increase during the winter season. These results are likely related to the influence of fuels used for heating purposes. During the winter months, with greater heating requirements, the combustion of fossil fuels and the resulting emissions may lead to an increase in the levels of CO, NO2, and UVAI. In contrast, during the summer months, the effects of warmer weather and increased sunlight may contribute to the dispersion of pollutants and a decrease in their levels. These trends highlight the relationship between air pollution in the region and seasonal variations.

In addition, the transportation line that facilitates coal transportation in the region, specifically in Karabuk and Zonguldak, exhibits high levels of pollutants such as CO and NO_2. In Kastamonu and Sinop provinces, the pollution levels are relatively low compared to other cities. These cities have a smaller number of factories and industrial facilities established throughout the urban area. Additionally, the presence of extensive forested areas in both regions contributes to lower pollution levels.

The areas where pollution levels have increased in the Western Black Sea region have been identified and mapped using Google Earth application, focusing on the sources of pollutants in the region. Figure 7. illustrates the visual representation of this situation, while Table 2. presents the main pollutant sources.

Location	Main industrial sites and activities
Eregli, Zonguldak	Iron and steel factory
Kozlu, Zonguldak	Port yard and transportation activities
Kilimli, Zonguldak	Coal treatment plant, mining activies (coal, quartzite, basalt)
Caycuma, Zonguldak	Paper mill
Bartin city	Mining activities (marble, brick-tile building stone), cement factory, ceramic factory
Safranbolu, Karabuk	Food factories, mining activities (marble, quartzite)
Center, Karabuk	Iron and steel factories
Sinop city	Port yard and transportation activities
Bolu city	Feed mills, food factory, organized industrial zone, mining activities
Duzce city	Food factories, textile factories, organized industrial zone, mining activities

Table 2. The sources of pollutants in Western Black Sea region

As observed from the results, industrial facilities and factories in the study area are the main contributing factors to the increase in pollution levels. In addition, seasonal weather conditions also play a role in this regard. Furthermore, seasonal weather patterns and meteorological conditions can also influence the dispersion and accumulation of pollutants. For example, during the winter months, temperature inversions and stagnant air conditions can trap pollutants near the surface, leading to higher pollution levels. In contrast, during the summer months, increased air movement and dispersion can help alleviate pollution levels.

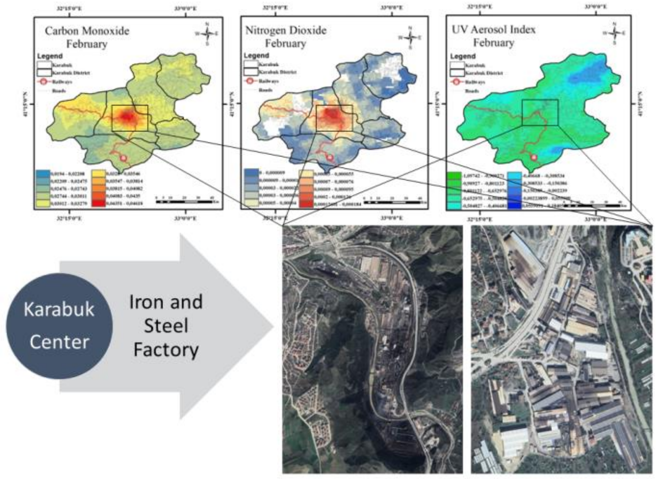

Figure 7. The location of the iron and steel factory in Karabuk

6. CONCLUSION

Recent technological advancements have had a significant impact on the field of remote sensing. Thanks to the effective and efficient use of satellite systems and products, monitoring climate change and air quality has become possible. In this study, images from the Sentinel-5 satellite, based on the Google Earth Engine (GEE) platform, were utilized to obtain parameters such as CO, NO_2, and UVAI. Our findings demonstrate that the use of GEE for the detection and monitoring of air pollution, both spatially and temporally, is an effective approach.

The integration of GEE and satellite-based monitoring systems provides a powerful means to study and understand the dynamics of air pollution. It allows for the identification of pollution sources, the assessment of temporal trends, and the evaluation of the effectiveness of pollution control measures. This information is crucial for policymakers, researchers, and environmental agencies to develop targeted strategies and interventions to mitigate the impacts of air pollution and address climate change challenges.

Overall, the utilization of GEE and satellite imagery has proven to be an effective approach in the detection and monitoring of air pollution, facilitating a better understanding of its spatial and temporal patterns and supporting informed decision-making for environmental management and policy development.

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