Spatio-temporal monitoring of air pollution over Bulgaria's largest industrial area using Sentinel-5p TROPOMI data

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ABSTRACT

Air pollution is one of the most significant environmental problems in the world nowadays. A considerable part of anthropogenic emissions is produced by industry and Bulgaria is no exception. The most important air pollutants that have a significant impact on the air quality and have a direct or indirect influence on climate change are nitrogen dioxide (NO_2), carbon monoxide (CO), methane (CH_4) and sulphur dioxide (SO_2). This paper reports on pollution monitoring results in Bulgaria's largest industrial area, located in the triangle between the cities of Stara Zagora, Haskovo and Plovdiv. Daily satellite data from the Sentinel 5P - TROPOMI instrument were used to study high levels of nitrogen dioxide, carbon monoxide, methane and sulphur dioxide emissions from October 2018 to December 2022. Validation of the results was carried out using ground data from the nearest Automatic Identification System (AIS) station. The monitoring results show that the study area has the highest levels of NO_2 pollution. However, many cases of SO_2 pollution have also been recorded.

Keywords: Remote Sensing, Air pollution, NO_2, CO, SO_2, methane

1. INTRODUCTION

Air pollution is one of the most important environmental problems worldwide today[1]. About 90% of the urban population in Europe is exposed to pollutants at concentrations significantly exceeding the limit values for the pollutant type. It is important to enforce more ambitious environmental standards in Europe, as large parts of the European population do not live in a healthy environment, which is detrimental to human health[2]. Air pollution levels in and outside urban areas depend mainly on the amount and type of pollutants emitted into the atmosphere, as well as the type of pollution sources. Meteorological processes are also an important factor that directly influence the rate of accumulation and dispersion of pollutants in the atmosphere for a given area at different time periods[3]. However, air quality does not always improve proportionally and instantaneously when anthropogenic emissions of air pollutants decline. The reasons are many and complex. In fact, the relationship between decreasing emissions and air pollutant concentrations is not always linear. In order to assess the extent of air pollution, it is necessary to know the concentration limit values of pollutants. Furthermore, it is very important to take into account the importance and different nature of point and non-point sources of pollution. A detailed emission inventory should record all sources in an area, scientifically investigating their nature and taking into account the topography and meteorology for the specific area.

A significant part of air pollution is generated by the energy sector. There are several large industrial areas in Bulgaria that periodically generate significant emissions of air pollutants such as sulphur dioxide, dust, nitrogen oxides, lead aerosols, hydrogen sulphide, etc. Such an industrial zone is located in the municipality of Stara Zagora (Figure 1). It is one of Bulgaria's most economically and socially developed municipalities. Stara Zagora Municipality is located in South Central Bulgaria. The city of Stara Zagora is situated on the southern slopes of the Sredna Gora Mountain. Stara Zagora is a densely populated, industrial city with heavy traffic and no central heating. The region is rich in thermal mineral springs, with numerous spas and health centres. In addition, the region's rich soils make it excellent for productive agriculture and food production. Forests are one of the most valuable natural resources of the Stara Zagora region, offering great opportunities for the regional economy.

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On the other hand, environmental problems related to urban air pollution in Stara Zagora have a long history. The combination of the city's compact layout with the thousands of closely located pollution sources - households, heavy traffic, and the presence of large industrial pollution sources - are responsible for the city's local air pollution problems. All these problems have led to a high level of public concern about air quality in the Community. Pollution levels, their frequency and intensity must be thoroughly investigated using modern scientific techniques, including extensive ground and satellite data.

Most of the region's revenues are generated from coal mining and electricity production, with Stara Zagora accounting for around 30% of Bulgaria's total electricity production. The largest brown coal mine and the largest open-pit mine area in Bulgaria is located here. The Maritsa East thermal power plant is located in the Stara Zagora area, on high-quality arable farmland, in close proximity to the settlements. The thermal power plant (TPP) includes three heating plants operating with low calorific coal with high ash, sulphur and briquette content. Many attempts have been made to correlate the risk of respiratory problems in the region with air quality parameters[4, 5]. In addition, many field and forest fires occur in this region, which are another source of air pollution[6- 8]. This combination of sources with high industrial pollution and a region very attractive for agriculture, spa, and tourism gives us a reason for continuous monitoring in an attempt to contribute to reducing air pollution.

2. REGION, DATA AND METHODS DESCRIPTION

The study area is located southeast of the town of Stara Zagora, in the south-central part of Bulgaria Figure 1.

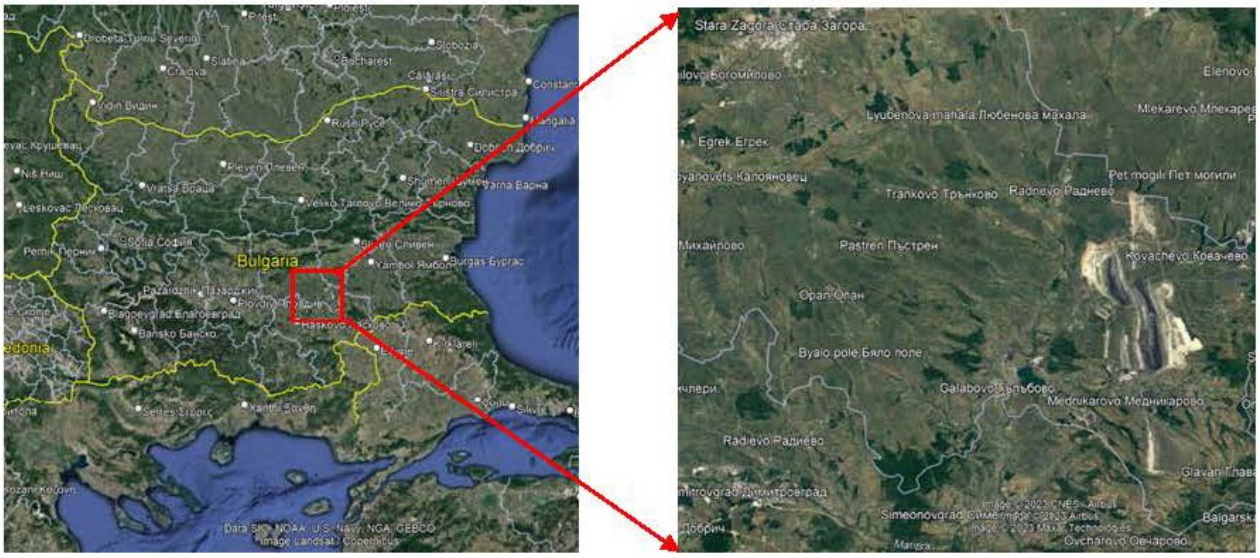

Figure 1. The study area of Stara Zagora, Bulgaria. Map provided by Google Map

Our research team from the Space Research Institute - Bulgaria has vast experience in conducting long-term air pollution monitoring in this region. From mid-2005 until the end of 2009, we carried out daily web-based monitoring based on combined satellite MODIS and ground station data, funded under a contract with the municipality of Stara Zagora[9]. Between 2010 and 2016, this monitoring was funded by the Ministry of Defence [10].

MODIS data are multispectral with a spatial resolution of 250 m in the visible spectrum and 1 km in the other spectral bands. However, this type of satellite data only allows us to detect air pollution but not to reveal its chemical composition. After 2011, MODIS data show a significant decrease in the number of recorded air pollution events in the Stara Zagora region [11]. Data from AURA, GOME, GOME2, etc. with a spatial resolution of 40 to 50 km do not detect pollutants like SO_2 and methane, but show considerable NO_2 pollution over the study region [12, 13].

From mid-2018, the TROPOMI instrument on board the Sentinel-5P satellite provides open source data on key air pollutants such as NO_2, SO_2, CO and methane [14, 15]. Sentinel-5P is a product of the European Space Agency and is in a sun-synchronous orbit. Its data are open access and available 2 to 4 days after the acquisition, which is daily, with a bandwidth of 2600 km, local flyby time of about 13 h. The spatial resolution for each pollutant is between 3.5 and 7 km[16-18]. The TROPOMI data has irregular geometry and precise georeferencing is required. This data enables more detailed spatial and temporal monitoring compared to previously used satellite information. We also present for the first time the results of monitoring SO_2 and methane emissions in the industrial region we studied around Stara Zagora.

There are many ground stations in our study area that measure various air pollutants, but only three of them are open access (located in Stara Zagora, Dimitrovgrad and Galabovo). Figure 2 shows the location of the AIS used in the study. The closest to the study area AIS is situated in Galabovo. The Air Quality Information System[19] provides hourly and daily NO_2 and SO_2 data from each AIS starting from the beginning of 2015. AIS - Stara Zagora also provides data for CO and NO. Similar data from AIS can be found in the Air Quality Data Platform of the Europena Enviromental Agency[20] since 2013 until now. None of the ground stations around the study area have open access methane data.

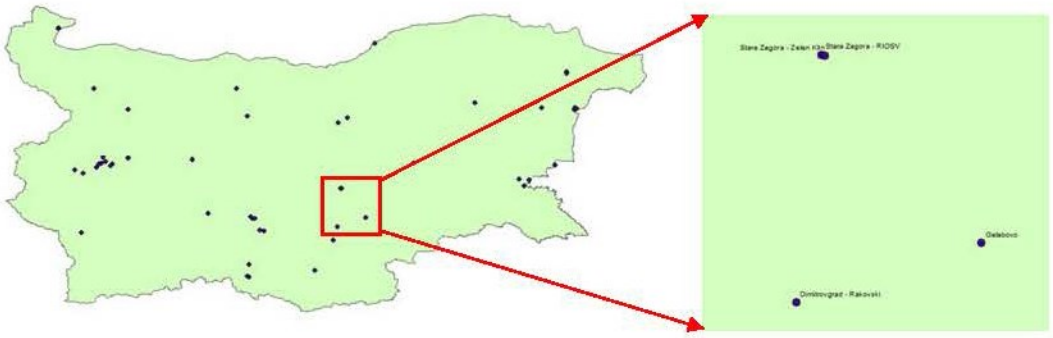

Figure 2. Location of the three AIS in the study area. Map provided by the Air quality information system for the general public [19]

In this study, we used a combination of ground-based AIS and Sentinel-5P satellite data to investigate air pollution. From 30 April 2018 to the end of 2022, we conducted a detailed study using TROPOMI data to record daily high NO_2, SO_2, methane and CO emission events in the study area. We then compared the results with the ground station data from the three AISs in Figure 2. A method presented in more detail in [21, 22] was used to detect emission events. This method allows relatively fast computational procedures and is divided into two steps. In the first stage, the background concentrations of each of the investigated air pollutants are calculated for the study area. In the second stage, the data are filtered for the presence of background emission events. The results are presented in the next chapter of this paper.

3. RESULTS

Figure 3 shows emission events of NO_2, SO_2 and methane with TROPOMI data used. No significant CO emission events are detected over the region.

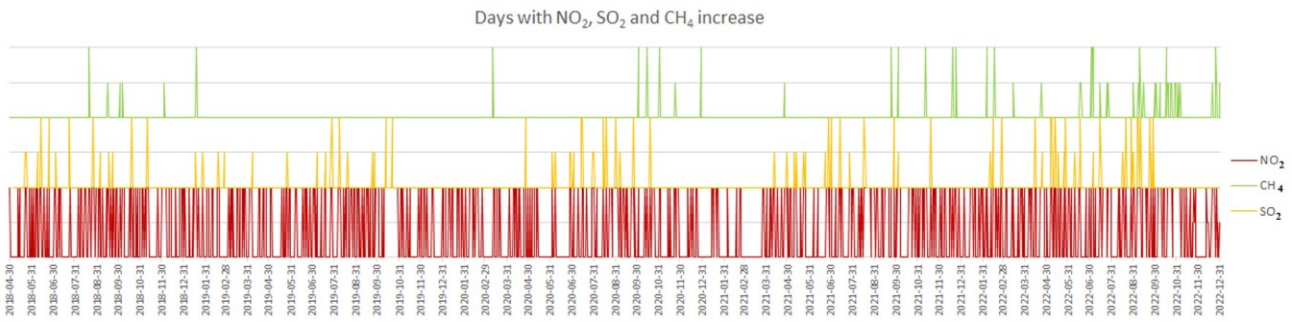

Figure 3. Days with high NO_2, SO_2 and CH_4 concentrations above the background over the study area.

Figure 4 shows the temporal distribution of SO_2 at each of the three AIS stations.

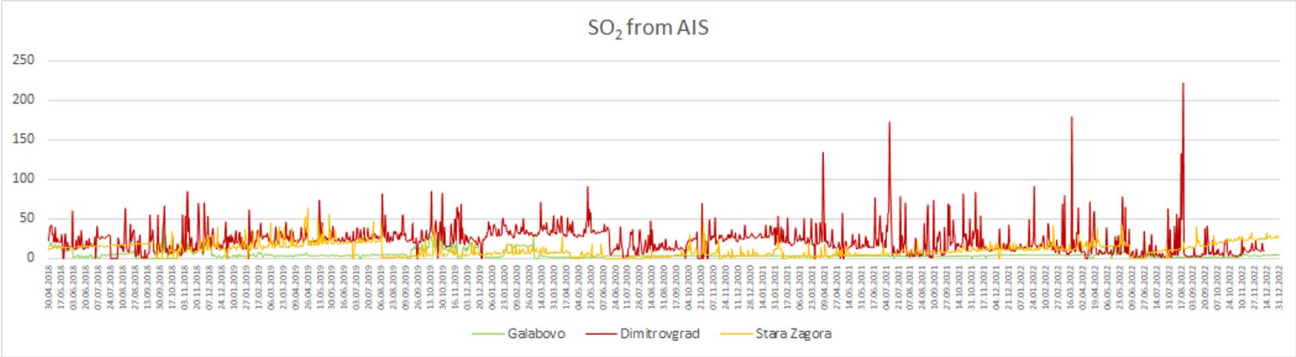

Figure 4. Temporal distribution of SO_2 in the three AIS from Figure 2.

Higher SO_2 values were detected in the AIS data at Dimitrovgrad, as shown in Figure 4. There is increase temporal behavior in the same place. Last events with a significant increase in SO_2 here was registered at the 6th and 7th of September 2022 and also between the 23rd and 25th of September 2022. Emissions events at 6th and 7th of September were also detected from TROPOMI data as it is shown on Figure 5.

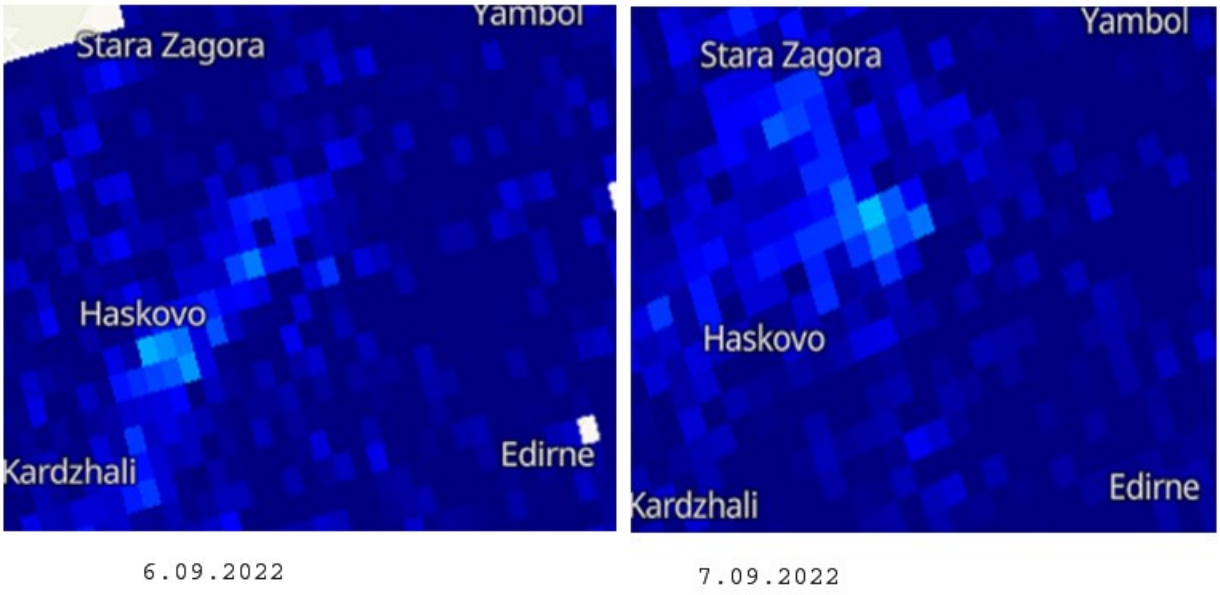

Figure 5. High emission events of SO_2 over the study area at 6th and 7th September 2022, registered by TROPOMI.

According to the TROPOMI data, significant transboundary transport of SO_2 was observed between 23th and 25th of September 2022 from North Macedonia.

The temporal distribution of NO_2 at each of the three AIS stations is shown in Figure 6.

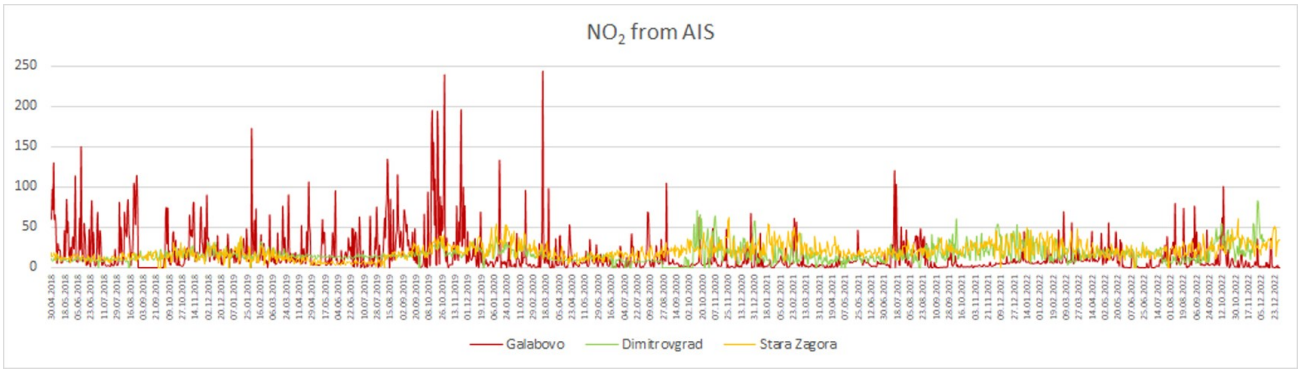

Figure 6. Temporal NO_2 distribution in the three AIS from Figure 2.

Higher values of NO_2 were registered in Galabovo as shown in Figure 6. According to AIS data, NO_2 show decrease temporal trend. Such a decline is not visible in the satellite data from TROMOPI.

Figure 7 shows the number of days with high emissions of NO_2, SO_2 and CH_4 on an annual basis from TROPOMI data. There is an upward trend in this number, especially in 2022.

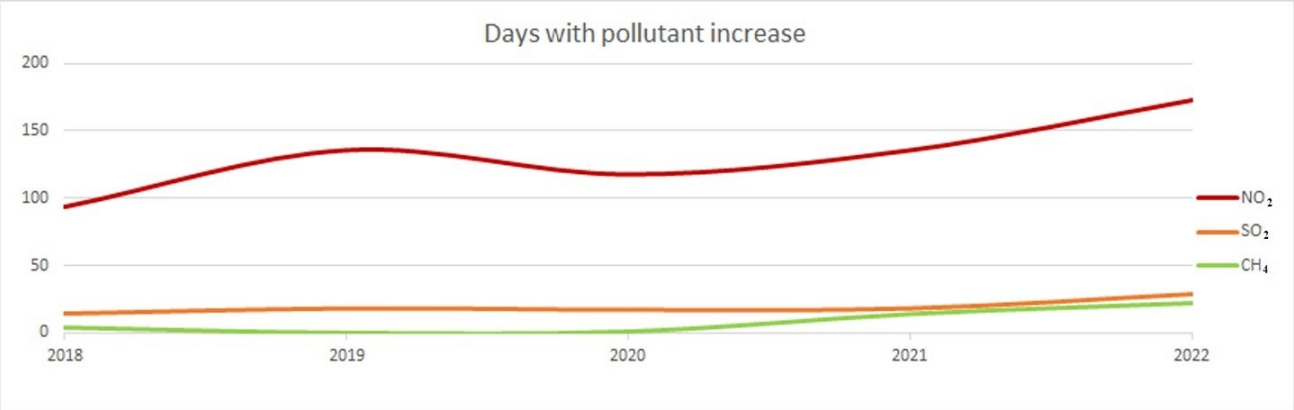

Figure 7. Number of days with high emissions of NO_2, SO_2 and CH_4 on an annual basis from TROPOMI data over the study area.

Meanwhile, lower values of monitored air pollutants were observed in AIS - Stara Zagora. This is probably due to its location.

4. DISCUSSION AND CONCLUSION

The area studied in this paper is one of the pollution hotspots in Bulgaria. High levels of NO_2 emissions are frequently observed over the opencast coal mine area as well as in the area around the thermal power plants. However, these emissions are recorded relatively less frequently by the AIS in the area compared to the satellite measurement data obtained by TROPOMI.

High SO_2 emissions around the Maritsa East thermal power plant are also frequently recorded by AIS-Dimitrovgrad, especially in 2022. Despite our observation of a significant reduction in total pollution from MODIS data after 2011[3, 4], which is in agreement with SO_2 reduction results reported from other sources [23], an increase in SO_2 is observed in 2022 from both TROPOMI and AIS Dimitrovgrad data.

Increased levels of methane emissions in the atmosphere over Bulgaria are relatively rare, but episodic increases in concentrations of this greenhouse gas are observed in the study region. The levels of pollution observed over the study area during the last year and the availability of a better quality satellite data are a good reason for the continuation of the current monitoring.

The data and results of this research will be able to serve Destination Earth (DestinE), which is an ambitious initiative of the European Union to create a digital model of the Earth that will be used for monitoring the effects of natural and human activities on our planet, prediction of extreme events and adapting policies to the climate challenges[24]. The data and models will serve the Bulgarian initiative for the construction of the Digital Twins, which is being pilot developed in the department of Aerospace Information, Space Research and Technology Institute – Bulgarian Academy of Sciences. Open Data were used in this study, with the aim of promoting the Open science policy and FAIR principles as much as possible.

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